Modelización de los consumos de energía, agua y emisiones, para poder aplicar estrategias de eficiencia energética en establecimientos hoteleros de las islas Canarias.

Tesis Doctoral

Francisco Javier Díaz Pérez

Universidad San Jorge. Facultad de ciencias de la salud

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Tutora. Dra. María Rosa Pino Otín

DEDICATORIA

A mi mujer Cristina y a mis hijos Adrián y Orión, que me han apoyado durante estos largos años de investigación.

Dr. David Chinarro Vadillo, Vicedecano de Investigación de la Escuela de Arquitectura y Tecnología de la Universidad San Jorge (USJ),

Dr. Ricardo Díaz Martín, Catedrático de Ing. Química y Materiales de la Escuela de Ciencias Técnicas e Ingeniería de la Universidad a Distancia de Madrid (UDIMA),

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CERTIFICAN

Que el trabajo de investigación recogido en la presente Memoria titulada: **"Modelización de los consumos de energía, agua y emisiones, para poder aplicar estrategias de eficiencia energética en establecimientos hoteleros de las islas Canarias"** presentada en la Universidad San Jorge, ha sido realizado bajo su dirección por **D. Francisco Javier Díaz Pérez** y autorizan su presentación para optar al grado de Doctor.

Y para que conste, firmamos el presente certificado en Villanueva de Gállego (Zaragoza), a 8 de julio de 2018:



Dr. David Chinarro Vadillo



Dr. Ricardo Díaz Martín



Dr. Adib Guardiola Mouhaffel



Dra. María Rosa Pino Otín

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RESUMEN

La investigación sobre la reducción de consumos energéticos, emisiones de gases de efecto invernadero (GEI) y la huella del carbono en los edificios turísticos de alojamiento, se puede considerar que se ha hecho casi imprescindible, debido a las normativas de sostenibilidad energética, medioambientales y a los requisitos de los diferentes turoperadores. En la actualidad, con un promedio de 15.000 hoteles operativos en España, los edificios en los que se ubican estos establecimientos se han de encaminarse hacia su reestructuración a corto o medio plazo, para conseguir la meta de crear hoteles y edificios de energía cero (ZEB) o casi cero (nZEB), y poder seguir con su actividad productiva de forma sostenible, cumpliendo con los requerimientos actuales y futuros impuestos por las diferentes organizaciones e instituciones.

La realización de este estudio de investigación se ha considerado necesario, para conseguir que los edificios hoteleros actuales tengan una referencia sobre las técnicas más apropiadas para obtener pronósticos para poder reducir sus consumos energéticos y de emisiones actuales y futuras. Esta investigación se ha centrado en los establecimientos turísticos de las islas Canarias, un destino cuyo equilibrio entre sostenibilidad y turismo se hace imprescindible para poder seguir manteniendo el alto valor ecológico y medioambiental de este destino.

Inicialmente se ha buscado definir un modelo de pronóstico matemático para el cálculo de los consumos de los diferentes suministros de los hoteles, que sea aplicable a cualquier establecimiento que se quiera investigar, y cuyas predicciones obtenidas sean válidas para los estudios de reducción de consumos o emisiones que se quieran adoptar. Se comienza por la investigación de los consumos de agua en hoteles de categoría 4 y 5 estrellas, comprobando que dichos consumos se corresponden con una función de regresión potencial, en la mayor parte de los casos, respecto de la variable de ocupación diaria de clientes. Para confirmar este método de cálculo para los pronósticos de consumos, se prueba también sobre todos los suministros de un grupo de hoteles de 4 estrellas, para la energía total, la electricidad y el agua, comprobando nuevamente que, mediante un modelo de regresión potencial, se consiguen unos coeficientes de correlación muy altos respecto de la variable estudiada de la ocupación diaria. Con estos resultados se puede afirmar, que los modelos regresivos son de gran utilidad para comprobar y pronosticar los consumos de los suministros de un hotel o grupo de hoteles con características similares.

El siguiente paso fue comprobar las emisiones producidas por la energía y el agua, de un grupo de hoteles de categorías 3, 4 y 5 estrellas, que son los que reciben cerca del 95% de las estancias turísticas hoteleras de las islas Canarias, por lo cual, sobre estos establecimientos son los que hay que centrar las acciones a desarrollar e implantar de eficiencia energética. Con los diferentes factores de emisión de los suministros energéticos, se comprobó la huella del carbono de alcance 1 y 2 de la energía utilizada, observando la importancia de la electricidad en las emisiones totales de los complejos, que representan el 83% del total, pero corresponden sólo al 58% de la energía consumida, siendo este tipo de energía la principal a considerar su reducción para disminuir las emisiones de los edificios actuales. Estas emisiones se comprueban que son casi tres veces superiores que las producidas en hoteles de España peninsular, a igualdad de consumos. Sobre estos mismos edificios también se estudió la huella del carbono de la producción de agua industrial para sus consumos propios, mediante desaladoras locales situadas en los establecimientos, o por suministros externos con desaladoras centralizadas, comparando los resultados obtenidos con las emisiones que se generarían para el mismo consumo en hoteles de la península. Se evidencia como las desaladoras locales generan una menor huella del carbono que las producidas por los sistemas centralizados. También se observa que nuevamente las emisiones del suministro de agua son mucho menores en la península, siendo un 88,7% inferiores en la península que, en las islas orientales de Canarias, para el modelo de suministro externo centralizado. En este estudio, también se demuestra que la categoría de los hoteles influye de forma importante en los consumos y las emisiones finales, siendo éstas, cerca del doble en los hoteles de 5 estrellas que de los de 3 estrellas.

El destino de Canarias muestra una importante cantidad de piscinas en los establecimientos hoteleros, por lo cual, se estudian las necesidades de agua para el mantenimiento de las mismas, realizando los cálculos de pronóstico de consumos de agua y de huella del carbono debidos a la generación de ésta. Basándose en los datos de consumos obtenidos de 42 piscinas de 14 establecimientos turísticos, se ha realizado un cálculo para el conjunto de todas las piscinas turísticas de Canarias, para obtener una estimación de las necesidades hídricas para mantener todas las piscinas del archipiélago. Se demuestra que la variable del volumen de las piscinas es el principal factor para el cálculo del consumo totales de agua en las piscinas. También se analizan las diferencias de consumos energéticos y huellas de carbono debida a la generación de agua en las diferentes islas del archipiélago, para los modelos de suministro local y centralizado por distribución mediante las redes de suministro actuales, demostrando que los

modelos de producción locales son un 28% más eficientes que los centralizados, debido principalmente a las perdidas en las redes de suministro.

Debido a la importancia de los consumos y gastos de los sistemas de calentamiento para el agua caliente sanitaria (ACS), se comprueba la viabilidad de utilizar equipos basados en bombas de calor de alta temperatura con disipación mediante aerotérmia, para reducir estos consumos y gastos económicos respecto de los sistemas basados en energías fósiles. Se realiza el estudio y seguimiento de dos instalaciones basadas en esta tecnología, donde se han conseguido un ahorro energético de más del 60% y un ahorro económico, en el gasto de energía del ACS, superior al 70% , comprobando también la rápida amortización de estos equipos.

Una vez comprobada la importancia de la electricidad en los hoteles, así como la huella del carbono que este tipo de suministro genera en los mismos, se observa la necesidad de buscar modelos de generación eléctrica alternativa que estén basadas en energías renovables (EERR) para poder reducir la dependencia externa y la huella del carbono total del suministro eléctrico. El modelo de generación que se ha investigado es el basado en los sistemas de generación fotovoltaicos, desarrollando un modelo de cálculo de la generación y de la irradiación para zonas geográficas con escasez de datos. Demostrando la viabilidad de utilizar modelos matemáticos no lineales como el Box-Jenkins, más conocido como ARIMA, y el de las transformadas de Fourier, mediante los cálculos de pronósticos de producción de plantas solares fotovoltaicas. Finalmente como anexo a la investigación, se comparan las principales bases de datos de irradiación actuales respecto de los valores de generación obtenido de instalaciones en uso, generando un algoritmo de cálculo de irradiación para la zona geográfica de estudio y demostrando como los datos de la norma UNE 94003:2007 son con los que se obtienen unos pronósticos más acertados, respecto de la producción real de las plantas revisadas.

Los resultados obtenidos en esta investigación han demostrado la posibilidad de aplicar un método eficaz para el cálculo de emisiones, consumos energéticos y consumos de agua en un establecimiento hotelero respecto de la variable de su ocupación. También se ha evidenciado la importancia de utilizar la generación de agua de forma local y no centralizada, debido a las grandes pérdidas en los sistemas de suministro. Se ha demostrado el valor del consumo de agua de las piscinas y su cuantía en el total del destino. También se ha avanzado en el estudio de los métodos de cálculo de pronósticos de la generación de electricidad en sistemas fotovoltaicos, mediante alternativas basadas en modelos matemáticos y en bases de datos.

ABSTRACT

Research on the reduction of energy consumption, greenhouse gas emissions (GHG) and the carbon footprint of tourist accommodation buildings can be considered to have become almost essential, due to the energy, environmental and sustainability regulations the requirements of the different tour operators. Currently, with an average of 15,000 hotels operating in Spain, the buildings in which these establishments are located must move towards restructuring in the short or medium term, to achieve the goal of creating zero energy hotels and buildings (ZEB) or almost zero (nZEB), and to be able to continue with its productive activity in a sustainable manner, complying with the current and future requirements imposed by the different organizations and institutions.

The realization of this research study has been considered necessary, to ensure that the current hotel buildings have a reference on the most appropriate techniques to obtain forecasts to reduce their energy consumption and current and future emissions. This research has focused on tourism establishments in the Canary Islands, a destination whose balance between sustainability and tourism is essential to continue maintaining the high ecological and environmental value of this destination.

Initially we have sought to define a mathematical forecast model for the calculation of the consumptions of the different supplies of the hotels, which is applicable to any establishment that wants to investigate, and whose predictions obtained are valid for studies of consumption or emissions reduction that they want to adopt. It starts with the investigation of water consumption in hotels of category 4 and 5 stars, verifying that these consumptions correspond to a potential regression function, in most cases, with respect to the daily occupancy variable of clients. To confirm this method of calculation for consumption forecasts, we also test all the supplies of a group of 4-star hotels, for total energy, electricity and water, once again proving that, by means of a potential regression model, very high correlation coefficients are obtained with respect to the studied variable of daily occupation. With these results it can be affirmed that the regressive models are very useful to check and forecast the consumptions of the supplies of a hotel or group of hotels with similar characteristics.

The next step was to check the emissions produced by energy and water, from a group of hotels of categories 3, 4 and 5 stars, which are those that receive about 95% of the tourist stays in the Canary Islands, so which, on these establishments, are the ones that must be focused on the

actions to be developed and implemented in the future. With the different emission factors of the energy supplies, the carbon footprint of scope 1 and 2 of the energy used was verified, observing the importance of electricity in the total emissions of the complexes, which represent 83% of the total, but they correspond to only 58% of the energy consumed, this type of energy being the main one to be considered in the emissions of the current buildings. These emissions are found to be almost three times higher than those produced in hotels in Spain peninsular, with equal consumption. The carbon footprint of the industrial water production for its own consumption was also studied on these same buildings, by means of local desalination plants located in the establishments, or by external supplies with centralized desalination plants, comparing the results obtained with the emissions that would be generated for the same consumption in peninsular Spain. It is evident how local desalination plants generate a lower carbon footprint than those produced by centralized systems. It is also observed that again the emissions of the water supply are much lower in the peninsula, being 88.7% lower in the peninsula than, in the eastern Canary Islands, for the centralized external supply model. In this study, it is also shown that the category of hotels has an important influence on consumption and final emissions, which are about twice as high in 5-star hotels as in 3-star hotels.

The destination of the Canary Islands shows an important amount of swimming pools in the hotel establishments, for which, the needs of water for the maintenance of the same are studied, making the calculations of forecast of water consumption and carbon footprint due to the generation this. Based on the consumption data obtained from 42 pools of 14 tourist establishments, a calculation has been made for all the tourist pools of the Canary Islands, to obtain an estimate of the water needs to maintain all the pools of the archipelago. It is demonstrated that the variable of the volume of the pools is the main factor for the calculation of the total water consumption in the pools. The differences in energy consumption and carbon footprints due to the generation of water in the different islands of the archipelago are also analysed, for the models of local supply and centralized by distribution through the current supply networks, demonstrating that the local production models are 28% more efficient than centralized ones, mainly due to the losses in the supply networks.

Due to the importance of the consumption and expenses of the heating systems for domestic hot water (DHW), the feasibility of using equipment based on high temperature heat pumps with dissipation by aerothermy, to reduce these consumptions and economic expenses is checked regarding systems based on fossil energies. The study and monitoring of two facilities

based on this technology is carried out, where energy savings of more than 60% and economic savings have been achieved, in the energy expenditure of the ACS, over 70%, also proving the rapid amortization of these machines.

Once the importance of electricity in hotels has been proven, as well as the carbon footprint that this type of supply generates in them, it is necessary to look for models of alternative electric generation that are based on renewable energies (EERR) to be able to reduce external dependence and the total carbon footprint of the electricity supply. The generation model that has been investigated is based on photovoltaic generation systems, developing a generation and irradiation calculation model for geographic areas with scarce data. Demonstrating the feasibility of using nonlinear mathematical models such as the Box-Jenkins, better known as ARIMA, and that of the Fourier transforms, through the calculations of production forecasts of solar photovoltaic plants. Also, as an annex to the research, the main current irradiation databases are compared with respect to the generation values obtained from installations in use, generating an algorithm for calculating irradiation for the geographical area of study and demonstrating how the data of the standard UNE 94003: 2007 are the ones with which more accurate forecasts are obtained, with respect to the actual production of the plants reviewed.

The results obtained in this research have shown the possibility of applying an effective method for the calculation of emissions, energy consumption and water consumption in a hotel with respect to the variable of their occupation. The importance of using water generation locally and non-centrally has also been demonstrated, due to the large losses in the supply systems. The value of the water consumption of the pools and its amount in the total destination has been demonstrated. Progress has also been made in the study of methods for calculating forecasts of electricity generation in photovoltaic systems, using alternatives based on mathematical models and databases.

1.

INTRODUCCIÓN

1.1. INTRODUCCIÓN

1.1.1. Efecto invernadero y cambio climático

Los procesos que ocurren en el sistema climático de la Tierra son el resultado de las interacciones entre la atmósfera, la hidrosfera, la biosfera y la geomorfología continental. Con el estudio de las alteraciones y tendencias de los patrones climáticos observados en los últimos cien años, debido a diversas causas, se llega a la acepción general de cambio climático. Las emisiones de dióxido de carbono (CO_2), consideradas entre los factores causantes, son originadas tanto en los procesos naturales orgánicos e inorgánicos como en los sistemas generadores de energía masiva creados por el ser humano *[IPCC,2013]*. El Panel Intergubernamental sobre Cambio Climático (IPCC) que celebró del 13 al 16 de marzo de 2018 en Paris sus 30 años *[IPCC]* de reconocida investigación científica, sigue reafirmando en sus informes que la actividad acelerada e incontrolada del hombre incide en la aceleración del calentamiento del planeta. Asumiendo esa responsabilidad o conciencia social respecto a las causas antrópicas, numerosos países han introducido medidas políticas que inciden en la regulación de la producción y consumo energético en las actividades económicas. Así, la eficiencia energética se ha convertido es un aspecto esencial de la estrategia europea para un crecimiento sostenible para los horizontes 2020, 2030 y 2050 y una de las formas más rentables para reforzar la seguridad del abastecimiento energético y reducir las emisiones de gases de efecto invernadero (GEI) y de otras sustancias contaminantes. La aplicación de medidas de eficiencia energética, así como la integración de los sistemas de energía renovable (EERR), son tareas complicadas en el camino para conseguir el edificio energía cero (ZEB) *[Attia, Mlecniki et al, 2011]* o casi cero (nZEB) *[Crawley, Pless et al, 2009]*. Teniendo en cuenta que el 40 % del consumo total de energía y el 36% de las emisiones de gases de efecto invernadero en la Unión Europea (EU) corresponden a los edificios *[EU, 2.010]* y que el sector de la edificación se encuentra en fase de expansión, lo que hará aumentar el consumo de energía, la EU se ha puesto una meta de la reducción de las emisiones de CO_2 al 20% para el año 2.020 respecto a las de 1.990, y que el 20% del consumo total de energía provenga de las EERR Además, ya se han establecido nuevos objetivos para futuras etapas *[EU, 2017]*, fijando para el 2.030 una reducción del 40% de las emisiones respecto las de 1.990, el 27% de EERR, aumento de la eficiencia energética en un 27-30% y un 15% de interconexión eléctrica, es decir, que la electricidad generada en la EU debe poder transportarse a otros estados miembro. Para el año

2.050 la EU determina un 80-95% de reducción de las emisiones de gases de efecto invernadero respecto a los niveles de 1990.

Según los datos actualizados de Eurostat *[EU Eurostat, 2.017]* sobre los países de la EU que se muestran en la ***Tabla 1.1,*** se comprueba como aún no se han alcanzado estos objetivos, siendo el sector del transporte el que más lejos está de conseguirlo. La electricidad lo ha superado y el sector de generación de calor y refrigeración está también cerca de lograrlo, siempre que se actúe de forma apremiante, tanto en edificios de nueva construcción, como en las reformas de los ya existentes.

ZONA	TIPO	2.007	2.008	2.009	2.010	2.011	2.012	2.013	2.014	2.015	2.016
EU	Energía Total	10,5%	11,1%	12,4%	12,9%	13,2%	14,4%	15,2%	16,1%	16,7%	17,0%
	Transporte	3,1%	3,9%	4,6%	5,2%	3,9%	5,6%	5,9%	6,5%	6,6%	7,1%
	Electricidad	16,1%	17,0%	19,0%	19,7%	21,7%	23,5%	25,4%	27,4%	28,8%	29,6%
	Calor y refrigeración	12,9%	13,3%	14,9%	15,0%	15,6%	16,4%	17,0%	18,1%	18,7%	19,1%
ESPAÑA	Energía Total	9,7%	10,8%	13,0%	13,8%	13,2%	14,3%	15,3%	16,1%	16,2%	17,3%
	Transporte	1,4%	2,2%	3,7%	5,0%	0,6%	0,7%	0,8%	0,8%	1,2%	5,3%
	Electricidad	21,7%	23,7%	27,8%	29,8%	31,6%	33,5%	36,7%	37,8%	37,0%	36,6%
	Calor y refrigeración	11,3%	11,7%	13,3%	12,6%	13,6%	14,1%	14,1%	15,7%	16,8%	16,8%

Tabla 1.1. *Valores porcentuales de utilización de EERR según tipo utilización. Fuente: Eurostat*

A nivel mundial, alrededor de dos tercios de las emisiones globales de carbono provienen del consumo de energía, y en estudios llevados a cabo por las naciones unidas (UN) *[UN, 2013]*, junto con la Organización Mundial del Turismo (OMT) y el IPCC *[OMT-IPCC, 2.011]*, se ha realizado un cálculo estimativo de la emisiones mundiales de la industria del turismo para el año 2.007, contribuyendo el sector del turismo en un 5% a las emisiones mundiales de CO_2, siendo el 21% de estas emisiones provenientes del sector de los alojamientos *[Gössling, 2005]*, lo que significa que más del 1% de las emisiones mundiales vienen del alojamiento del turismo, por todo ello, los edificios junto con las instalaciones hoteleras que operan en áreas geográficas de gran concentración turística y uso intensivo estacional, suponen un importante reto para la sostenibilidad de los destino.

En la siguiente ***Tabla 1.2*** se puede observar la distribución de las emisiones en el sector del turismo, siendo el transporte el principal causante de estas emisiones, con un 75% de las mismas. Estos valores de emisiones se prevé que aumenten hasta unos valores de 3.164 MTq

CO_2 para el año 2.035, según las previsiones del World Economic Forum (WEF) *[WEF, 2.009]*, por lo cual es necesario actuar de forma urgente sobre las fuentes de las mismas.

TIPO	Millones Tq CO_2	%	Incertidumbre
Transporte aéreo	515	40%	+- 10%
Transporte por carretera	420	32%	+-25%
Otros transportes	45	3%	+-25%
Alojamiento	274	21%	+-25%
Otras actividades	48	4%	+-100%
Total, turismo	1.302		+-25%
Total, Mundial	26.400		
% Turismo sobre el mundial		**5%**	

Tabla 1.2. *Distribución emisiones de CO_2 de la industria del turismo mundial, año 2.007. Fuente: OMT-IPCC.*

Actualmente se han empezado a realizar los primeros proyectos con éxito en edificios hoteleros para convertirlos en ZEB y nZEB, existiendo ya varios ejemplos realizados por todo el mundo, como el edificio Zero Carbon Building de Hong Kong *[ZCB]*, el hotel Stadthalle of Vienna *[Stadthalle]*, o en los 16 hoteles del proyecto de la EU Nearly Zero-Energy Hotels (neZEH) *[neZEH]* que estudió la viabilidad de renovación de los hoteles existentes para convertilos en ZEB o nZEB, proyecto en el cual se consiguió una disminución promedio del 63% de los consumos energéticos y un aumento en la utilización de las EERR hasta el 46% *[Tsoutsos, et al, 2016]*, *[Tsoutsos, et al, 2017]*. Estos casos de éxito ayudan a tener un referente para la introducción de la eficiencia energética y la sostenibilidad en el sector hotelero. La construcción y reforma de hoteles, incorporando parámetros de sostenibilidad al amparo de normativas y certificaciones, está siendo un objetivo estratégico, no sólo por el ahorro de costes y reducción del impacto medioambiental asociado a la actividad, sino también para atender la demanda actual de los clientes que buscan alojamientos comprometidos con el medio ambiente y la sostenibilidad del destino.

Los estudios sobre la posibilidad de conseguir que edificios actuales pasen a ser considerado como ZEB o nZEB son diversos y también se han realizado en varios continentes, los cuales nuevamente han demostrado la posibilidad de alcanzar esta meta energética mediante la reestructuración de las instalaciones, aumento de la eficiencia energética y la autogeneración mediante EERR. El estudio de 2015 realizado por Ali AlAjmi, Hosny Abou y Adel Ghonemein *[AlAjmi et al, 2.016]* demuestra la posibilidad de convertir un edificio público en Kuwait

mediante el modelizado de tres escenarios diferentes, en un ZEB con la comparación de las diferentes tecnologías, su viabilidad económica y las mejoras medioambientales conseguidas. El estudio de 2016 de Ajla Aksamija *[Aksamija, 2.016]* explora la posibilidad de alcanzar los objetivos de energía cero en la adaptación de un edificio comercial existente en Massachusetts (EEUU), mediante la maximización del ahorro energético, la simulación de múltiples factores, la mejora de la envolvente y la aplicación también de EERR, principalmente la solar, para el suministro energético. Las investigaciones para el cambio de viviendas unifamiliares a ZEB han sido realizados por varios autores, como Maurizio Cellura, Francesco Guarino, Sonia Longo y Marina Mistreno *[Cellura et al, 2.015]*en Italia en 2014, o por Stephen Berry, David Whaley, Wasim Saman y Kathryn Davidson *[Berry et al, 2014]* en Australia en 2014. En ambos estudios se adecuan las viviendas mediante la reducción de las necesidades energéticas con la mejora de la envolvente de los edificios, el uso eficiente de la iluminación natural y la modelización de las necesidades energéticas a cubrir por las EERR. En estos casos se comprueba la viabilidad de los sistemas y la posibilidad de conseguir los nZEB en viviendas de climas templados o cálidos.

La EU ha dado mucha importancia a la eficiencia energética mediante la publicación de varias directivas sobre la misma, como la directiva 2010/31/EU *[EU, 2.010]* sobre eficiencia energética en edificios, la cual ha generado varios estudios como los de A. García Hooghuis y F.J. Neila *[García-Hooghuis y Neila, 2.013]* sobre su aplicación en los estados miembros o los de M. Kraus, and D. Kubečková *[Kraus y Kubečková, 2013]* su aplicación en edificios actuales. Dicha directiva ha sido transpuesta parcialmente por el Real Decreto (RD) 235/2013 *[Gobierno de España, Ministerio de la presidencia, 2.013]* de certificación energética en edificios y modificada recientemente por el RD 564/2017 *[Gobierno de España, Ministerio de la presidencia, 2.017]*. Posteriormente, la directiva 2012/27/EU *[EU, 2.012]* relativa a la eficiencia energética, fue transpuesta a la normativa española en el RD 56/2016 *[Gobierno de España, Ministerio de industria, Energía y Turismo, 2016]*, donde se pone de manifiesto la importancia de fomentar la eficiencia energética de los edificios actuales y futuros, marcándose plazos para conseguir los ZEB y nZEB en las nuevas construcciones, siendo las fechas límites para empezar su aplicación este año 2.018 en las administraciones públicas y para el año 2.020 el resto de edificios. La obligación de aplicación de la directiva en los diferentes países de la EU ha sido estudiada por Orsolya Bányai, László Fodor *[Bánya y Fodor, 2014]* y más específicamente centrándose en Lituania, por parte de A. Zīgurs y U. Sarma *[Zīgurs y Sarma,*

2015]. También en los congresos nearly Zero Energy Hotels que tuvo lugar en 2015 en Niza, Francia *[neZEB, 2015]*, y la del siguiente año en Madrid en 2016 *[neZEB, 2016]* ofrecieron a los participantes la oportunidad de obtener nuevas perspectivas sobre las posibilidades de innovación energética en el sector turístico, conocer los proyectos en macha, aprender sobre las herramientas y mecanismos usados en los edificios piloto y convertirse en un punto de encuentro entre los actores clave involucrados en temas relacionados con el turismo y los edificios sostenible.

Las empresas turísticas también han empezado a incluir la sostenibilidad medioambiental de los establecimientos dentro de la responsabilidad social corporativa (CSR), cuyas actividades medioambientales ya corresponden al 39% de las actividades realizadas por dichos establecimientos, los cuales se han centrado en seis facetas principalmente *[OMT, 2017]*:

1. La reducir la polución ambiental,
2. Las certificaciones medioambientales,
3. La reducción de consumos energéticos,
4. El aumento de la eficiencia energética,
5. La formación del personal y
6. La adhesión a los acuerdos de turismo sostenible creados por diferentes instituciones y asociaciones internacionales

Teniendo en cuenta las necesidades de disminución de los consumos energéticos en los edificios, y que según datos del 2º plan de acción de eficiencia energética 2.011-2.020 del Instituto para la Diversificación y Ahorro de la Energía (IDAE) *[IDAE, 2011]* el consumo de los edificios en el 2.020 habrá aumentado un 2% respecto del 2.010, y donde se prevé un ahorro debido principalmente a la aplicación de las medidas presentadas en los edificios actuales, de 2.866,96 Ktep respecto del año 2.007. Teniendo en cuenta que el consumo de los edificios del sector servicios representan el 8,6% del consumo de energía primaria total de España y dentro de estos consumos totales, los edificios de este sector destinados a restaurantes y alojamientos representan el 9% del consumo total, siendo éste el sector que más utiliza la electricidad con un 68,2% del consumo total de este tipo de energía. Debido a la importancia de estos datos y consumos característicos, es imprescindible que las medidas de ahorro se implanten en estos edificios.

En la siguiente ***Tabla 1.3*** se muestran los consumos totales de energía de las diferentes ramas del sector servicios, así como la distribución del consumo de energía primaria según usos finales de la misma, en térmicos o electricidad.

Ramas Sector Servicios. Año 2.015	EERR		Energía Total		Consumo Total según Usos		
	Total ktep	% Renov. sobre total	Total ktep	% Sobre total	Térmicos ktep	Eléctricos ktep	% Electric.
Comercio	4,2	0,1%	4.077	40,6%	1.619	2.458	60,3%
Oficinas	42,7	1,5%	2.781	27,7%	934	1.846	66,4%
Otros Servicios	71,24	6,5%	1.098	10,9%	431	667	60,7%
Hospitales	5,9	0,6%	929	9,3%	453	476	51,2%
Restaurantes y Alojamientos	19,8	2,2%	907	9,0%	288	618	68,2%
Educación	5,7	2,4%	241	2,4%	115	126	52,4%
Consumo total	153	1,5%	10.036	100,0%	3.841	6.192	61,7%

Tabla 1.3. *Distribución de los consumos energéticos en el sector servicios del año 2015. Fuente: IDAE.*

1.1.2. El turismo y la sostenibilidad

En las últimas décadas el turismo no ha dejado de aumentar, incrementando su importancia mundial, siendo el protagonista de las mayores subidas de sectores económicos a nivel mundial *[OMT, 2016]*. Esta dinámica, ha convertido al turismo en un motor clave del progreso socioeconómico de los países receptores del mismo, el cual afecta positivamente al empleo directo e indirecto, la demanda de bienes y servicios, y la balanza de pagos por medio del gasto turístico, lo cual implica un aumento de recaudación por parte de los estados y un mayor nivel de actividad económica *[Vega Altamira y Muñoz Vivas, 2007]*. El balance del turismo internacional (tanto ingresos en destino como transporte de pasajeros) representa el 30% de las exportaciones de servicios, pasando la cuota del turismo en las exportaciones totales de bienes y servicios del 6% al 7% en 2.015, manteniéndose como el cuarto año consecutivo en que el crecimiento del turismo internacional supera al del comercio mundial de mercancías *[OMT, 2016]*. La expansión general del turismo ha sido beneficiosa, en términos económicos y de empleo, para muchos sectores relacionados, lo cual produce un efecto multiplicador en la economía de los países receptores de turistas, siendo un pilar importante en la creación de empleo y mejora la economía local *[UN, 2013]*.

A nivel mundial, la economía del turismo representaba ya el 9% del PIB mundial en el 2014, con unos ingresos superiores a los 1.400 miles de millones de dólares *[OMT, 2015]*. En los últimos 20 años los ingresos del turismo han aumentado una media del 6,04% anual, y con un aumento total del 195% de los ingresos, respecto del año 1995 *[The World Bank, 2016]*. Junto con el aumento de ingresos, también han aumentado la llegada de turistas internacionales a nivel mundial, con un incremento más moderado en estos 20 años de 4,16% de media. Se puede comprobar, por medio de una regresión, que los datos de gastos de turismo y llegadas de turistas mundial de los últimos 20 años presenta una tendencia exponencial en ambos casos, como se puede observar en la ***Figura 1.1***. Se comprueba como el aumento de turistas también ha ido acompañado de un aumento del gasto, pero teniendo éste un mayor crecimiento en estos años, lo que implica, que los turistas con el paso del tiempo han incrementado su gasto medio en los destinos, siendo éste cuantificado en un 37% superior en estos últimos 20 años. Esto también se puede comprobar, mediante el nivel de empleo mundial, donde el sector servicios representa actualmente ya el 51% de la mano de obra mundial, y dentro de ésta, el turismo genera el 17,6%

de los empleos de forma directa e indirecta debidos a la actividad turística en los destinos *[OMT, 2016]*.

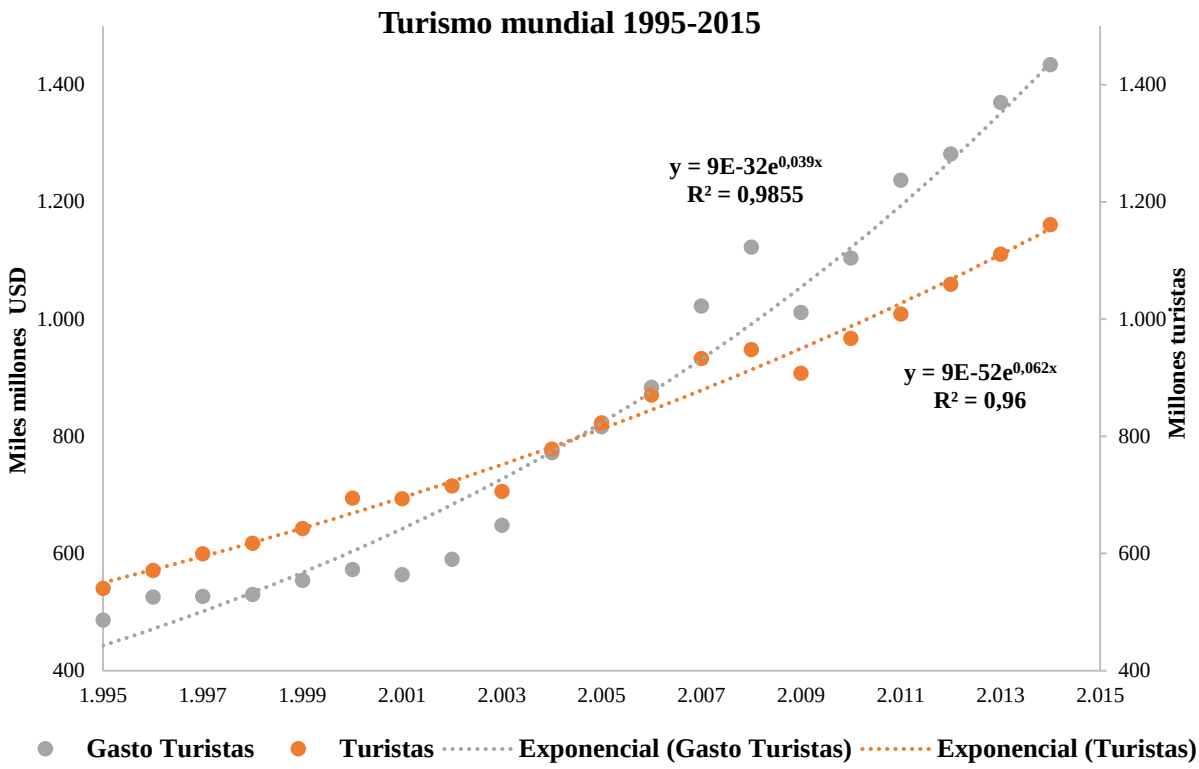


Figura 1.1. *Turismo mundial: gastos y turistas 1995-2015. Fuente: OMT y The World Bank.*

Este crecimiento sostenido durante estos años de ingresos y turistas está generando que el turismo tenga una mayor importancia en el PIB de los países receptores, como puede ser el caso de España, que en el año 2.017 represento el 11,5% del PIB total del país y el 13% del empleo *[Exceltur, 2018]*. Se ha de tener en cuenta que en las proyecciones de la OMT presentadas en la asamblea general del 11 de octubre de 2.011, se mostraban las estimaciones turísticas hasta el año 2.030, con unos valores pronosticados para ese año de 1.800 millones de turistas *[OMT, 2011]*, casi que duplicando los valores del 2.010, y con una tasa constante de crecimiento anual del 3,3%, el cual no será igual en todas las zonas geográficas, correspondiendo el mayor crecimiento a los países emergentes, con un 4,4% anual, los cuales duplicaran el crecimiento de las economías avanzadas que tan solo se estima crezcan un 2,2% anual. Europa seguirá siendo el destino preferido de los visitantes, pero pasará del 51% actual al 41% de turistas mundiales en el 2.030. Las zonas turísticas tradicionales de Europa y América concentran el mayor número de plazas hoteleras con tres cuartas partes del total, sin embargo, sus tasas de crecimiento son menores que las correspondientes a otras zonas turísticas emergentes, como

Asia Oriental y el Pacífico, lo que demuestra un desplazamiento de los flujos turísticos futuros hacia regiones menos tradicionales. La capacidad hotelera mundial se ha estimado en 16 millones de camas en el año 2.000, se pronosticado que ha aumentado un 65% a nivel global en el año 2.016, teniendo la mayor proporción de camas en términos absolutos Europa, con un 40%, seguida por América con un 32%, repartiéndose el resto entre los otros continentes *[OMT, 2001]*. En la ***Figura 1.2*** se observan las tendencias del turismo por zonas, hasta el año 2.030.

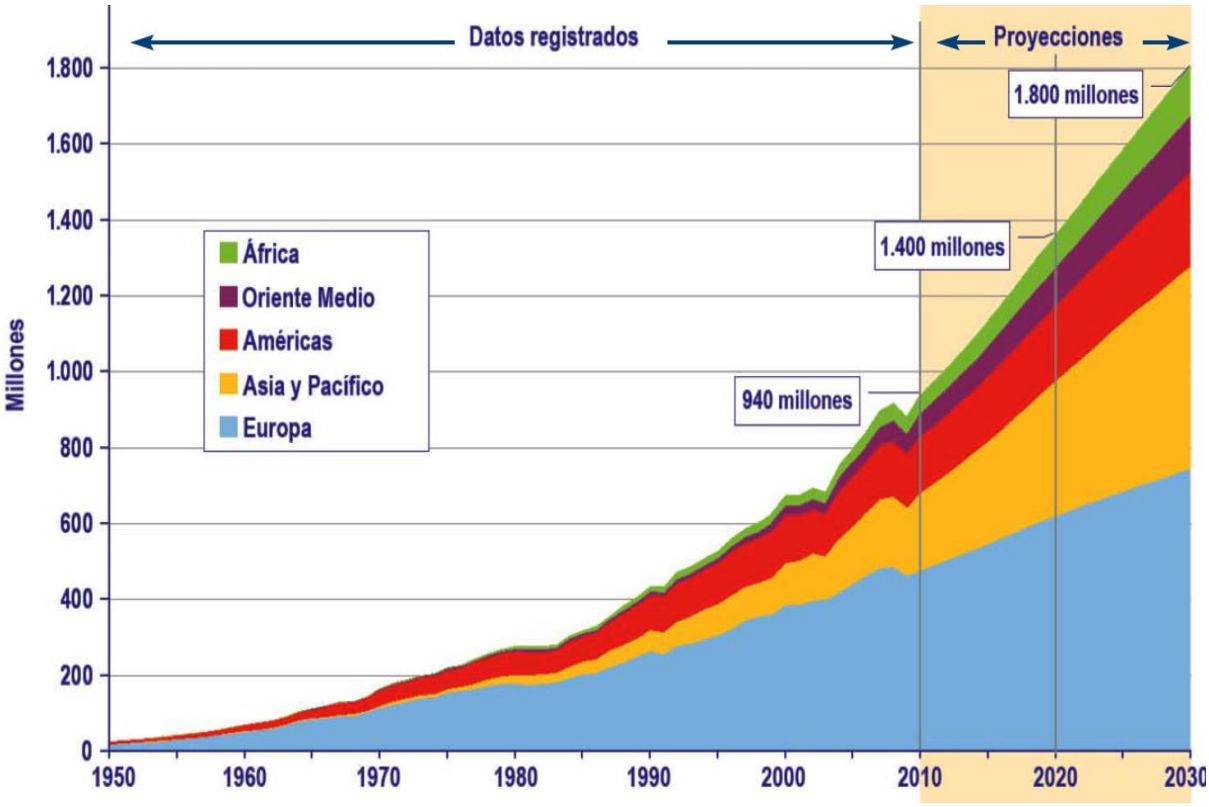


Figura 1.2. *Tendencias y proyecciones del turismo 1950-2030. Fuente: OMT*

Es muy importante tener en cuenta que el aumento del turismo ha de ir acorde con la sostenibilidad de los destinos, principalmente en los que tienen alto valor ecológico, con un uso responsable y eficiente de la energía y el agua, siendo primordial mantener la biodiversidad de los mismos *[OMT, 2010]*, *[United Nations Environment Programme (UNEP), 2011]*. Se han de considerar las perspectivas futuras del cambio climático esperado, con aumento de las temperaturas y disminución de las precipitaciones, por lo cual, las necesidades energéticas e hídricas de la industria turística, se incrementarán de forma considerable en los diferentes destinos *[OMT-IPCC, 2011]*. El binomio agua / energía seguirá aumentando, debido a las necesidades de desalación de agua para el consumo humano, al irse agotando los acuíferos

actuales por la sobreexplotación y falta de recarga de los mismos, debido principalmente a la disminución de las lluvias *[Bates, Kundzewicz et al, 2008]*. Teniendo en cuenta los diferentes informes de la OMT *[OMT, 2011]* sobre la proyección del turismo de cara al 2030, los informes de la Organización Internacional del Trabajo (OIT) *[OIT, 2010]* sobre los cambios que van a afectar a los trabajadores debidos al aumento del turismo en las próximas décadas, los informes de la Agencia Internacional de la Energía (IEA) *[IEA, 2014]*, también los informes de la EU *[EU, 2003]* sobre los consumos energéticos y su evolución estimada en el mundo y en Europa, así como los informes del IPCC *[IPCC, 2015]* sobre la proyección de cambio climático según las diferentes escenarios de emisión esperada para el siglo actual, se pone de manifiesto con todos estos informes, datos y previsiones, las necesidades urgentes de adaptación de la industria turística a los cambios que se van a dar en las próximas décadas, obteniendo una visión global de los futuros problemas para poder , de por donde han de evolucionar los destinos turísticos y los complejos hoteleros, para poder adaptarse a estas transformaciones futuras.

Los territorios insulares, debido a su dependencia externa y lejanía, suelen ser más vulnerables para el turismo, como es el del archipiélago de las islas Canarias, donde el sector turístico es su principal motor de la economía, representando en el año 2016 el 34,3% del PIB y generando el 39,7% del empleo en las islas *[Exceltur, 2017]*, y motivo principal también, de su movilidad laboral *[Leon Santana y Godenau, 2015]*. En estos destinos, se siguen con los mismos patrones de expansión basados en grandes complejos turísticos de 4 y 5 estrellas, y según datos del Instituto canario de estadística (ISTAC), estos complejos representan el 44,2% de los establecimientos hoteleros abiertos y el 66,9% de las plazas de alojamiento ofertadas en las islas *[ISTAC, 2016]*. En la siguiente ***Figura 1.3*** se pueden observar el número de pernoctaciones del año 2.015, donde se comprueba que los hoteles de 4 y 5 estrellas se llevan cerca del 70% de todas las pernoctaciones anuales, y si a estas se añaden los establecimientos de 3 estrellas, entonces ya representa cerca del 95% de las estancias totales, por lo cual se ve prioritario centrarse en este tipo de establecimientos, que son donde se concentran casi todas las estancias de alojamiento de las islas. La falta de inversión en EERR, tanto por parte de los complejos hoteleros como por las empresas generadoras y suministradoras de energía eléctrica, han producido que las emisiones de GEI debidas al consumo eléctrico en Canarias, sean muy superiores a las de España peninsular.

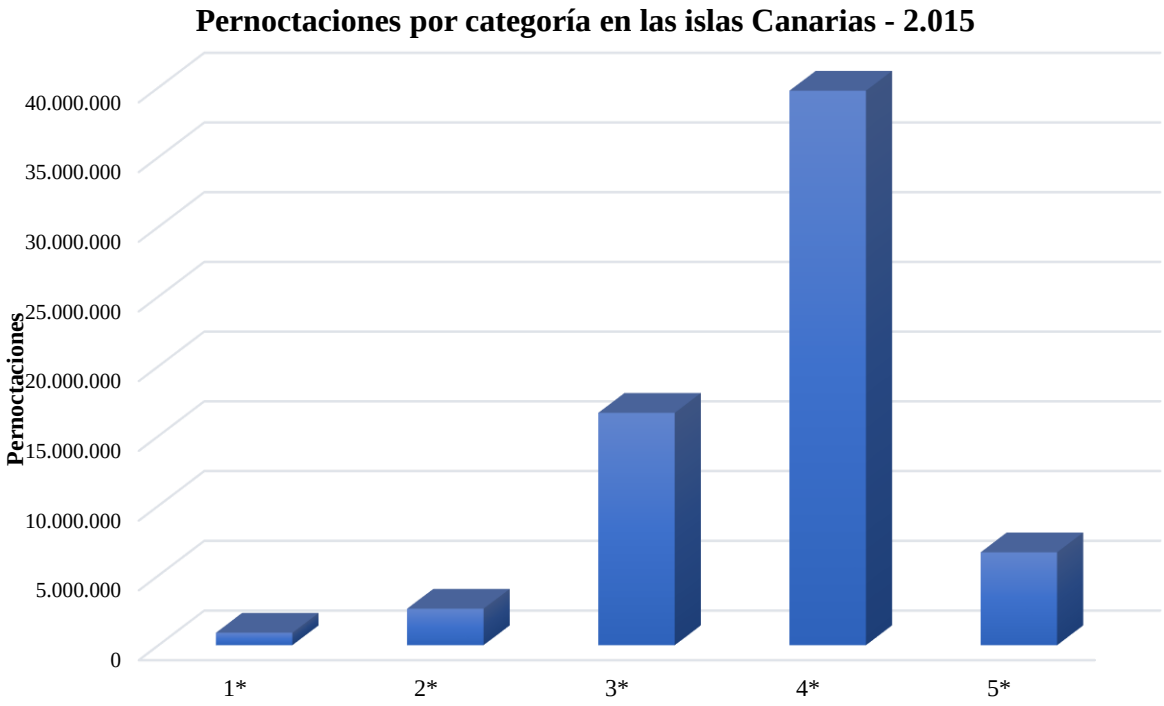


Figura 1.3. *Pernoctaciones por categorías en las Islas Canarias del año 2015. Fuente: ISTAC.*

Comprobada la importancia a nivel mundial del turismo , así como de los ingresos económicos generados para los países receptores del mismo, es necesario centrase en una zona de alto valor ecológico cuya sostenibilidad es muy importante y complicada, como es el destino de las Islas Canarias, donde según datos del Sistema de información medioambiental de Canarias (SIMAC) el 63% de la superficie terrestre está declarado reserva de la biosfera por la Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura (UNESCO) *[SIMAC, 2016]*. Este archipiélago se considera un espacio que posee un valor singular, tanto a nivel ecológico como en capacidad de implementación de modelos de desarrollo compatibles con su conservación, lo cual hace necesario un estudio del impacto del turismo en las islas para contribuir en las actuaciones tecnológicas y estrategias políticas que ayuden a reducir los consumos y mitiguen las emisiones generadas. Como se puede comprobar en la siguiente ***Tabla 1.4***, las islas menores tienen el 100% de su superficie protegida, y son sobre las cuales la sostenibilidad del destino cobra mucha importancia, siendo las islas orientales más áridas de Lanzarote y Fuerteventura donde se han de centrar los estudios, ya que son las más dependientes externamente, tanto de la energía como del agua, la cual es necesario producirla industrialmente mediante desalación.

ISLAS	Superficie isla km^2	Superficie protegida km^2	Año declaración	% Protegido
Lanzarote	846	846	1.993	100%
Fuerteventura	1.657	1.657	2.008	100%
Gran Canarias	1.560	656	2.005	42%
Tenerife	2.034	155	2.015	8%
La Gomera	372	372	2.012	100%
La Palma	708	708	1.983	100%
El Hierro	287	287	2.000	100%
Total Canarias	**7.464**	**4.681**		**63%**

***Table 1.4**. Distribución de superficies terrestre declarada Reserva de la Biosfera. Fuente: SIMAC.*

1.1.3. Los edificios turísticos de alojamiento

Centrándose en los edificios del sector servicios destinados a establecimientos de alojamiento, en España se encuentra que el número total de los mismos varía debido a los cierres por temporada, como se puede comprobar para los datos del 2.015 del Instituto Nacional de Estadística (INE), donde en el mes de agosto había 16.836 hoteles abiertos que ofrecen 1.773.799 plazas hoteleras, valores que van variando durante los diferentes meses del año, con unos valores extremos de hasta en un -25% en los meses de invierno, por lo cual se ha considerado un promedio de 15.000 establecimientos abiertos y 1.440.000 plazas de alojamiento ofertadas *[INE]* para todo el año.

En el destino estudiado de las islas Canarias, se contaba en el año 2.015, con 626 hoteles que ofertan más de 244.000 plazas hoteleras, y con un número de visitantes anuales cercano a los 13.000.000 de turistas, los cuales producen más de 100.000.000 de pernoctaciones en los establecimientos turísticos de las islas *[ISTAC, 2016]*, siendo estos valores muy estables a lo largo del año, sin grandes cambios por temporada como los hoteles y apartamentos peninsulares. Canarias también se diferencia del resto de España en la baja variación de las plazas hoteleras, existiendo tan solo una diferencia de ±0,5% de plazas y habitaciones durante todo el año, ya que es un destino que está operativo todo el año y de baja estacionalidad. En la ***Tabla 1.5*** se puede comprobar la distribución de los establecimientos de alojamiento por categoría, donde se puede observar que las categorías superiores de 3, 4 y 5 estrellas, abarcan el 69,3% de los edificios y un total del 93,2% de las plazas turísticas ofertadas.

CATEGORÍAS	Hoteles	% Sobre total	Plazas	% Sobre total
1 estrella	115	18,4%	4.551	1,9%
2 estrellas	77	12,3%	11.984	4,9%
3 estrellas	157	25,1%	64.294	26,3%
4 estrellas	233	37,2%	137.618	56,2%
5 estrellas	44	7,0%	26.210	10,7%
TOTAL	**626**		**244.657**	

Tabla 1.5. *Distribución de hoteles y plazas por categorías. Fuente: ISTAC.*

Hay que tener en cuenta, que los consumos energéticos de la industria turística del sector alojamiento en Canarias, representan ya el 15% del consumo eléctrico anual *[Gobierno de Canarias, Consejería de Economía, Industria, Comercio y Conocimiento, 2016]*, y el 11% del

consumo de agua *[Delgado Díaz, González Cabrera et. al, 2011]*, respecto del total de las islas, valores variables según las mismas. Considerando la importancia del turismo en Canarias, es imprescindible la búsqueda de modelos de consumos energéticos y de agua, sostenibles y eficaces para poder aplicar estrategias de eficiencia energética en los establecimientos hoteleros. Conseguir que los edificios hoteleros existentes, hagan una reconversión energética para ser clasificados como ZEB o nZEB puede ser muy difícil y no siempre es posible o viable, debido a las necesidades de renovaciones y reformas extremadamente costosas. No obstante, ante las directivas legales promulgadas en favor de la sostenibilidad y la eficiencia de la energía, se hace necesario investigar las metodologías que optimicen los procedimientos que se han de aplicar a los edificios existentes, de forma que se maximice el cumplimiento de los criterios de sostenibilidad y se logre una calificación, lo más próxima posible, al edificio de balance energético cero ZEB o casi cero nZEB.

Para poder realizar un estudio de mejoras energéticas en los edificios hoteleros actuales, es necesario conocer los consumos de éstos y la distribución de los mismos, para saber dónde se pueden y deben hacer las mejoras y modificaciones de los equipos o sistemas. Los consumos varían según las zona geográficas, instalaciones y categorías de los establecimientos, como se puede comprobar por los estudios ya realizados en varios países, como ejemplos, en los hoteles del Caribe donde el 48% de la energía eléctrica se consume en el aire acondicionado (AA) *[Monzón-Alejandro y Colmenar-Santos, 2016]*, en Hong Kong donde el AA representa el 45% del consumo eléctrico *[Shiming y Burnett, 2002]*, en los hoteles de las Islas Baleares donde el consumo de energía total se divide en un 22% para el agua caliente sanitaria (ACS), el 14% para el AA y el 21% para la calefacción *[Moiá-Pol, Karagiorgas et al, 2006]*. En los hoteles de Estados Unidos los consumos se dividen, de forma general, con la climatización con el 31% el AA con el 15%, el ACS con el 17% y el resto, para otros usos *[HES, 2011]*, en Gran Bretaña la distribución típica es del 47% en calefacción y el 20% en ACS *[The Carbon Trust, 2015]*, en Grecia la distribución típica es del 35% en calefacción, el 15% en AA y el 22% en ACS *[Karagiorga et al, 2007]*. También las asociaciones turísticas junto con varias universidades han realizado diferentes estudios para proporcionar puntos de referencia de consumos energéticos, agua y huella del carbono a nivel mundial, teniendo en cuenta la diferenciación por categorías y tipos de establecimientos y su zona geográfica *[Chong y Ricaurte, 2015]*.

1.1.4. La energía en Canarias

Canarias tiene una gran dependencia energética exterior, muy superior a la media de España, teniendo tan solo una producción energética propia que representa el 1,5% de la energía primaria del archipiélago, en el año 2.015, siendo dicha cifra la aportada conjuntamente de todas las energías renovables instaladas: eólica, fotovoltaica, soltar térmica, hidro eólica, minihidráulica y biogás de vertedero *[Gobierno de Canarias, Consejería de Economía, Industria, Comercio y Conocimiento, 2016]*, mientras que en el conjunto de España el valor se elevaba al 6% para ese el mismo año [*Gobierno de España, Ministerio de industria, energía y turismo, 2016]*.

Centrándose en la energía eléctrica de Canarias, y según los datos de infraestructuras proporcionados por Red Eléctrica de España (REE), se observa como el sistema de generación y distribución eléctrico canario tiene la singularidad de que son seis subsistemas eléctricos aislados y de pequeño tamaño *[REE]*, uno por isla, menos Fuerteventura y Lanzarote que están unidos por un cable submarino, creando esta circunstancia un problema en la calidad del servicio, ya que es más complicado conseguir una estabilidad y seguridad en estos micro sistemas que en los grandes macro sistemas de generación, como son los peninsulares, donde las variaciones de consumos o de generación de EERR son más fácilmente asumibles. Debido a la división en estas zonas del sistema eléctrico canario, la conexión de los equipos de generación de EERR se hace más complicado por la dificultad de la gestión de los mismos. El modelo energético actual canario, tiene como una de sus principales necesidades para poder conseguir un sistema sostenible, la ampliación de los equipos de generación por EERR, tanto mediante autogeneración como por sistemas conectados a la red, ya que los valores de generación por EERR están muy por debajo de los obtenidos en España peninsular, donde este tipo de generación ha pasado de un 19,4% en 2.006 al 40,5% en el 2.016, mientras que en Canarias, su valor se ha mantenido casi sin cambios, pasando del 6,2% de 2.006 al 8% de 2016 *[REE, 2017]*. Como se puede observar en la ***Figura 1.4***, de la estructura de generación de energía eléctrica entre los años 2.006 al 2.016, las EERR han tenido una tendencia alcista durante estos años, principalmente en el sistema peninsular *[REE, 2017]*.

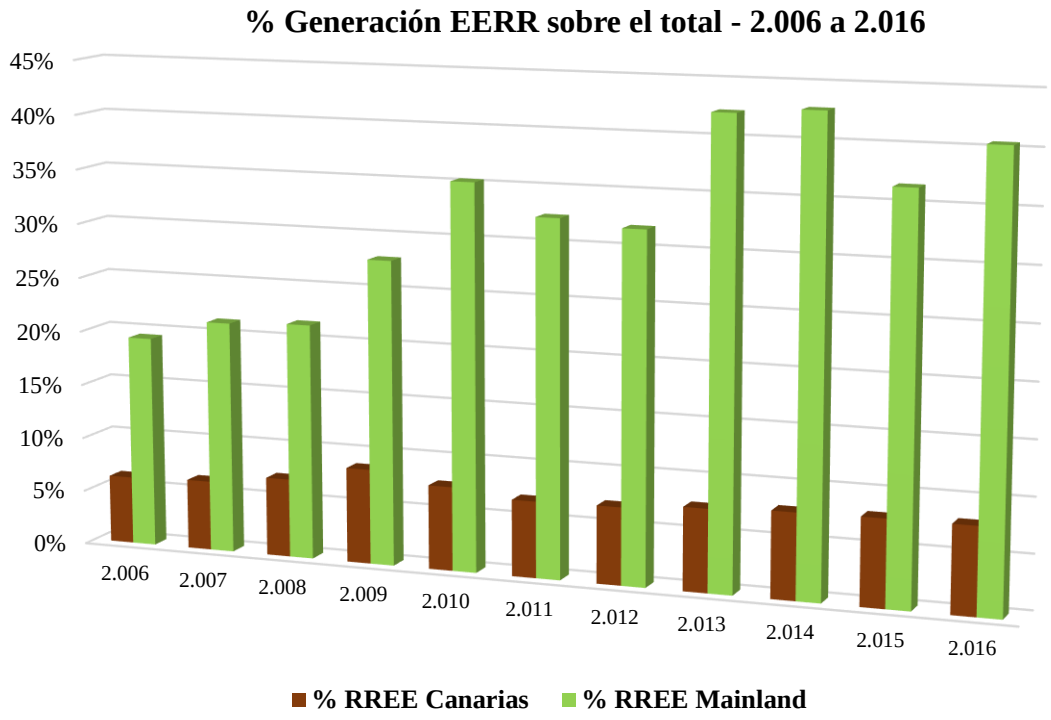


Figura 1.4. *Porcentaje de generación de EERR sobre el total en Península y Canarias. Fuente: Red Eléctrica Española (REE).*

Este aumento de la generación mediante EERR, en la península principalmente, ha sido debido, entre otros motivos, al incremento de las instalaciones generadoras basadas en la energía eólica y en la energía solar fotovoltaica, siendo estas últimas las que más aumentaron entre los años 2.006 al 2.011 *[REE, 2017]*, pasado de 125MW en el 2.006 a 4.560MW en el 2.012, debido principalmente a las ayudas y los incentivos a la producción de electricidad mediante EERR. Este aumento continuado de instalaciones y la imposibilidad de sostenibilidad del sistema de incentivos, obligo a los distintos gobiernos a ir recortando estas ayudas a la producción, comenzando este declive económico de incentivos en el año 2.010 *[Gobierno de España, Jefatura del estado, 2010]* y terminando con la suspensión definitiva de estas ayudas e incentivos a la producción en el año 2.012 *[Gobierno de España, Jefatura del estado, 2012]*. Esto significó una paralización de las nuevas instalaciones a partir de ese año, como se puede comprobar gráficamente en la ***Figura 1.5*** sobre la evolución de la instalación de potencia fotovoltaica a nivel nacional, donde se observa como a partir del año 2.012 la potencia fotovoltaica instalada se mantiene constante sin un aumento apreciable de la misma. Debido a esta suspensión de las retribuciones a las EERR, en la actualidad las instalaciones con conexión a red ya no tienen una rentabilidad comparable a los años previos al 2.012, aun que, debido a su duración prevista de las instalaciones y equipos de 25 años, no ha dejado de ser una mala

inversión, pero con una rentabilidad muy baja, y teniendo en cuenta que se mantenga la seguridad jurídica en su regulación *[Guaita-Pradas y Marí Soucase, 2014]*.

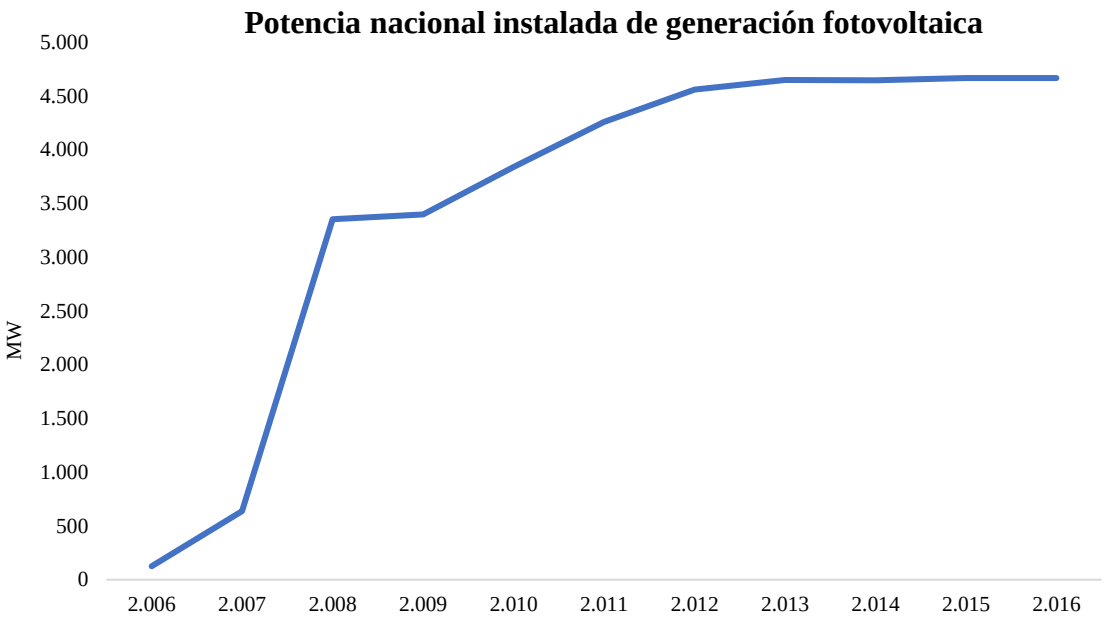


Figura 1.5. *Potencia fotovoltaica instalada en España 2006-2016. Fuente: REE.*

Teniendo en cuenta esta desaparición de incentivos y falta de subvenciones, las aplicaciones de autoconsumo y la integración de placas fotovoltaicas en edificios (BIPV), se han convertido en un modelo interesante para su instalación e integración en edificios actuales *[Matallanas, Castillo-Cagigal et al, 2011]*, que junto con otras EERR, se pueden realizar modelos de generación mixtos, como se ha comprobado en varias instalaciones *[Gallo, Téllez Molina et al. 2014]*, *[Badwawi, Abusara et al, 2015]*, *[Kim, Kim et al, 2015]* para cubrir las diferentes demandas de energía de los edificios, con el fin de conseguir edificios ZEB o nZEB. Por parte de la IEA, se ha realizado un estudio sobre el autoconsumo mediante energía solar fotovoltaica, comparando e informando sobre las políticas de los diferentes países respecto de la viabilidad y legislación sobre el autoconsumo *[Masson, Ignacio Briano et al, 2016]*.

España es el cuarto país de la EU, con mayor irradiación media anual para su utilización en generación de EERR *[Šúri, Huld et al, 2007]*, lo cual lo sitúa en un puesto de cabeza para poder conseguir altos rendimientos en las instalaciones solares fotovoltaicas o térmicas, siendo cualquier instalación de autoconsumo mucho más eficaces en España que en la mayor parte de los países de la EU. Las islas Canarias tienen una posición geográfica privilegiada para la

aplicación de estas tecnologías basadas en la energía solar, debido a su mayor irradiación media anual que el resto de las comunidades peninsulares *[Aemet, 2012]*.

La utilización de las EERR, como se ha comprobado anteriormente, sobre todo en la península, ha conseguido disminuir los factores de emisiones de la electricidad peninsular, mientras que en Canarias se ha quedado en unos valores que son un 262% superior que los peninsulares, como se puede comprobar gráficamente en la ***Figura 1.6*** donde se muestran la evolución de los factores de emisión de la electricidad entre los años 2.006 a 2.016.

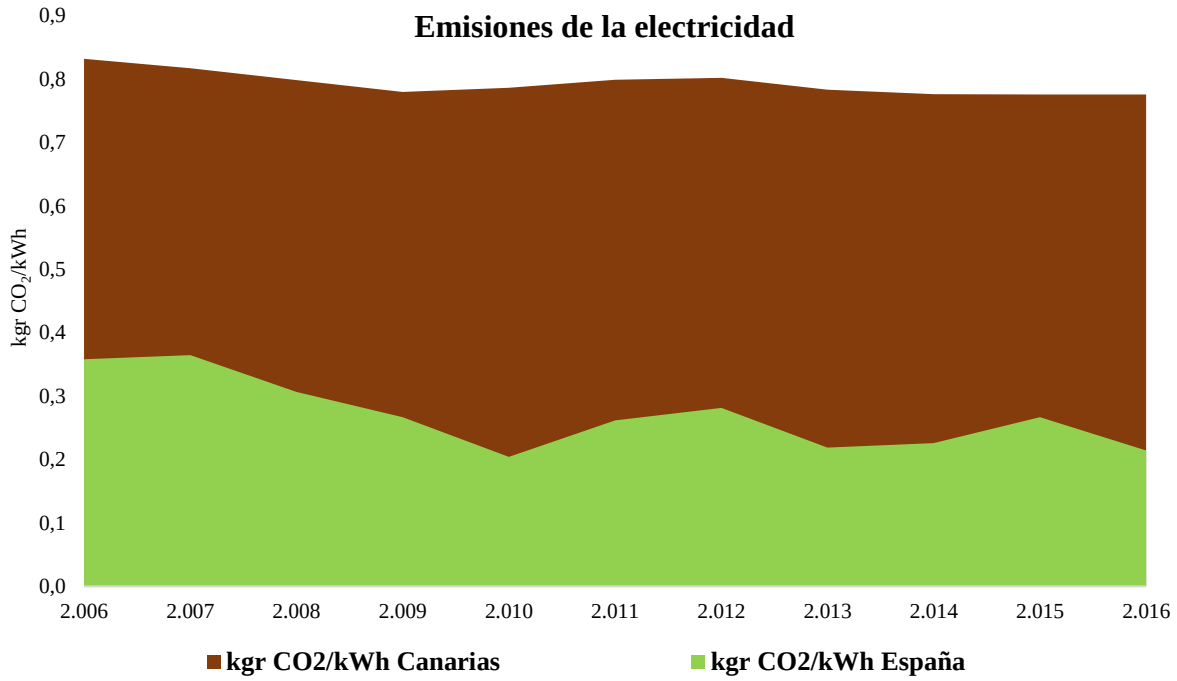


Figura 1.6. *Emisiones en kg CO_2/kWh de la electricidad 2.006-2.016. Fuente: REE.*

Un dato importante para poder evaluar los gastos energéticos de los edificios hoteleros, son los diferentes coeficientes de consumos totales de energía, los cuales se pueden realizar teniendo en cuenta la superficie construida y calcular los kWh/m^2_año o teniendo en cuenta la ocupación media de los establecimientos, donde se puede obtener los coeficientes de kWh/habitación_ocupada_día (kWh/h) o kWh/pernoctación_cliente_día (kWh/p).

Son varios los estudios que se han realizado para obtener estos datos de coeficientes de consumos, siendo muy utilizados por las empresas turísticas los referidos a la ocupación de clientes, donde se ha podido comprobar que los datos muestran una gran variación dependiendo de la zona geográfica y las categorías de los establecimientos. Ejemplos de estos estudios son los realizados sobre varios hoteles de Grecia *[Karagiorgas, Tsoutsos et al, 2007]* obteniendo

valores promedio de 68,15 kWh/p en los hoteles de categoría superior y de 17,59 kWh/p en los de inferior categoría, o en 200 hoteles de Taiwán *[Chun Wang, 2012]* donde los consumos también se comprobaron que dependen de la categoría del hotel, con valores promedio por habitación ocupada entre los 26,7 kWh/h a los 9,4 kWh/h, siendo el 84% de la energía consumida, energía eléctrica. Otros estudios han calculado la intensidad energética en kWh/m^2 según la superficie construida de los hoteles *[Priyadarsini, Xuchao et al, 2009]*, *[Yao, Zhuang et al 2015]* sin tener en cuenta la ocupación de los mismos.

Las emisiones debidas al consumo energético del turismo han sido estudiadas en varios temas, siendo el del alojamiento de turistas el más variable. La gran variedad en las emisiones en los destinos es debido principalmente a los diferentes coeficientes de emisión de los combustibles utilizados y de la generación eléctrica que varía mucho según tecnologías y zonas geográficas, así como el debido a la eficiencia energética de las instalaciones. Estudios realizados en varias zonas de la isla de Menorca *[Sanyé-Mengual, Romanos, et al, 2014]* dieron un resultado de emisiones medias 14,6 kgCO_2/pernoctación_día (CO_2/p). Otros estudios de las emisiones de 58 hoteles de lujo de Taiwán *[Huang, Chun Wang et al, 2015]* arrojaron unos valores medios de 29 CO_2/p, o los estudios de dos hoteles de Gran Bretaña *[Filimonau, Dickinson et al 2011]* se obtuvieron unos valores para las emisiones de 11,65 CO_2/p a 8,25 CO_2/p. También se ha realizado una estimación promedio para las estancias mundiales en hoteles *[Gössling, Peeters et al 2005]* calculando un promedio de 20,6 CO_2/p. Estos estudios han acercado más la problemática de emisiones del turismo, debido al alojamiento.

Teniendo en cuenta la necesidad de reducir las emisiones y la zona geográfica privilegiada del archipiélago de las islas Canarias respecto de la radiación solar, este trabajo de investigación se centra también en la importancia y posibilidad de instalar sistemas de autoconsumo de placas solares fotovoltaicas, ya que está es una energía limpia y renovable, mediante modelos de pronósticos de irradiación solar. Este tipo de instalaciones tienen la posibilidad de ser modulares y aumentar la potencia de las plantas generadoras de forma sencilla, mediante un aumento de superficies de generación, así como la posibilidad de su integración arquitectónica en edificios actuales, lo cual lo hace muy recomendable para su instalación en edificios hoteleros en uso, para ayudar a conseguir de esta forma que dichos edificios sean ZEB o nZEB, existiendo múltiples ejemplos de su aplicación como BIPV *[Yoon, Song et al, 2011]*, *[World Map of 360 international known nZEB]* y en otro tipo de instalaciones como en aeropuertos *[Rüther y Braun, 2009]*.

También hay que tener en cuenta la posibilidad de utilización de sistemas basados en energía eléctrica para el calentamiento del ACS de equipos que se puedan considerar como renovables como se define en la Directiva 2009/28/CE *[EU, 2009]*. Estos equipos poder considerarse como equipos basados en EERR han de tener un factor del rendimiento estación (SPF) *[EU, 2008]* diferente según el tipo de equipo, como puede ser las bombas de calor de accionamiento eléctrico cuyo SPF ha de ser mayor de 2,5 para ser consideradas renovables *[EU, 2013]*. Estos sistemas se han estudiado en varias instalaciones para su utilización en edificios ZEB *[Aste, Adhikari et al, 2017]* o en viviendas *[Aira, Fernández-Seara et al, 2017]*, así como modelos mixtos de bombas de calor y placas solares fotovoltaicas para la alimentación del sistema *[Aguilar, et al, 2016]*, *[Toradmal, et al, 2018]*.

Teniendo en cuenta la posibilidad de realizar sistemas de autogeneración eléctrica mediante placas solares fotovoltaicas en zonas con alta irradiación, como son las islas Canarias, es necesario comprobar que los datos estimados de producción calculados mediante las diferentes bases de datos (DB) y generar un modelo correcto de irradiación para la zona de instalación de los establecimientos hoteleros, cuyos pronósticos se ajusten lo máximo posible con los valores finales reales obtenidos, ya que los diferentes valores de las DB pueden generar diferencias de estimación muy altas, como se pudo comprobar en los estudios de datos de irradiación calculadas por satélites *[Vernaya, Pitavala et al, 2014]*, *[Šúri, Remund et al, 2008]* o en la comparación DB obtenidas por web para Polonia *[Mazurek, 2014]*, donde se puede evidenciar la sobreestimación de los inviernos y la subestimación los veranos. También se puede calcular la función característica de irradiación características de cada zona mediante cálculos estadísticos con los valores obtenidos en mediciones de campo, como se han realizado para varios países, en Turquía *[Bezir, Akkurt et al, 2010]*, Tíbet *[Li, Ma et al, 2011]*, en la India *[Katiyar y Kumar, 2010]*, en Arabia Saudi *[El-Sebaii, Al-Hazmi et al, 2010]* o en Argelia *[Chegaar y Chibani, 2001]* entre otros, comprobándose la validez de sus cálculos obtenidos en verificaciones posteriores.

1.1.5. El agua en Canarias

El agua es imprescindible para el desarrollo humano, siendo en el origen en las islas muy variable, desde encontrarse en acuíferos naturales hasta tener que ser generada industrialmente mediante desalación de agua de mar principalmente. En el archipiélago de las islas Canarias, debido a la diferencia de sus zonas climáticas y geográficas, el origen del agua para el consumo humano varía entre las diferentes islas, pudiendo proceder de aguas superficiales, subterráneas o desaladoras de agua de mar o salobre. En la actualidad, mayoritariamente el origen del abastecimiento es la desalación de agua de mar o salobre, que según datos del Instituto Canario de Estadística (ISTAC) se sitúa en el año 2014 en el 90,5% del total suministrada y facturada para ese año *[ISTAC, 2017]*, siendo este porcentaje variable entre las diferentes islas del archipiélago. En la ***Tabla 1.6*** se puede comprobar la evolución y tendencia actual del suministro de agua mediante desaladoras, donde en estos últimos 20 años ha aumentado el agua total suministrada en un 75,8%, mientras que el origen de la misma también se ha modificado y ha pasado a depender principalmente de la desalación, con un aumento de un 204,9% en este tiempo. Para el resto de los suministros de riego o industrial, se utiliza principalmente el agua subterránea y superficial, aunque también se está imponiendo la desalada para estos tipos de suministro.

Origen Agua	1.996		2.000		2.005		2.010		2.014	
	Hm^3	%	Hm^3	%	Hm^3	%	Hm^3	%	Hm^3	%
Superficiales	3.716	4,7%	18.961	17,6%	17.881	13,7%	47.386	32,6%	5.404	3,9%
Subterráneas	33.984	43,1%	11.657	10,8%	40.415	31,0%	8.652	5,9%	7.803	5,6%
Desalación	41.125	52,2%	76.835	71,5%	71.941	55,2%	89.535	61,5%	125.386	90,5%
TOTAL	**78.825**		**107.453**		**130.237**		**145.573**		**138.593**	

Tabla 1.6*. Captación de agua total suministrada y facturada en Canarias en* Hm^3*. Fuente: ISTAC*

En las Canarias ya se han empezado a sufrir los problemas de la sobreexplotación de los acuíferos subterráneos, que según datos del Instituto Tecnológico de Canarias (ITC) obtenidos del proyecto ISLHáGUA *[Peñate Suarez, Martel Rodríguez, et al, 2008]* en los últimos años han acusado una disminución en las reservas naturales de dichos acuíferos subterráneos en un 36,4% en Gran Canarias y en un 35,3% en Tenerife, por lo cual, este tipo de suministros está también migrando hacia la desalación mediante plantas desaladoras. Según datos del 2.013 existen en funcionamiento en toda Canarias unas 319 desaladoras, de las cuales 126 son

exclusivamente para el riego, con una producción de 119.518 m^3/día y las restantes 193 plantas son para suministro de agua de consumo o mixta (consumo + riego) con una producción de 484.725 m^3/día *[Hernández Suarez, 2013]*.

La necesidad de generación industrial de agua en las islas ha creado un binomio agua / energía que es debido a que el suministro de agua depende principalmente de las desaladoras como se ha expuesto, y éstas dependen del suministro energético a las mismas, principalmente la electricidad. Teniendo en cuenta el aumento de la población y del número de turistas, las administraciones han dado mucha importancia al consumo de agua, y mediante los planes hidrológicos de las diferentes islas, se intenta ir ajustando las dotaciones estimadas de agua, para que se puedan ir aproximando a los consumos reales de las mismas, para de esta forma mantener un equilibrio entre: necesidades, bienestar y sostenibilidad.

En la ***Tabla 1.7*** aparecen los ejemplos de las dotaciones medias de agua aprobadas para la isla de Lanzarote *[Gobierno de Canarias, decreto 362/2015, 2015]* y la isla de Fuerteventura *[Gobierno de Canarias, decreto 45/2015, 2015]*, cuyos valores están muy lejos de los consumos reales de los establecimientos actuales. Teniendo en cuenta que esta investigación se centra principalmente en estas dos islas, se puede comprobar como su clima se caracteriza por su extrema aridez, ya que el 87% de la superficie de las islas se considera árida y el 13% semiárida, un valor muy superior a la media del archipiélago donde es considerado árido el 43% de la superficie *[Tejedor, Jiménez Mendoza et al 2013]*. Con estos datos de aridez y teniendo en cuenta las muy bajas precipitaciones hídricas de las islas, las cuales la media anual está entre los 98mm de Fuerteventura y los 111mm de Lanzarote *[AEMET, 2012]*, se entiende la necesidad del uso del agua de desaladoras tanto para el consumo humano como para el riego, usando también para esta última agua regenerada de las depuradoras actuales.

ZONA	Unidades	Lanzarote	Fuerteventura
Área urbana	l/persona día	150	180
Zona Turística	l/persona día	200	250
Viviendas	l/persona día	100	
Riego Máximo	l/m^2 jardín día	2,33	1,1

Tabla 1.7*. Dotación de agua objetivo para las islas de Lanzarote y Fuerteventura. Fuente: Gobierno de Canarias.*

En los sistemas actuales de distribución de las islas mediante desaladoras centralizadas, hay que tener en cuenta las pérdidas de las redes y aljibes de distribución los cuales actualmente tienen unas pérdidas muy altas, que según los datos oficiales de cada isla se encuentran entre un 23% de mínimo en la isla de Gran Canaria *[Gobierno de Canarias, 2015]*, hasta unos valores máximos del 48,7% en la isla del Hierro *[Gobierno de Canarias, 2015]*, como se puede observar en la ***Tabla 1.8*** que muestra las perdidas en las redes de suministro de las islas, según los datos de diferentes planes hidrológicos presentados y aprobados para las diferentes islas del archipiélago.

ISLA	% Pérdidas en la distribución
Gran Canaria	23,0%
Fuerteventura	35,8%
Lanzarote	42,0%
Tenerife	35,0%
La Palma	43,0%
La Gomera	24,0%
El Hierro	48,7%

Tabla 1.8*. Pérdidas de agua en las redes de distribución. Fuente: Gobierno de Canarias.*

Como se ha comprobado los suministros de agua del archipiélago son principalmente generados industrialmente mediante desalación de agua de mar o salobre, y cuyas desaladoras pueden ser propias de los establecimientos o centralizadas con distribución por las redes de suministro actuales, crean una necesidad de reducción de los consumos de agua debido a que esta generación tienen gran importancia para el consumo energético total del destino y de las emisiones producidas.

Los consumos de agua, igual que la energía, también tienen una gran variación según las zonas geográficas y categorías de los establecimientos. Ejemplos de estas variaciones de los consumos se pueden observar en los estudios llevados a cabo en la mayor parte del Mediterráneo *[Grenon y Batisse 1989]* donde se situá entre los 250 litros/pernoctación (=l/p), en Marruecos *[EU Eurostat, 2009]* donde dependen de la categoría y pueden variar los consumos entre 300 l/p a 600 l/p , en Australia *[Bohdanowicz y Martinac, 2007]* con unos valores promedios de 750 l/p, en la isla de Zanzíbar *[Gössling, 2001]* con una media de 685 l/p. A nivel mundial se han realizado estimaciones *[Gössling, Peeters et al, 2012]* que sitúan el consumo promedio en unos 284 l/p, comprobando en este estudio como se puede llegar a valores extremos en algunos

destinos de hasta 2.000 l/p. Estos estudios proporcionan unas estimaciones de los consumos del turismo los cuales puede llegar a ser una proporción superior al resto de los usos de las diferentes zonas, como puede ser en Malta *[Mangion, 2013]* que representa el 38% de gastos de agua de la isla. También las instalaciones de los establecimientos influyen en los consumos de agua, comprobándose en la isla de Hawái [*Gopalakrishnan y Cox, 2013]* la importancia del número de campos de golf y de piscinas de los diferentes resorts sobre el consumo total de la isla, o en el caso de la isla de Mallorca donde se evidenció la importancia de las piscinas en el consumo de agua de los hoteles *[Deyà y Tirado, 2011]*. En Canarias se hace necesario el estudio de los consumos de las piscinas de los establecimientos turísticos, ya que según datos del Sistema de Información Nacional de Piscinas (SILOE) en éstas se almacenan cerca de 0,5 hm^3 de agua dulce *[Siloe]*. La estimación de los consumos de agua debidos a su mantenimiento se presenta como un estudio fundamental para el control de consumos de los establecimientos turísticos y de la huella del carbono generada por la producción de la misma, siendo la modelización de estos consumos esencial para su optimización.

Varios estudios sobre las perdidas evaporativas de las piscinas han sido realizados por algunos autores, iniciando las investigaciones Carrier en 1918 *[Carrier, 1918]*, y continuando otros investigadores con varios estudios teniendo en cuenta otras variables de cálculo, como el número de usuarios dentro de la piscina, que puede llegar a incrementar el consumo entre un 40% y un 70% *[Smith, Lof et al, 1999]*, *[Shah, 2003]*, o según el tipo de envolvente de las piscinas interiores y número de usuarios *[Hens, 2009]*. Shah realizó varios estudios para todo tipo de vasos de piscinas, obteniendo diferentes correlaciones según las características de las mismas *[Shah, 2014]*. Además de las pérdidas por evaporación, también hay que considerar otras debidas al funcionamiento general de las piscinas, los cuales son necesarios tener en cuenta, como se comprobó en las piscinas de California (USA) *[Koeller, 2010]* donde la evaporación era responsable tan solo del 56% de las recargas de agua, mientras que a la limpieza de filtros correspondían un 23% y a las perdidas varias y otros motivos el 21% restante. Se comprueba la importancia y necesidad de realizar estudios que tengan en cuenta todas las pérdidas de agua y no solo las debidas a la evaporación de las piscinas.

1.2. PREGUNTAS DE LA INVESTIGACIÓN

Una vez comprobado la importancia del sector turístico en la zona de estudio del archipiélago de las islas Canarias, así como su dependencia energética externa y la necesidad de generación de agua potable de forma industrial para el suministro a la población e industria, se hace evidente la necesidad de reducir los consumos energéticos y de agua, así como aumentar la eficiencia de los sistemas actuales y de esta forma conseguir la sostenibilidad del destino y la autosuficiencia energética de los edificios turísticos alojativos. Con estas premisas y necesidades mostradas, se han generado las preguntas principales que se intentan responder en este trabajo de investigación, que son:

- ¿Cuál es el principal indicador del consumo energético de los establecimientos hoteleros?
- Los consumos energéticos y de agua, ¿responde a alguna función característica?
- ¿Cuáles son los principales factores que influyen en los consumos energéticos y en las emisiones de los establecimientos?
- ¿Es posible la modelización de los consumos energéticos, de agua y de las emisiones de CO_2 en los establecimientos hoteleros?
- ¿Qué importancia tiene la generación de agua en los consumos energéticos de los hoteles?, y ¿Cuál es la huella del carbono asociada a esta generación?
- ¿Qué sistemas son más eficientes para el suministro de agua a los hoteles mediante los sistemas de desalación centralizados o los sistemas locales?
- Las piscinas de los establecimientos turísticos, ¿Cuál es la importancia de sus consumos en los establecimientos?, y ¿En el total de Canarias?
- A igualdad de consumos energéticos y de agua, los hoteles canarios respecto de los peninsulares, ¿Cuál es la diferencia de su huella del carbono?
- ¿Qué importancia tiene la categoría de los hoteles en sus consumos y emisiones?, y ¿Sobre qué categorías han de realizarse las mejoras para disminuir los consumos totales del sector?
- Tomando como base la energía solar fotovoltaica para un posible sistema de autoabastecimiento energético en los establecimientos, ¿Se podrían utilizar otras instalaciones en funcionamiento para realizar pronósticos de generación?, ¿Qué modelos matemáticos se pueden usar para realizar dichos pronósticos?, ¿Cuáles son las bases de datos de irradiación con las que se obtienen pronósticos de generación más reales?

2.

OBJETIVOS

2.1. OBJETIVOS

Como consecuencia de haber formulado unas preguntas de investigación, se generan unas hipótesis como respuesta a lo que se ha planteado, mediante la definición de los objetivos de este trabajo de investigación.

El punto de partida es analizar las actividades de un conjunto de edificios hoteleros y plantas generadoras fotovoltaicas del archipiélago de las islas Canarias, en relación con los consumos energético de las fuentes de energía utilizadas, los consumos de agua, las emisiones de gases de efecto invernadero (GEI) resultantes de la actividad, la generación eléctrica obtenida de los diferentes sistemas fotovoltaicos, las condiciones ambientales de las zonas de estudio y la irradiación solar característica de la zona geográfica investigada.

Los objetivos generales de este trabajo de investigación son:

- Identificar y verificar los modelos energéticos de los establecimientos hoteleros en el ámbito de estudio, así como sus emisiones asociadas para poner de relieve los principales orígenes de emisiones de GEI, con el fin de determinar los modelos óptimos de reducción efectiva de los mismos, que facilite el logro para conseguir edificios ZEB o nZEB.
- Analizar el aprovechamiento de la irradiación local en el área geográfica considerada, para poder pronosticar la eficiencia y rentabilidad de la implantación de EERR basadas en sistemas de generación solar fotovoltaica, en los establecimientos hoteleros, así como realizar la estimación de su contribución en la compensación del balance de emisiones GEI de los establecimientos de estudio.

Los objetivos específicos que se han buscado fueron:

- Dentro de las herramientas, lenguajes de implementación y técnicas matemáticas de modelización, investigar el método idóneo para identificar el modelo energético que mejor caracterice los sistemas energéticos de los edificios hoteleros de estudio, comparando los consumos de energía total y de las diferentes energías primarias de forma independiente, generando sus modelos de consumo correspondientes.
- Comprobar la importancia del agua y su influencia en los consumos energéticos de los hoteles de estudio, realizando un modelizado de los consumos de agua para compararlos con los consumos energéticos de los edificios de estudio, determinando qué modelo de

consumo mejor se aproxima a la descripción del comportamiento del binomio energía-agua de los establecimientos de estudio.

- Comparar los edificios actuales de las islas Canarias con otros edificios de la península con consumos equivalentes, justificando causalmente las diferencias de emisiones de GEI encontradas según los destinos, zonas geográficas y categoría de los hoteles.
- Dentro de los consumos de agua de los hoteles, comparar y comprobar la proporción del riego dentro de los establecimientos y su dependencia respecto de los diferentes indicadores climáticos (temperatura y la pluviosidad) de la zona geográfica estudiada.
- Debido a las características climáticas de la zona en estudio, cuya agua de consumo es necesaria generarla industrialmente, se comparar los sistemas de suministro y generación de agua mediante desaladoras propias o centralizadas con suministro por las redes de abastecimiento actuales, así como su influencia en la huella del carbono y emisiones de GEI debido a los consumos de agua asociados a los complejos turísticos.
- Basado en los modelos establecidos para los consumos de agua y energía de los establecimientos de estudio, evidenciar y cuantificar las emisiones de GEI que producen y comprobar la distribución de los diferentes combustibles en la huella del carbono de los establecimientos.
- Teniendo en cuenta la importancia de las piscinas en el destino vacacional de estudio como son las islas Canarias, estimar el consumo de agua de estas instalaciones y las necesidades energéticas asociadas a la generación industrial de esta agua para el mantenimiento de sus servicios, así como las emisiones GEI asociadas. Llevar el ámbito de estudio al conjunto de todas las piscinas de los establecimientos turísticos del archipiélago.
- Debido a la importancia de las emisiones de GEI generadas por el consumo de agua en el mantenimiento de las piscinas turísticas, llevar a cabo un estudio comparativo entre los modelos de generación de agua mediante desaladoras locales o centralizadas por suministro por las redes de abastecimiento actuales.
- Comprobar las diferencias de emisiones de GEI y consumos energéticos necesarias para la generación de agua en modo centralizado y si hay diferencias entre las diferentes islas de suministro.

2. OBJETIVOS

- Analizar modelos de reducción de consumos energéticos en instalaciones de ACS basados en tecnologías actuales y accesibles, que se puedan implantar en establecimientos hoteleros actuales y comprobar los beneficios económicos que se pueden obtener.
- Comprobar la posibilidad de utilización de datos de plantas solares fotovoltaicas existentes para establecer pronósticos de irradiación basados en modelos matemáticos no lineales, para facilitar las estimaciones predictivas de generación energética sostenible en edificios hoteleros existentes.
- Analizar con que bases de datos se obtiene predicciones más exactas de generación eléctrica con paneles solares fotovoltaicos comparándolos con los datos reales de instalaciones en uso.

El alcance de la investigación es de 12 hoteles de diferentes cadenas hoteleras españolas, 42 piscinas de 14 establecimientos diferentes y de 11 plantas fotovoltaicas generadoras en uso, todos ellos situados en el archipiélago de las islas Canarias, que se definen en el apartado metodología de esta investigación. El estudio de la huella del carbono y emisiones de GEI será de alcance 1 y 2, de aplicación a los consumos energéticos y de agua de los diferentes establecimientos.

2.1.1. Resultados esperados con la investigación

Con este estudio de investigación se pretende dar respuesta a las preguntas planteadas con anterioridad, y de forma concreta, conseguir los siguientes resultados:

- Modelos y patrones de consumos de energía total, de electricidad y de agua en las instalaciones hoteleras actuales, y la caracterización de los principales consumidores energéticos de dichos establecimientos.
- Un modelo de distribución típica de las emisiones de GEI, identificando los sistemas de energía primaria que generan la mayor parte de las emisiones de GEI de los establecimientos hoteleros de estudio.
- Cuantificar la contribución del consumo de agua en los consumos energéticos y emisiones de GEI de los establecimientos de estudio, enunciando las mejoras necesarias para conseguir reducirlas, pero sin producir un detrimento de los servicios hoteleros actuales que afectan a los usuarios.
- La configuración de instalación de piscina más adecuada para reducir las necesidades de agua en su mantenimiento, y cuantificar la importancia de las piscinas turísticas en el consumo energético y de agua de los establecimientos.
- Determinar el sistema de suministro de agua generada industrialmente más eficiente y con menor emisiones de GEI asociadas, para los establecimientos hoteleros actuales y las diferencias entre las islas del archipiélago.
- Algoritmo de aprovechamiento óptimo de irradiación solar en las zonas geográficas de estudio, para su uso en pronósticos de generación fotovoltaica, basado en datos de producción de plantas de generación fotovoltaicas actuales es funcionamiento.

En general, como resultado de esta investigación se habrá conseguido un procedimiento basado en tecnologías y modelos matemáticos ágiles y efectivos para el diagnóstico, el diseño de actuaciones de reformas y la verificación del estado energético como base para mejorar la eficiencia energética y la reducir de las emisiones de GEI de los establecimientos tipo estudiados, así como demostrar la viabilidad de lograr cuantificar las necesidades reducción energética y de emisiones para lograr un edificio ZEB o nZEB siguiendo las pautas estudiadas en esta investigación.

3.

METODOLOGÍA

3.1. METODOLOGÍA

La investigación realizada está basada en edificios turísticos de alojamiento con la categoría de hotel, situados en el archipiélago de las islas Canarias, para lo cual se ha contado con los datos suministrados por los departamentos corporativos y directivos de 12 hoteles de diferentes categorías, de 3, 4 y 5 estrellas, como se puede comprobar en la ***Tabla 3.1*** donde aparecen el listado de los hoteles estudiados y sus características principales.

DATOS	EPG	ESH	HPE	HT	ESA	ECA
Isla	Fuerteventura	Fuerteventura	Fuerteventura	Fuerteventura	Fuerteventura	Fuerteventura
Localidad	Antigua	Antigua	Pájara	Pájara	Antigua	Antigua
Categoría	5*	5*	4*	4*	4*	4*
Año construcción	2.002	2.006	2.000	2.004	2.003	2.007
Superficie	13.179 m^2	41.806 m^2	30.000 m^2	34.879 m^2	27.163 m^2	34.670 m^2
Superficie construida	8.124 m^2	35.888 m^2	25.912 m^2	31.132 m^2	22.710 m^2	28.307 m^2
Habitaciones	61	266	333	354	266	346
Plazas (camas)	122	532	678	710	532	692
Superficie jardines		15.000 m^2	8.000 m^2	11.000 m^2	6.000 m^2	14.000 m^2
N.º Edificios	1	1	7	1	1	1
N.º Plantas	3	6	10	7	7	5
Tipo suministro agua consumo humano	Pública	Pública	Desaladora propia	Desaladora propia	Pública	Pública
Tipo suministro Riego		Depurada	Desaladora propia	Desaladora propia	Depurada	Depurada
DATOS	**HRP**	**HTI**	**MSL**	**ECE**	**ESJ**	**PPC**
Isla	Lanzarote	Lanzarote	Lanzarote	Fuerteventura	Fuerteventura	Fuerteventura
Localidad	Playa Blanca	Playa Blanca	Tías	Antigua	Antigua	Oliva
Categoría	4*	4*	4*	3*	3*	3*
Año construcción	2.001	1.997	1.988	1.998	1.997	1.993
Superficie	94.970 m^2	38.622 m^2	26.163 m^2	15.424 m^2	24.659 m^2	12.000 m^2
Superficie construida	46.297 m^2	34.112 m^2	24.507 m^2	12.968 m^2	33.421 m^2	9.165 m^2
Habitaciones	593	329	343	169	354	142
Plazas (camas)	1.286	658	718	507	1.170	388
Superficie jardines	35.000 m^2	8.000 m^2	5.000 m^2	3.000 m^2	2.500 m^2	
N.º Edificios	18	2	2	3	3	3
N.º Plantas	6	4	5	3	4	2
Tipo suministro agua consumo humano	Desaladora propia	Desaladora propia	Desaladora propia	Pública	Pública	Pública
Tipo suministro Riego	Depurada	Desaladora propia	Desaladora propia	Pública	Pública	

Tabla 3.1*. Principales datos de los hoteles de investigación.*

De estos establecimientos se han recopilado todos los datos utilizados en la investigación, los cuales se han revisan con los responsables técnicos de cada establecimiento, filtrando los datos

erróneos, debido principalmente a fallos en la recogida de los mismos o a otro tipo de eventos casuales ajenos a la operativa habitual (fugas de agua, reformas instalaciones, roturas, etc.). Los datos obtenidos corresponden a los años entre el 2007 al 2017, con un mínimo de 3 años de datos por hotel.

Para la realización de los cálculos de emisiones de CO_2, consumos de energía y agua, los datos filtrados y revisados, se convirtieron a una misma unidad de medida para posibilitar la comparación entre ellos: el agua en metros cúbicos (m^3) y la energía a kWh, transformando los valores de los diferentes combustibles primarios de acuerdo a los factores de conversión de energía de cada uno de ellos, para posteriormente poder realizar los cálculos de correlación para obtener las funciones características de consumos y emisiones de los establecimientos.

Para poder realizar los cálculos de emisiones y consumos de las desadoras, se obtuvieron los datos de 5 desaladoras propias de los hoteles y de 3 grandes desaladoras para suministro centralizado, todas ellas situadas en las islas de Fuerteventura (FU) y Lanzarote (LZ), como se observa en la ***Tabla 3.2*** que se muestran los principales datos de estas. Todas las plantas desaladoras son de osmosis inversa y con aporte de agua bruta procedente de agua de mar mediante sondeo de captación o toma directa en pozos abiertos al mar. Para los cálculos se han tomado los últimos datos actualizados de los años 2015 y 2016, según cada planta desaladora.

DATOS	PRO	GTA*	COR	HPE	HT	HRP	HTI	MSL*
Isla	FU	FU	FU	FU	FU	LZ	LZ	LZ
Localidad	Puerto del Rosario	Tuineje	Oliva	Pájara	Pájara	Playa Blanca	Playa Blanca	Tías
N.º de bastidores	4	2	2	1	1	1	1	1
Producción Max m^3/día	23.700	4.000	4.000	288	288	528	264	432
Producción promedio m^3/día	21.299	2.695	3.205	215	228	486	220	233
Coeficiente generación kWh/m^3	3,83	6,21	3,07	4,34	4,80	3,40	3,80	5,10

* GTA y MSL sin recuperación de energía

Tabla 3.2*. Datos característicos de las desaladoras de estudio.*

También se han realizado los cálculos de los gastos de agua en piscinas con los datos de los consumos de 42 piscinas de 14 establecimientos turísticos, proporcionados por la dirección de los mismos. Los periodos de las muestras están entre un mínimo de 6 meses y un máximo de 10 años, entre los años 2007 al 2016. Los datos de consumo obtenidos fueron los de renovación de agua mensual, filtrando los valores erróneos y obteniendo los datos de consumo de agua diaria por piscina. La ***Tabla 3.3*** se muestra el resumen las características de las piscinas.

HOTEL	Nombre	Volumen	Superficie	Tipo	Instalación
ECA	Grande	706 m^3	589 m^2	No climatizada	Exterior
ECA	Clima	459 m^3	356 m^2	No climatizada	Exterior
ECE	Infantil	20 m^3	30 m^2	No climatizada	Exterior
EPG	Infantil	12 m^3	20 m^2	No climatizada	Exterior
ESA	Grande	841 m^3	599 m^2	No climatizada	Exterior
ESA	Clima	298 m^3	331 m^2	Climatizada	Exterior
ESH	Grande	756 m^3	619 m^2	No climatizada	Exterior
ESH	Clima Int	135 m^3	125 m^2	Climatizada	Interior
ESJ	Infantil 1	8 m^3	10 m^2	No climatizada	Exterior
ESJ	Infantil 3	8 m^3	10 m^2	No climatizada	Exterior
ESJ	Grande 2	185 m^3	162 m^2	No climatizada	Exterior
ESJ	Grande 1	300 m^3	195 m^2	No climatizada	Exterior
EVE	Grande	90 m^3	77 m^2	No climatizada	Exterior
HC	Infantil	14 m^3	30 m^2	No climatizada	Exterior
HC	Grande	970 m^3	613 m^2	No climatizada	Exterior
HC	Clima	220 m^3	157 m^2	Climatizada	Exterior
HC	Clima Int	120 m^3	100 m^2	Climatizada	Interior
HOS	Grande 1	350 m^3	250 m^2	No climatizada	Exterior
HOS	Clima	215 m^3	171 m^2	Climatizada	Exterior
HPE	Infantil	30 m^3	50 m^2	No climatizada	Exterior
HPE	Grande	735 m^3	525 m^2	No climatizada	Exterior
HPE	Clima Int	130 m^3	86 m^2	Climatizada	Interior
HRP	Calimera	179 m^3	440 m^2	No climatizada	Exterior
HRP	Cascada	262 m^3	215 m^2	No climatizada	Exterior
HRP	Cocoloco	622 m^3	429 m^2	No climatizada	Exterior
HTI	Redonda	385 m^3	590 m^2	No climatizada	Exterior
HTI	Grande	450 m^3	450 m^2	No climatizada	Exterior
ORM	Infantil 3	16 m^3	8 m^2	No climatizada	Exterior
ORM	Infantil 4	16 m^3	8 m^2	No climatizada	Exterior
ORM	Infantil 5	16 m^3	8 m^2	No climatizada	Exterior
ORM	Infantil 7	16 m^3	8 m^2	No climatizada	Exterior
ORM	Infantil 9	16 m^3	8 m^2	No climatizada	Exterior
ORM	Infantil 1	77 m^3	280 m^2	No climatizada	Exterior
ORM	Tobogán	115 m^3	105 m^2	No climatizada	Exterior
ORM	Oasis3	187 m^3	262 m^2	No climatizada	Exterior
ORM	Oasis4	187 m^3	262 m^2	No climatizada	Exterior
ORM	Oasis 7	187 m^3	262 m^2	No climatizada	Exterior
ORM	Oasis 9	187 m^3	262 m^2	No climatizada	Exterior
ORM	Olas	668 m^3	540 m^2	No climatizada	Exterior
ORM	Clima Recep	320 m^3	330 m^2	Climatizada	Exterior
PPC	Infantil	32 m^3	80 m^2	No climatizada	Exterior
PPC	Clima	185 m^3	137 m^2	Climatizada	Exterior

***Tabla 3.3**. Resumen de las característicos de las piscinas de estudio.*

En España, las piscinas públicas y privadas de comunidades de vecinos han de estar autorizadas y registradas en el sistema nacional de control sanitario de piscinas (SILOÉ) *[SILOÉ]*, que es el sistema de información sanitario que recoge todos los datos de las piscinas y de su calidad

del agua. Para el desarrollo de esta investigación, se han obtenido los datos de todas las piscinas registradas de la comunidad autónoma de Canarias, con un total de 3.565 piscinas, de las cuales, solo se han tenido en cuenta las piscinas con volumen superior a 5 m^3, considerando que las inferiores a este volumen tienen un consumo despreciable sobre el total para los fines de esta investigación. El total de piscinas mayores de 5 m^3 son 3.317, las cuales tiene un volumen de agua almacenada de 894.384 m^3. Dentro de esta cantidad de piscinas, estudiamos el conjunto de las piscinas de los establecimientos turísticos representan el 57% del total, con 1.890 piscinas, y el 54,1% del volumen de agua almacenada, con un total de 484.290 m^3. En la siguiente ***Tabla 3.4***, aparecen la distribución de piscinas por tipos, climatizadas, frías, cubiertas y externas. La ***Tabla 3.5*** muestra la distribución de las piscinas por islas del archipiélago.

TIPO DE PISCINAS Volumen > 5m^3			Piscinas totales	Piscinas Turísticas	% Piscinas turísticas sobre total
Externas	**No climatizadas**	**N.º Piscinas**	2.089	1.039	49,7%
		Volumen	529.671 m^3	267.281 m^3	50,5%
	Climatizadas	**N.º Piscinas**	1.073	812	75,7%
		Volumen	318.790 m^3	212.889 m^3	66,8%
Cubiertas	**No climatizadas**	**N.º Piscinas**	8		0,0%
		Volumen	831 m^3		0,0%
	Climatizadas	**N.º Piscinas**	147	39	26,5%
		Volumen	45.093 m^3	4.120 m^3	9,1%
Total piscinas		**N.º Piscinas**	**3.317**	**1.890**	**57,0%**
		Volumen	**894.384 m^3**	**484.290 m^3**	**54,1%**

Tabla 3.4. *Distribución de piscinas en Canarias por tipos.*

ISLA	N.º Piscinas	Volumen piscinas m^3	% Piscinas isla sobre total	% Volumen isla sobre total
Gran Canaria	662	139.395 m^3	35,0%	28,8%
Fuerteventura	312	94.756 m^3	16,5%	19,6%
Lanzarote	314	84.230 m^3	16,6%	17,4%
Tenerife	519	143.888 m^3	27,5%	29,7%
La Palma	49	16.390 m^3	2,6%	3,4%
La Gomera	29	5.092 m^3	1,5%	1,1%
El Hierro	5	538 m^3	0,3%	0,1%

Tabla 3.5. *Distribución de piscinas en Canarias por islas.*

Teniendo en cuenta la falta de sistemas basados en EERR en los hoteles de estudio, y para poder realizar estimaciones reales para implantar sistemas de generación fotovoltaica en los mismos, utilizando estas instalaciones como un posible método de reducción de emisiones y como

medida de reducción de la dependencia externa de energía de los establecimientos, se investigan la posibilidad de utilización de modelos matemáticos no lineales, como el modelo Box-Jenkins [*Box y Jenkins, 1973]* y la transformada de Fourier *[Fourier, 1822] , [Condon, 1937]* que es el procedimiento para analizar funciones periódicas a través de la descomposición de las mismas en una suma infinita de funciones sinusoidales. Con este estudio proporcionamos los pronósticos de la irradiación en una zona geográfica donde no existan datos fiables de irradiación, pero se puedan obtener los datos de generación de plantas solares fotovoltaicas instaladas y en funcionamiento. Para poder realizar las estimaciones basadas en esas medidas de generación real, se cuenta con los datos de generación eléctrica de 11 plantas generadoras solares fotovoltaicas, con valores de las series de producción desde 2010 al 2014 y con datos de muestreo de entre 3 y 5 años. Se comprueban en tres estaciones los valores reales y pronosticados por los métodos no lineales comentados. Con los datos del resto de instalaciones se hace una comparación de la energía generada respecto de la calculada con los datos de irradiación obtenidos de las principales bases de datos actuales *[PVGIS], [ADRASE-Ciemat], [NASA-SSE], [AEMET], [Soda-pro], [ITC-Canarias], [IDEA, 2009], [UNE, 2009]* cuyos resultados se muestran en el Anexo 2 y 3. La ***Tabla 3.6*** muestra las características de las estaciones generadoras fotovoltaicas estudiadas de la isla de Fuerteventura.

Instalación	Marca	Modelo placas solar	Wp placa	N.º Placas	Potencia pico W	Ángulo inclinación
FEM	SolarWorld	SW220	220 W	400	88.000 W	10º
INP	SolarWorld	SW230	230 W	1.920	441.600 W	10º
HIE	SolarWorld	SW230	230 W	2.400	552.000 W	10º
INS1	Schott	ASE165T- 170	170 W	592	100.640 W	10º
INS2	Sky Global	SCM 72-180	180 W	576	103.680 W	10º
INS3	Photowatt	PW1650-175 PW1650-170	175 W 170 W	495 175	116.375 W	10º
INS4	Photowatt	PW1650-175 PW1650-170	175 W 170 W	495 175	116.375 W	10º
INS5	Photowatt	PW2050-200	200 W	518	103.600 W	10º
INS6	SolarWorld	SW240-245	245 W	448	109.760 W	10º
CAR	Photowatt	PW2050-210	210 W	512	107.520 W	10º
OCA	Photowatt	PW2050-205	205 W	1.606	329.230 W	10º

Tabla 3.6*. Datos característicos de las estaciones generadoras fotovoltaicas.*

3.1.1. Organización y procedimiento de investigación

El proceso de investigación general seguido para la realización de este estudio ha sido:

1. Recopilación de datos de las diferentes instalaciones: hoteles, piscinas y estaciones generadoras fotovoltaicas.
2. Revisión, filtrado y comprobación de los datos de estudio. Con los datos obtenidos se realizan las conversiones a una misma unidad de medida: energía, agua o emisiones GEI.
3. Realizar los cálculos de correlación para los consumos totales de los hoteles para obtener la función característica de consumo de estos.
4. Calcular y comparar las emisiones de GEI de los hoteles debidas al consumo de energía y agua, teniendo en cuenta la diferencia entre los coeficientes de emisiones del archipiélago respecto de los de la Península.
5. Con los valores del consumo de agua de las piscinas, se calculan las necesidades de energía para suministrar toda el agua necesaria desde desaladoras para los establecimientos estudiados y para todas las piscinas turísticas. Calcular la función característica que describa las necesidades de renovación de agua de las piscinas, mediante correlación simple y múltiple.
6. Cálculo de las emisiones de GEI de las piscinas canarias, teniendo en cuenta las pérdidas y gastos de energía para la generación de toda el agua necesaria de forma industrial, suministradas mediante desaladora locales o centralizadas y compararlas con las correspondientes a igualdad de consumo en la península.
7. Comprobar la viabilidad de usar los valores de generación fotovoltaica para el cálculo de pronósticos de irradiación mediante métodos matemáticos no lineales, en zonas que no se tengan datos fiables de irradiación, pero se tengan datos de producción fotovoltaica.
8. Posibilidad de uso de sistemas basados en bombas de calor para la reducción de consumos energéticos.
8. Conclusiones de la investigación y necesidades futuras para la disminución de consumos de agua y energía en los establecimientos hoteleros.

Para realizar los cálculos de emisiones de la electricidad CO_2, se ha utilizado el coeficiente promedio ponderado anual de las emisiones del año 2016, siendo este año el escogido como base para el cálculo de los $kgCO_2/kWh$ de energía consumida *[REE,2017]*. La ***Figura 3.1*** muestra el flujo de la investigación general llevado a cabo en este estudio.

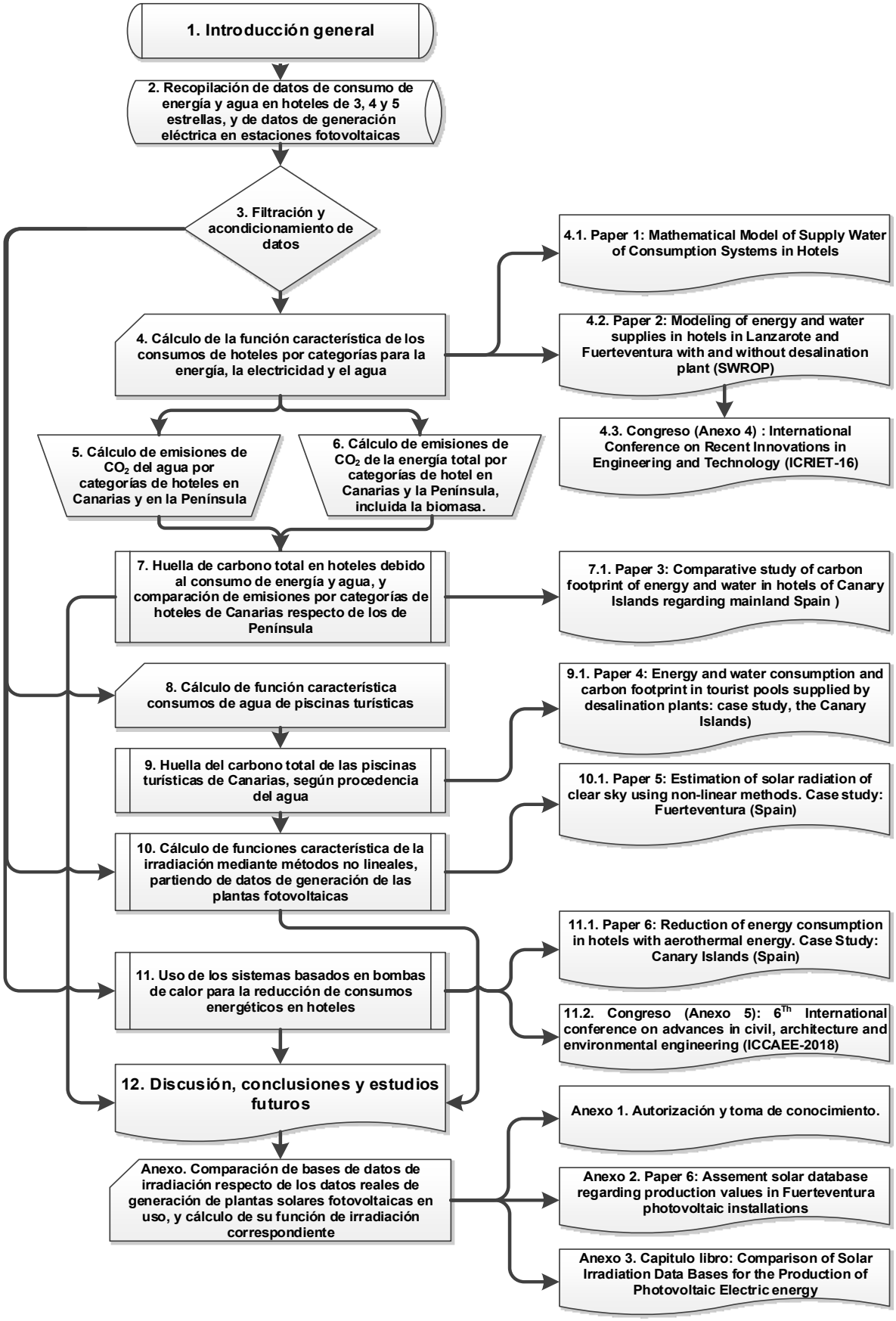


Figura 3.1. *Flujo de investigación.*

3.1.2. Descripción del flujo de investigación

Se realiza una descripción y explicación del flujo de investigación mostrado en la ***Figura 3.1***, el cual ha sido el hilo conductor de este trabajo de investigación.

1. **Introducción general.** Se realiza la presentación de los principales temas de la investigación, comenzando por el problema del efecto invernadero y la importancia del sector turístico en el mismo. Posteriormente se explica el turismo mundial y su evolución, centrándonos en la zona de estudio de las islas Canarias por su gran importancia y dependencia económica y laboral de este sector, describiendo los edificios turísticos de España y Canarias y su distribución por categorías. Se presenta la problemática de los principales suministros necesario para los hoteles que son la energía y el agua, debido a la dependencia energética exterior y a la necesidad de producción industrial de agua para el suministro a los establecimientos turísticos. Se finaliza exponiendo las preguntas planteadas en este trabajo de investigación.

2. **Recopilación de datos de consumo de energía y agua en hoteles de 3, 4 y 5 estrellas, y de datos de generación eléctrica en estaciones fotovoltaicas.** Se han tenido que recopilar todos los datos para esta investigación de los consumos de energía y agua de los hoteles de 3, 4 y 5 estrellas, los datos de generación de las estaciones fotovoltaicas y los datos de consumos de agua de las piscinas en establecimientos turísticos para el mantenimiento de las mismas. Siendo todos los datos pertenecientes a hoteles o sistemas generadores de la zona geográfica de investigación de las Islas canarias. Estos datos son suministrados por las direcciones y gestores de los diferentes establecimientos y plantas generadoras. La identificación de las instalaciones se ha codificado por protección de datos de hoteles y plantas generadoras.

3. **Filtración y acondicionamiento de datos**. Con los diferentes datos recopilados, se comprobó la coherencia de los mismos, para lo cual se verificó con los jefes de mantenimiento de las diferentes instalaciones los valores extraños o fuera de rango, los cuales eran debidos principalmente a errores en la toma de datos o fallos en las instalaciones que estaban fuera del rango normal de funcionamiento. Los datos una vez acondicionados, se convirtieron a una misma unidad de medida para posibilitar las comparaciones entre ellos, el agua en metros cúbicos (m^3) y la energía a kWh,

transformando los valores de los diferentes combustibles, de acuerdo con los factores de conversión de energía primaria de cada uno de ellos.

4. **Cálculo de la función característica de los consumos de hoteles por categorías para la energía, la electricidad y el agua**. El siguiente paso fue realizar la distribución agrupada por intervalos de los diferentes suministros, para conseguir los distintos puntos característicos de los consumos por ocupación y realizar los cálculos de correlación. Los valores se ordenaron por ocupación diaria de clientes y posteriormente por ocupación porcentual también de clientes, lo cual nos da una correlación más exacta que los sistemas clásicos de consumos mensuales o anuales, consiguiendo una distribución de valores más ajustada a sus cuantías reales. Para comprobar a qué tipo de correlación se asemejan más los modelos de consumos, se realizarán los cálculos de correlación para los modelos, lineal, exponencial, logarítmica, potencial y polinómico de segundo grado, para lo cual se estudió su coeficiente de determinación y se calculó su función de modelización característica. Se modelizan los consumos de energía, electricidad y agua.

   4.1. **Paper 1: "Mathematical Model of Supply Water of Consumption Systems in Hotels".** Inicialmente se realiza el modelo de cálculo para los consumos de agua de hoteles de categoría superior, de 4 y 5 estrellas. Mediante el sistema de análisis calculado y demostrado, se podrán realizar modelizaciones de consumos de agua mediante la simulación de valores de ocupación. Se comparan con los diferentes tipos de regresión para comprobar el modelo que se ajusta más y generar el algoritmo de cálculo de dichos consumos. Se demostró la validez de los modelos de regresión potencial y polinómica. El artículo concluye con las funciones para el cálculo de consumos de agua por cliente y día, y de riego porcentual según la temperatura ambiente de la zona geográfica estudiada.

   4.2. **Paper 2: "Modeling of energy and water supplies in hotels in Lanzarote and Fuerteventura with and without desalination plant (SWROP)".** Para confirmar el modelo anteriormente desarrollado, se realiza un estudio de todos los suministros de un grupo de hoteles de 4 estrellas: energía total, electricidad y agua. Se realiza el procedimiento de modelización de los consumos mediante regresiones, comprobando que también en este caso, los modelos potencial y polinómico son los que obtienen unos indicadores de correlación más ajustados para todos los hoteles. Se demuestra nuevamente como los modelos de correlación son los indicados para

los pronósticos de suministros en hoteles o grupos de hoteles con características similares. Se finaliza mostrando los algoritmos de cálculo para todos los consumos energéticos, de electricidad y de agua según la ocupación de los establecimientos.

4.3. Congreso (Anexo 4): "International Conference on Recent Innovations in Engineering and Technology (ICRIET-16)". Celebrado el 5 y 6 de noviembre de 2016 en Gandhi Institute of Engineering & Technology, (G.I.E.T), Gunupur, 765022, Rayagada, Odisha. India. Donde se presentó el artículo anteriormente comentado: Modeling of energy and water supplies in hotels in Lanzarote and Fuerteventura with and without desalination plant (SWROP), publicando el artículo en el libro del congreso, Track IV, chapter 19.

5. **Cálculo de emisiones de CO_2 del agua por categorías de hoteles en Canarias y en la Península**. Teniendo en cuenta los consumos de agua de los hoteles de estudio, se calculó la huella del carbono para la generación del agua mediante desaladoras. Comparando las emisiones producidas en Canarias respecto de la Península a igualdad de consumos, según los diferentes coeficientes de emisiones para la producción de agua.

6. **Cálculo de emisiones de CO_2 de la energía total, por categorías de hotel en Canarias y la Península, incluida la biomasa.** Se calcula la huella del carbono de alcance 1 y 2, más la biomasa, de los hoteles según su ocupación. Comparando los datos de emisiones de los suministros energéticos de Canarias respecto de los de península a igualdad de consumos, teniendo en cuenta los diferentes coeficientes de emisiones de la electricidad.

7. **Huella de carbono total en hoteles debido al consumo de energía y agua, y comparación de emisiones por categorías de hoteles de Canaria respecto de los de Península.** Se realiza la comparación de la huella del carbono total de energía y agua obtenida anteriormente y se comparan los hoteles de Canarias respecto de los de Península a igualdad de consumos. Con los resultados obtenidos, se obtiene las funciones características de emisiones por categoría y suministro.

   7.1. Paper 3: "Comparative study of carbon footprint of energy and water in hotels of Canary Islands regarding mainland (Spain)". En este artículo se realiza una estimación de las emisiones por categorías de hoteles, se tomó una muestra de 12 hoteles de 5, 4 y 3 estrellas de las islas Canarias situados en las islas orientales más áridas del archipiélago, que corresponde a Fuerteventura y Lanzarote sobre un total

de 122 hoteles existentes, donde el agua para el consumo proviene de plantas de desalación de agua de mar mediante ósmosis inversa. Teniendo en cuenta los consumos energéticos y de agua de los hoteles de estudio, se calculó su huella del carbono de alcance 1 y 2 más la biomasa, generando la energía unas emisiones promedio 13,1 kg CO_2/cliente_noche, y del agua un promedio entre 1,14 kg CO_2/cliente_noche a 2,18 kg CO_2/cliente_noche según tipo de distribución y modelo de desaladora. Estos datos se compararon con hoteles de las mismas características en España peninsular, comprobando que las emisiones insulares son un 150% superior a las peninsulares, así como que las emisiones de la electricidad son un 192% superior en las islas que en la península.

8. **Cálculo de función característica consumos de agua de piscinas turísticas.** Las piscinas de establecimientos turísticos representan el 57% de las piscinas dadas de alta en el SILOÉ de la comunidad autónoma de Canarias, por lo cual, tiene una gran importancia el conocimiento de los gastos de agua que se producen en el mantenimiento y uso de las mismas. Un dato importante ha tener en cuenta es el origen del agua de estas piscinas, que en este estudio se considera como agua de distribución de consumo humano procedente de desaladoras. Con los resultados obtenidos, se ha demostrado la dependencia de consumo total de agua respecto del volumen de las piscinas, siendo éste el principal factor a tener en cuenta para los cálculos de necesidades hídricas en las piscinas turísticas.

9. **Huella del carbono total de las piscinas turísticas de Canarias, según procedencia del agua**. Mediante los cálculos de necesidades hídricas para el mantenimiento de las piscinas calculado anteriormente y con el algoritmo de pronóstico generado, se realiza el cálculo de las emisiones de CO_2 debidas a la producción industrial de agua mediante desaladoras. Se presentan dos alternativas de suministro de agua: primero mediante desaladoras locales en la zona de consumos, en el propio hotel o urbanización, y segundo mediante desaladoras centralizadas que realizan el suministro por la red de abastecimiento actual de las islas, para lo cual se tienen en cuenta las diferentes pérdidas en las redes de los principales suministradores de las diferentes islas del archipiélago, según los datos de los planes hidrológicos actualizados de cada isla.

   9.1. Paper 4: "Energy and water consumption and carbon footprint in tourist pools supplied by desalination plants: case study, the Canary Islands)". En este

artículo se analizan los consumos de agua producidos por las piscinas turísticas y como afectan a las necesidades de agua de los destinos. También se obtiene la huella del carbono producida para la generación de agua necesaria para cubrir las necesidades hídricas de las piscinas mediante desalación. Con los datos de consumos de agua de 42 piscinas turísticas de 14 complejos hoteleros, se estudian las necesidades diarias de agua mediante métodos de regresión, obteniendo la función característica que define el consumo de agua de las piscinas. Con el algoritmo obtenido y los datos oficiales de todas las piscinas turísticas de Canarias, se obtienen las necesidades de agua, energía y huella del carbono para el conjunto de estas instalaciones. Se comparan los dos posibles modelos de suministro local o centralizado, demostrando que el consumo centralizado genera un 28% más de emisiones que los sistemas de generación locales, debido a las grandes pérdidas de las principales redes de suministro de las islas.

10. **Cálculo de funciones característica de la irradiación mediante métodos no lineales, partiendo de datos de generación de las plantas fotovoltaicas**. Como medida alternativa de energía basada en EERR, se ha considerado la energía solar fotovoltaica, para lo cual es imprescindible tener el valor de la irradiación local de la zona a instalar para poder realizar pronósticos de generación realistas. Para el cálculo de irradiación se pueden comparar las principales bases de datos actuales (se realiza como Anexo) o mediante la comparación con datos de instalaciones generadoras fotovoltaicas en uso. Este último método, se ha desarrollado para varias estaciones generadoras de la isla de Fuerteventura, comparando los datos de irradiación obtenidos respecto de los calculados mediante métodos matemáticos no lineales. Se observa la posibilidad de utilizar estos métodos de cálculo como alternativa para la realización de pronósticos de generación en zonas geográficas sin valores de irradiación fiables, pero con estaciones de generación fotovoltaica en uso.

    10.1. **Paper 5: “Estimation of solar radiation of clear sky using non-linear methods. Case study: Fuerteventura (Spain)”.** En este artículo analizamos un método de cálculo de la irradiación incidente, basado en la estimación de la misma mediante la trasformación de los datos de producción de energía eléctrica generada, de instalaciones solares fotovoltaicas conocidas. Con los datos de varios años de tres instalaciones con características principales semejantes: ángulo de inclinación de

paneles, modelo de paneles solares, y misma zona geográfica; se realizan los cálculos mensuales de irradiación basados en la producción total de cada mes y con los datos obtenidos, se realiza un estudio matemático de los mismos, utilizando el modelo ARIMA y también realizando el estudio sobre el modelo de descomposición en series de Fourier. Se verifica la validez del método mostrado, para ambos modelos matemáticos, para la predicción de irradiación basada en la producción de instalaciones en uso.

11. **Uso de los sistemas basados en bombas de calor para la reducción de consumos energéticos en hoteles** Se ha demostrado un método sencillo y económico para reducir los consumos energéticos de varios establecimientos hoteleros mediante la puesta en marcha de un sistema sistemas basados en autómatas de control y bombas de calor de alta temperatura para el calentamiento del agua de ACS, y como la amortización de los equipos es tan rápida que produce durante la duración media de los equipos un ahorro cercano a diez veces a la inversión inicial realizado. Estos sistemas son aplicables a la mayor parte de instalaciones actuales debido a su facilidad de uso, instalación simple y bajo mantenimiento.

    11.1. **Paper 6 (Pendiente publicar): "Reduction of energy consumption in hotels with aerothermal energy. Case Study: Canary Islands (Spain)".** En este artículo se presenta un modelo de gestión y control de eficiencia energética en hoteles adaptado a los patrones de consumo que aseguran las exigencias de confort de los clientes e integrándose en el entorno de un complejo turístico inteligente. El análisis del sistema de ACS de dos hoteles de las islas Canarias con relación a su ocupación, arroja una solución basada en bombas de calor de alta temperatura con disipación por aerotermia y apoyadas por las calderas de GLP propano existentes. Obteniendo un resultado después de dos años y medio de registro de la actividad es un retorno de la inversión más rápido debido a la gestión energética optimizada del sistema, mediante el control de horarios de funcionamiento ajustados a las necesidades de los clientes y la tarificación horaria.

    11.2. **Congreso (Anexo 5 – Pendiente de publicar): "6Th International conference on advances in civil, architecture and environmental engineering (ICCAEE-2018)".** Congreso por celebrar el en Kuala Lumpur, Malasia el 19 y 20 de julio de

2018, en el cual se ha aprobado el artículo sobre la reducción de consumos energéticos en hoteles mediante bombas de calor basadas en aerotérmia.

12. **Discusión, estudios futuros y conclusiones finales.** Se ha demostrado: como es posible modelizar los consumos energéticos y de agua de un grupo homogéneo de establecimientos hoteleros, generando algoritmos válidos para su cálculo. Se ha demostrado las diferencias de consumos entre hoteles de diferentes categorías. Se ha comprobado la importancia de las emisiones de los hoteles, siendo su principal causante los altos coeficientes de emisión de la electricidad en Canarias. Se ha comprobado y analizado la importancia de los consumos de las piscinas en los hoteles, demostrando que la generación de agua de forma local en la zona de suministro es un 28% más eficiente que los sistemas centralizados con distribución por las redes de suministro actuales. Finalmente, se demuestra la posibilidad de utilización de un método de cálculo basada en los datos de generación de sistemas fotovoltaicos en uso y su posterior tratamiento mediante métodos matemáticos no lineales, para obtener pronósticos de irradiación y de generación fotovoltaica. También se ha expuesto un sistema de reducción de consumos energéticos en el ACS mediante bombas de calor basadas en aerotérmia. En los anexos, también se comparan las principales bases de datos de irradiación verificando con cual se obtienen pronósticos más precisos respecto a los valores obtenidos de instalaciones solares fotovoltaicas en uso. Los trabajos de investigación futuros han de centrase en la modelización de consumos con múltiples factores, el efecto del cambio climático sobre las instalaciones hoteleras actuales y la compatibilidad de un turismo sostenible con la demanda de servicios de los clientes.

ANEXOS. Comparación de bases de datos de irradiación, respecto de los datos reales de generación de plantas solares fotovoltaicas en uso, y cálculo de su función de irradiación correspondiente. El conocimiento de la irradiación solar se hace imprescindible para poder calcular y pronosticar la generación eléctrica producida por placas solares fotovoltaicas. Los datos de irradiación se pueden obtener por varios métodos, siendo el más utilizado el de buscarlo en bases de datos (DB) de irradiación mundial de las diferentes zonas geográficas. Existen múltiples DB que se pueden utilizar para el cálculo de generación de energía solar fotovoltaica. Teniendo en cuenta la importancia de tener valores lo más ajustados a la realidad, se realiza un estudio de las diferentes DB de irradiación utilizadas para los cálculos de producción de energía solar

fotovoltaica, comparando los valores de 8 DB ampliamente reconocidas y utilizadas, PVGIS, Adrase-Ciemat, NASA, AEMET, Soda-pro, ITC, IDAE-Censolar, y UNE 94003, respecto de los valores de irradiación equivalentes calculados de 11 instalaciones generadoras en funcionamiento, conectadas a red con ángulo de inclinación de 10º, todas ellas ubicadas en la isla de Fuerteventura, en el archipiélago de las Canarias y con potencias máximas instaladas desde los 88 kW a 552 kW.

Los resultados obtenidos de este estudio se han publicado en una revista científica con revisión por pares y en un libro de divulgación científica como un capítulo independiente de cálculos de irradiación, los cuales son los siguientes:

- **Anexo 1.** Autorización y toma de conciencia de autores y coautores de los artículos de que dichos trabajos se van a utilizar como parte de este trabajo de investigación y confirma que ninguno de ellos se ha utilizado previamente como parte de alguna tesis doctoral.
- **Anexo 2.** Assement solar database regarding production values in Fuerteventura photovoltaic installations. Indian Journal of Science and Technology, Volume 10, Issue 13, April 2017, Pp:16. DOI: 10.17485/ijst/2017/v10i13/110724. Artículo publicado sobre el estudio comparativo de las DB de irradiación solar para los cálculos de generación solar fotovoltaica.
- **Anexo 3**. Capítulo de libro: Advanced Engineering Research and Applications. Volume -VII, Comparison of Solar Irradiation Data Bases for the Production of Photovoltaic Electric energy. Capítulo 30, Pag 494-529. ISBN: 978-93-87374-270. Capítulo del libro de divulgación científica, sobre el estudio comparativo de las 8 DB principales de irradiación solar para los cálculos de generación solar fotovoltaica.

4.

RESULTADOS INVESTIGACIÓN

4.1. LISTADO DE PUBLICACIONES Y CONGRESOS

En este estudio de investigación, se han generado las siguientes publicaciones científicas y se ha participado en el congreso que se indican a continuación.

Cp	Título	Journal	Publicado	DOI:	Cite Score	SJR	Q
1	Mathematical Model of Supply Water of Consumption Systems in Hotels	International Journal of Applied Engineering Research	Volume 11, Issue 23, (2016). Pp. 11350-11357		0,13	0,149	4
2	Modeling of energy and water supplies in hotels in Lanzarote and Fuerteventura with and without desalination plant (SWROP)	Indian Journal of Science and Technology	Volume 9, Issue 47, December 2016. Pp: 19	10.17485/ijst/2016/v9i47/101908	0,76	0,251	1
3	Comparative study of carbon footprint of energy and water in hotels of Canary Islands regarding mainland Spain	Environment, Development and Sustainability	Online, 8 de febrero 2018. Pp:19	10.1007/s10668-018-0102-6	1,26	0,392	2
4	Energy and water consumption and carbon footprint in tourist pools supplied by desalination plants: case study, the Canary Islands	IEEE Access	Volume 6, 2018. Pp: 11727-11737	10.1109/ACCESS.2018.2808923	4,49	0,548	1
5	Estimation of Solar Radiation of Clear Sky using Non- Linear Methods Case Study: Fuerteventura (Spain)	International Journal of Applied Engineering Research	Volume 12, Issue 24, 2017. Pp: 15438-15446		0,13	0,199	4
6	Reduction of energy consumption in hotels with aerothermal energy. Case Study: Canary Islands (Spain)	International Journal of Engineering and Technology (UAE)	Volume 7, Issue 3.32, 2018. Pp. 127-131	10.14419/ijet.v7i3.32.18412	0,08	0,102	4

Tabla 4.1. *Listado de artículos publicados indexados*

Cp	Título	Journal	Publicado	DOI:
1	Assement solar database regarding production values in Fuerteventura photovoltaic installations	Indian Journal of Science and Technology	Volume 10, Issue 13, April 2017. Pp:16	10.17485/ijst/2017/v10i13/110724

Tabla 4.2. *Listado de artículos publicados no indexados (Anexo 2)*

Nº	Título libro	Editorial / Editor	Titulo capítulo	Capitulo / páginas	ISBN
1	Advanced Engineering Research and Applications. Volume - VII	Research India Publications. Hongseok Choi	Comparison of Solar Irradiation Data Bases for the Production of Photovoltaic Electric energy	Capítulo 30 Pag 494-529	978-93-87374-27-0

Tabla 4.3. *Listado de capítulos de libros publicados (Anexo 3)*

Nº	Congreso	Titulo artículo	Fecha / Lugar	ISBN / Capitulo
1	International Conference on Recent Innovations in Engineering and Technology (ICRIET-16)	Modeling of energy and water supplies in hotels in Lanzarote and Fuerteventura with and without desalination plant (SWROP)	5 y 6 de noviembre de 2016. Gandhi Institute of Engineering & Technology, (G.I.E.T), Gunupur, 765022, Rayagada, Odisha. India	97-9386163-56-1 Track IV, chapter 19
2	6Th International conference on advances in civil, architecture and environmental engineering (ICCAEE-2018)	Reduction Of Energy Consumption In Hotels With Aerothermal Energy. Case Study: Canary Islands (Spain)	ICONTES - 2018 19 y 20 de julio de 2018. Kuala Lumpur, Malaysia.	http://procedia.org/cpi/ICONTES-6-2111397

Tabla 4.4. *Listado de congresos publicados (Anexo 4)*

4.2. Artículo 1. Mathematical Model of Supply Water of Consumption Systems in Hotels

4.2.1. Resumen

En este artículo se realiza un estudia sobre los modelos de los consumos de agua en hoteles de categorías de 4 y 5 estrellas, de las Islas Canarias, analizando los consumos del riego y el consumo general de los establecimientos, con la finalidad de obtener y definir un patrón de consumo de agua de los establecimientos dependiendo de la ocupación media, y también modelizar el consumo del riego dependiendo de la temperatura media exterior. Se comparan los diferentes modelos y funciones de regresión de regresión para comprobar el modelo que más se ajusta a los consumos reales de los establecimientos de estudio y generar el algoritmo de cálculo que definan dichos consumos. Se demuestra la validez de los modelos de regresión potencial y polinómica para el cálculo de valores de consumos de agua, con validez para los establecimientos hoteleros estudiados con ocupaciones medias de clientes entre el 40% y 120%, que suelen ser las ocupaciones medias de los hoteles canarios durante los diferentes meses del año. También se demuestra que el modelo de regresión lineal es el más indicado para la modelización de los consumos de riego respecto de la temperatura media diaria de la zona geográfica donde se sitúan los establecimientos hoteleros de estudio.

Mediante el sistema de análisis calculado y demostrado, se podrán realizar modelizaciones de consumos de agua en hoteles o grupos de hoteles con características similares mediante la simulación de valores de ocupación y realizar las comprobaciones de reducción de consumos mediante dichas simulaciones, respecto de la ocupación prevista. El artículo concluye con las funciones para el cálculo de consumos de agua por cliente y día, y de riego según la temperatura, para hoteles con características similares a los del estudio.

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Mathematical Model of Supply Water of Consumption Systems in Hotels

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Abstract
In this article, a comparative study of water consumption in four and five - star hotels in the Canary Islands (Spain) is carried out in establishments located on the eastern islands of Fuerteventura and Lanzarote, both general consumption and irrigation, to define a consumption pattern of According to the average outdoor temperature of the different establishments. They are compared with the different types of regression to verify the model that fits the most and to generate the algorithm to calculate these consumptions. The validity of the potential and polynomial regression models for the calculation of validity values for most hotels will be demonstrated by the average client population between 40% and 120%, which is usually the average occupancy of the Canary Islands hotels during The different months of the year, and the linear model for the consumption of irrigation water in relation to the average temperature.
By means of the system of analysis calculated and demonstrated, it will be possible to carry out simulations for the consumptions of the hotels with the same characteristics and to make possible the reduction of consumption of water using the simulation of occupancy values to check the possible reductions of the same. The article concludes with the functions for the calculation of water consumption per customer and day, and percentage irrigation according to temperature, for hotels with characteristics similar to those of the study

Keywords: Canary hotels, modelling, water consumption, irrigation, sustainability.

INTRODUCTION

The archipelago of the Canary Islands, belonging to Spain and located in the Atlantic Ocean, North Africa, near the coast of southern Morocco and the Sahara, between the co-ordinates 27º37 'and 29º25' north latitude and 13º20 'and 18º10' west longitude and with a total surface area of 7447 km2, with an oceanic subtropical climate, it has stable temperatures all year long mitigated by the sea in winter And by the trade winds in summer. The islands of Fuerteventura and Lanzarote are the most oriental and with a typical dry climate. Currently, the tourism sector in Canaries represents 31% of the archipelago's GDP and generates 36% of employment in the islands [1], being the main driver of the economy and its labor mobility as demonstrated in the study of J.S. Leon Santana and Dirk Godenau (2015) [2] on the labor market in the Canary Islands. In this destination there are 626 hotels offering more than 244,000 hotel spaces [3]. Annually visit about 13,000,000 tourists and produce over 100,000,000 overnight stays in hotel establishments on the islands. The consumption of water in the tourist industry of the lodging sector, represent 11% of the consumptions [4] with respect to the total of the islands. Taking into account the importance of tourism in the Canary Islands, it is essential to search for models of sustainable and valid water consumption in order to maintain sustainable destination. Tourist associations along with several universities have conducted different studies on water consumption in hotels. The International Tourism Association (ITP), along with Cornell University, has published the results of Howard Chong's Cornell Hotel Sustainability Benchmarking (CHSB) and Eric E. Ricaurte [5] to provide hotels Consumption of water and worldwide. The Spanish Confederation of Hotels and Tourist Accommodation (CEHAT) and the Hotel Technological Institute (ITH) carried out an investigation of hotel consumption using the toolkit, which generated a comparative report with hotels of similar characteristics, comparing energy and water consumption in hotels Madrid [6] and the Canary Islands [7]. All these studies give typical values, but do not generate a reproducible model by means of the indicator of the occupation, that is primordial in the present tourist establishments.
Of the water consumption of the type hotels investigated. Also previously by Stefan Grossling [12] study on the consequences of tourism in the consumption of water with data for different countries and an approximate calculation worldwide being the average consumption of water very disparate, with Values between 100 and 2000 l/bed/night, which means that reliable water consumption averages cannot be generated per customer per day. On the island of Mallorca, a study was conducted on water consumption in hotel and residential populations by Angela Hof and Thomas Schmitt in 2011 [13], which concluded that consumption varies widely between 188-1181 l/bed/night and that The water in the pools represents 20 l/bed/night.
Regression models to obtain a hyperbolic model of the water consumption of the type hotels investigated. Also previously by Stefan Grossling [12] study on the consequences of tourism on the water consumption with data for different countries and an approximate global calculation being the Very different average water consumption, with values ranging from 100 to 2000 l/bed/night, which means that reliable water consumption averages cannot be generated per

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customer per day. On the island of Mallorca, a study was conducted on water consumption in hotel and residential populations by Angela Hof and Thomas Schmittb in 2011 [13], which concluded that consumption varies widely between 188-1181 l/bed/night and that The water in the pools represents 20 l/bed/night.

The main hotel chains also provide general information on the water consumption of their hotels, which may be useful for checking the average consumption of different establishments comparatively, but without establishing any consumption model or grouping similar hotels. Some examples of annual data published by the hotel chain NH, which gives the indicators per occupied room of 300 l/room/night [14], or the Riu hotel chain, with average consumption per guest of 371 l/bed/Night].

The research carried out focuses on hotel buildings in the Canary Islands and specifically in hotels of category 4 an 5 stars, both with desalination and without desalination for own water consumption, on the islands of Fuerteventura and Lanzarote. These two destinations have an average of 2.3 and 2 million tourists a year and 18.7 and 16.5 million stays respectively. The reason for the study to focus on 4 and 5-star hotels is that they represent near 60% of hotels in this islands and the 70% of stays [3], which will allow an approximation of the consumption of the most of the hotels on these Islands

EXPERIMENTAL

With the data obtained from the different hotels the filtration of the erroneous values is carried out and the main water consumptions of the establishments are differentiated, differentiating between the water of human consumption and the reused water that is used only for the irrigation. The case of saltwater swimming pools has not taken into account the expenses of the same. We will execute the calculation to make the histograms of the resulting data and generate the characteristic points grouped by frequency intervals using the Sturges formula [16] to calculate the optimal calculation intervals. We perform the distribution grouped by the calculated intervals and the arithmetic mean of the grouped data is realized to obtain the different characteristic points of the consumptions and to perform the correlation calculations. In order to verify which type of correlation the consumption models are most similar, the correlation calculations for the models, linear, exponential, logarithmic, polynomial of second degree and potential will be performed, checking their coefficient of determination and calculating its modeling function using the method of least squares [17]. With the generated functions, the calculation of its correlation between the values, which indicates the degree of dependence between the two variables, for which we will use the correlation coefficient of Karl Pearson [18]. Values closest to 1 imply a perfect positive linear relationship and -1 a perfect negative relation [19].

The correlation between the data is verified by the coefficient of determination R^2 that is interpreted as the proportion or percentage of variation of the dependent variable, which is explained by the variation in the independent variable, that is, the percentage of values that fit with the shape of the graph [20]. With the calculated functions the different graphs of the consumption of water of the hotels are generated and with the data of all of them we will calculate the characteristic function of the group of hotels. In order to group the data of hotels, taking into account that it has different capacities, the average daily percentage will be used to work with all establishments as if it were only use. For the calculation of the characteristic function of irrigation of hotels we will use the same methodology as if it were a single Hotel, taking into account the percentage consumption of hotels according to the outside temperature and the month of irrigation. In fig. 1 is shown schematically the workflow to be followed for the realization of the correlation calculations.

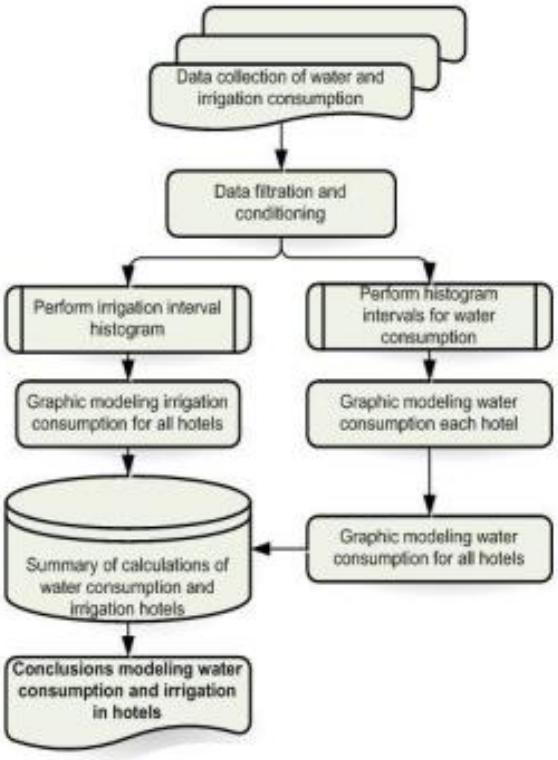


Figure 1: Diagram of the workflow for the research work.

For the realization of the study of consumption in hotels, several establishments characteristic of the Canary archipelago have been chosen, in the eastern islands of Fuerteventura and Lanzarote. In the search of hotels with homogeneous characteristics, facilities of seniority under 30 years, category 4 and 5 stars and all type of holiday with swimming pools have been chosen. The gardens of the hotels are irrigated with desalinated water or regenerated water. In modeling, calculations are made without regard to irrigation water when different methods are used in each hotel. The consumption data of the hotels have been obtained values between the years 2007 to 2015 according to the installation, with minimum values per hotel of 4 years and maximums of 6 years.

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Table 1. Details of facilities and characteristics of hotels studied. Source: Original.

DATES		EPG	ESH	HPE	HT	ESA	ECA	HRP	HTI	MSL
General	Location	FTV	FTV	FTV	FTV	FTV	FTV	LANZ	LANZ	LANZ
	Category	5	5	4	4	4	4	4	4	4
	Construction date	2.002	2.006	2.000	2.004	2.003	2.007	2.001	1.997	1.988
	Land area	13.179	41.806	30.000	34.879	27.163	34.670	94.970	38.622	26.163
	Constructed area	8.124	35.888	25.912	31.132	22.710	28.307	46.297	34.112	24.507
	Rooms	61	266	333	354	266	346	593	329	343
	Beds	122	532	678	710	532	692	1.286	658	718
	Garden area		15.000	8.000	11.000	6.000	14.000	35.000	8.000	5.000
	Water source	Public supply	Public supply	SWROP	SWROP	Public supply	Public supply	SWROP	SWROP	SWROP
	Irrigation source	Recycled	Recycled	SWROP	SWROP	Recycled	Recycled	Recycled	SWROP	SWROP
Pools	Nº Fresh water	2	2	2	1	2	1	5	8	1
	Area m2	220	740	572	240	702	589	1.091	1.160	1.084
	Volume m3	309	805	765	266	891	706	962	1.135	1.727
	Nº Climatized pool		2	1	4	1	2	3	2	2
	Area m2		585	86	277	331	439	1.583	85	120
	Volume m3		687	130	298	298	487	1.803	95	110
Years of date		2007-2012	2007-2012	2010-2015	2010-2015	2007-2011	2007-2011	2010-2015	2010-2015	2010-2014

Table 2. Main indicators of the hotels studied. Source: Original.

INDICATORS	EPG	ESH	HPE	HT	ESA	ECA	HRP	HTI	MSL	Average	Typical deviation
m2 Construction / rooms	133	135	78	88	85	82	78	104	71	**95**	24
m2 Gardens / rooms	0	56	24	31	23	40	59	24	15	**30**	19
% Garndens / Land area	0%	36%	27%	32%	22%	40%	37%	21%	19%	**26%**	12%
m2 Pools / rooms	3,6	5,0	2,0	1,5	3,9	3,0	4,5	3,8	3,5	**3,4**	1,1
m3 Pools / rooms	5,1	5,6	2,7	1,6	4,5	3,4	4,7	3,7	5,4	**4,1**	1,3

INDICATORS	*HPE*	*HT*	*ESA*	*ECA*	*HTI*	*MSL*	*Average*	*Typical deviation*
m^2 Gardens / rooms	24	31	23	40	24	15	**26**	9
% Garndens / land area	27%	32%	22%	40%	21%	19%	**27%**	8%
m^2 Pools / rooms	2,0	1,5	3,9	3,0	3,8	3,5	**2,9**	1,0
m^3 Pools / rooms	2,7	1,6	4,5	3,4	3,7	5,4	**3,5**	1,3

Data analysis:
Table 1 presents the general data of the establishments studied, with their main characteristics and facilities. Due to the protection of data of the hotels we refer to each hotel with a code that makes reference to the name. With the main data of the Hotels, the comparison of the same, to verify the average values of the facilities that appear in the table 2. In this comparison of the different facilities it is possible to verify the homogeneity of the establishments.

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Table 3. Total consumption, percentages and garden surface area for irrigation water. Source: Original.

TYPE		EPG	ESH	HPE	HT	ESA	ECA	HRP	HTI	MSL	TOTAL
Total all years	Total water + irrigation consumption	96.664	389.662	453.535	468.617	383.378	352.823	1.305.416	424.167	424.416	4.298.678
	Consumption irrigation	0	75.708	46.286	79.232	23.784	63.413	304.192	38.263	33.944	664.822
	% consumption irrigation	0,0%	19,4%	10,2%	16,9%	6,2%	18,0%	23,3%	9,0%	8,0%	**15,5%**
Total irrigation	m2 Garden		15.000	8.000	11.000	6.000	14.000	35.000	8.000	5.000	102.000
	Average daily consumption	0	41	21	36	13	43	139	17	19	329
	l/m2 Daily		2,73	2,63	3,27	2,17	3,07	3,97	2,13	3,80	**3,23**

Table 4. Average air temperature and percentage of monthly irrigation water consumption. Source: Original.

UNIT	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dic*	*Average*
T°	17,9	17,9	18,9	20,2	21,7	23,2	24,8	25,5	24,9	23,8	21,3	19,1	17,9
% irrigation	63%	66%	70%	81%	81%	92%	92%	100%	90%	77%	76%	69%	**79%**

Consumption water performance:

Water consumption is not taken into account in consumption calculations Irrigation water in hotels, in irrigation water can be of the types, in reused water that has specific regulations [21] for its application, the Which was studied AND compared with the other European countries by NV Parany chianakis, M. Salgot and AN Anelakis in 2015 [22], and water for human consumption [23], both of which are incompatible with each other.

In Table 3 shows the total water consumption costs, with an average expenditure of 15.5% of total water consumption. Taking into account the surface of the gardens, the irrigation consumption per m² of garden is calculated, with an average of 3.23 L/m² of garden. A simplified approximation of the irrigation consumption is made, taking only the temperature Of the air and no other factors as the type of crop, being the similar gardens, nor the rainfall of the islands, being the accumulated average annual, the smaller of all Canaries and Spain, of 100 l/m² year [24], which is why we will not consider this factor. With the average data of percentage of the Irrigation consumption with respect to the maximum value of the monthly values of the irrigation of the hotels shown in table 4, we will perform a linear regression to check its dependence with the temperature, proving that its coefficient of determination is Very high, so its dependence is very strong, as can be seen in fig. 2.

Table 5. Water consumption in recreational and climatized pools. Source: Original.

TYPE		EPG	ESH	HPE	HT	ESA	ECA	HRP	HTI	MSL	TOTAL
Total all years	Total water consumption	96.664	313.954	453.535	468.617	359.594	289.410	1.001.224	424.167	424.416	3.831.581
	Consumption water pools	6.305	94.944	53.929	26.342	45.829	55.111	215.529	40.976	102.444	641.409
	% consumption pool	6,5%	30,2%	11,9%	5,6%	12,7%	19,0%	21,5%	9,7%	24,1%	**16,7%**
Total pools	Volume water pool m3	309	1.492	895	564	1.189	1.193	2.765	1.214	1.837	11.458
	Average daily consumption	3,5	52	24,6	12	25,1	37,7	98,4	18,7	56,1	328,1
	% average daily consumption for m3 pool	1,13%	3,49%	2,75%	2,13%	2,11%	3,16%	3,56%	1,54%	3,05%	**2,86%**

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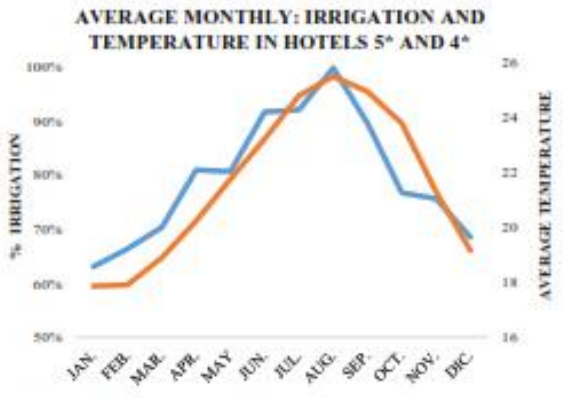


Figure 2. Average consumption of irrigation water and representation of the linear regression function.

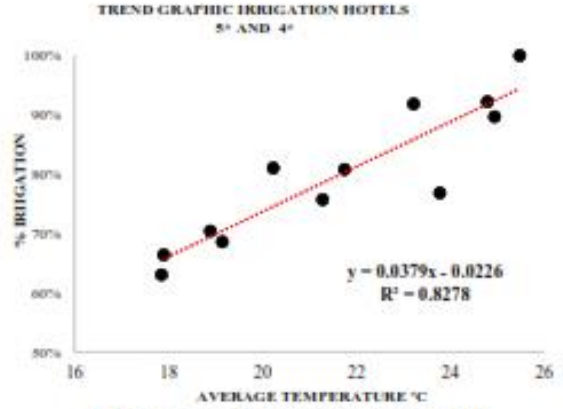


Figure 2.1. Trend graphic irrigations hotels.

The annual average daily consumption is 3.23 l/m² corresponding to 79% of the value of irrigation, corresponding to 100% a value of 4.09 l/m². With the function calculated by the linear regression, we generate the function of calculation of the monthly irrigation consumption in liters according to the garden surface.

$$W_{irr} = (4,09(0,0379t - 0,0226)A_g)d$$

Where "A_g" is the area of garden in m², "d" is the number of days of the month of calculation and "t" the average monthly temperature in °C in the area where the hotel is situated on the islands.

The consumption of water in swimming pools are another determinate factor in water costs. Table 5 shows the consumption data for hotel pools, together the cold and the heated pools. It is possible to verify the importance of these renovations that comes to be the 16.7% of the consumption of water of a hotel, without taking into account the consumption of renovations of whirlpools, which are affected by legionella regulation [25], that Marks the minimal water renewals of these types of vessels and has been studied for this type of thermal pools by Maciej Walczak, Aleksandra Burkowska-But, Maria Swiontek Brzezinska, and Arkadiusz Krawiec [26]. The consumption of renewal daily water for swimming pools, in a generic way, we will take a value of 2.86% per day of the total volume of the pool.

The approximations of the water consumption of swimming pools in m3 per month will be made, taking into account the volume of the pool by means of the following function:

$$Wp_m = (0,0286V_{Tp})d$$

Where "V_{TP}" is the total volume of cold water swimming pools, heated pools and Spas in m³, "d" is the number of days of the month of the calculation.

Water consumption in hotels without irrigation.

Having established the average consumption from swimming pools and irrigation, the correlation calculations of different levels of water consumption of hotels - recalling that the consumption of irrigation has not been taken into account, but the consumption of pools has -were performed. Table 6 summarizes the calculation values of the functions of the investigated regression models, where the different values of the coefficient of determination can be checked, with the potential and polynomial correlation which best fit the graph. The increased potential of consumption is due to the declining number of guests. Since the minimum consumption of some facilities is independent of the number of guests, we consider the minimum fixed consumption to be maintained.

Table 6. Summary of functions and coefficient of determination of the different types of correlation for water consumption. Source: Original.

CORRELATION TYPE	EPG	ESH	HPE	HT	ESA
Linear	y = -950,17x + 1256,9	y = -576,91x + 943,86	y = -171,1x + 470,95	y = -244,1x + 504,03	y = -201,5x + 599,88
Linear R²	0,7652	0,8558	0,9094	0,8604	0,7171
Exponential	y = 1680,5e$^{-1,318x}$	y = 1230,7e$^{-1,218x}$	y = 499,9e$^{-0,508x}$	y = 573,76e$^{-0,796x}$	y = 624,45e$^{-0,43x}$
Exponential R²	0,7474	0,8733	0,9192	0,8925	0,7402
Logarithmic	y = -615,8ln(x) + 363,99	y = -454,4ln(x) + 364,34	y = -131,9ln(x) + 302,03	y = -194,9ln(x) + 258,05	y = -163,1ln(x) + 396,32
Logarithmic R²	0,7837	0,8806	0,9130	0,8926	0,7642
Polynomial	**y = 1666,4x² - 3131,6x + 1948,3**	**y = 548,31x² - 1476,4x + 1287,5**	y = 93,841x² - 319,54x + 527,36	y = 237,12x² - 635,35x + 654,4	**y = 321,92x² - 732,68x + 804,02**
Polynomial R²	**0,7885**	**0,8886**	0,9145	0,8898	**0,7835**
Potential	y = 404,75x$^{-0,977}$	y = 363,21x$^{-0,948}$	**y = 302,79x$^{-0,598}$**	**y = 257,81x$^{-0,637}$**	y = 396,54x$^{-0,362}$
Potential R²	0,7542	0,8786	**0,9180**	**0,9029**	0,7798

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CORRELATION TYPE	ECA	HTI	MSL	HRP
Linear	y = -245,46x + 525,35	y = -106,49x + 406,26	y = -169,99x + 480,5	y = -432,33x + 829,03
Linear R^2	0,8461	0,6930	0,6717	0,8441
Exponential	$y = 609,6e^{-0,795x}$	$y = 414,26e^{-0,521x}$	$y = 504,84e^{-0,687x}$	$y = 1015,7e^{-0,902x}$
Exponential R^2	0,8376	0,6939	0,6835	0,8604
Logarithmic	y = -187,1ln(x) + 280,03	y = -80,18ln(x) + 301,04	y = -147,1ln(x) + 308,11	y = -356,8ln(x) + 393,69
Logarithmic R^2	0,7997	0,7421	0,7353	0,8405
Polynomial	**$y = -194,55x^2 + 75,543x + 401,98$**	**$y = 265,14x^2 - 507,82x + 549,91$**	**$y = 458,2x^2 - 957,27x + 801,1$**	$y = 154,62x^2 - 697,99x + 937,21$
Polynomial R^2	**0,8653**	**0,7955**	**0,8169**	0,8473
Potential	$y = 276,76x^{-0,199}$	$y = 301,69x^{-0,241}$	$y = 308,11x^{-0,42}$	**$y = 389,89x^{-0,788}$**
Potential R^2	0,7827	0,7410	0,7412	**0,8482**

Study mathematical model:

It is necessary to change the ratios of consumptions by customers to consumption by percentage of occupation of clients, having different maximum occupations in each hotel and in this way we can compare occupations of the same in equal conditions of occupancy percentage. With the amount of data of all the hotels it is verified that the occupancy intervals cover the values between 45% and 120%. With the calculations made, fig. 3 where the mean water consumption points are represented for the set of hotels, representing the plot of the trend line, according to the correlation function with the highest coefficient of determination R^2.

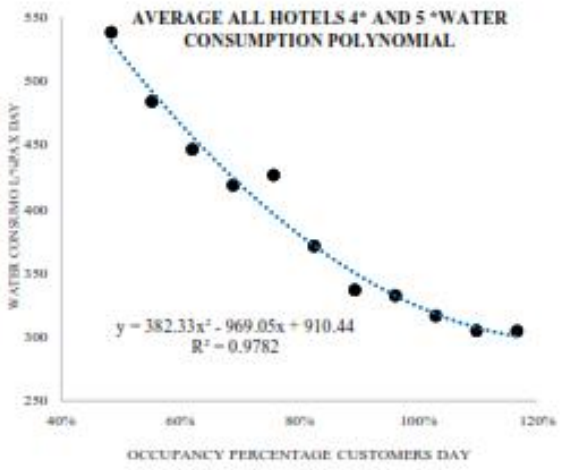


Figure 3. Characteristic function with the greatest correlation index for the consumption of water of all hotels.

Table 7 summarizes the calculations performed to obtain the functions for the water regression models.

Table 7. Summary of functions and coefficient of determination of the different types of correlation for consumption of water. Source: Original.

TYPE	*DATA FOR ALL HOTELS*
	WATER CUSTOMERS
Linear	y = -338,2x + 667,99
Linear R^2	0,9349
Exponential	$y = 774,55e^{-0,837x}$
Exponential R^2	0,9575
Logarithmic	y = -270,1ln(x) + 327,18
Logarithmic R^2	0,9698
Polynomial	**$y = 382,33x^2 - 969,05x + 910,44$**
Polynomial R^2	**0,9782**
Potential	**$y = 327,1x^{-0,678}$**
Potential R^2	**0,9749**

After verifying the strong correlation between the systems of potential and polynomial regression, the suitability of these functions can be confirmed, comparing the actual values of the averages for the hotels with values of the function generated by the regression models. All the regression models have been compared on the same graph, calculating the values of the functions from an occupancy rate of 1% to 140%, which is shown in Fig. 4. It can also be seen how the values of the regression functions have been paired for values of between 40% to 120% occupancy.

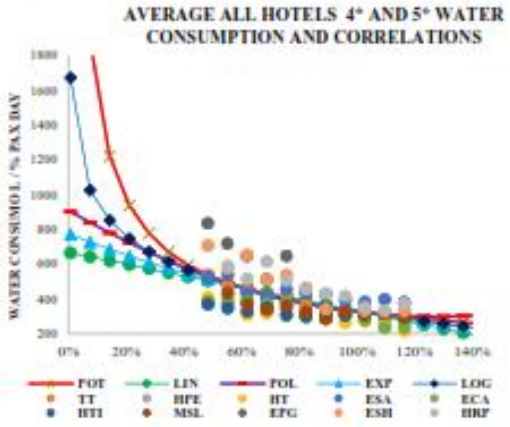


Figure 4. Representation of regression functions between 1 and 140% occupancy with respect to the midpoints of water consumption of the different hotels.

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RESULTS AND DISCUSSION

It was found that the values of the midpoints for the levels of consumption of the hotels approximately fit the values of the calculated functions. The next step was to check that the calculated mean values for all hotels fit with the generated function in order to demonstrate the validity of the models calculated for the average occupancy values, which range in a generic sense between 30% and 130%. In the following fig. 5, representation of the function of water.

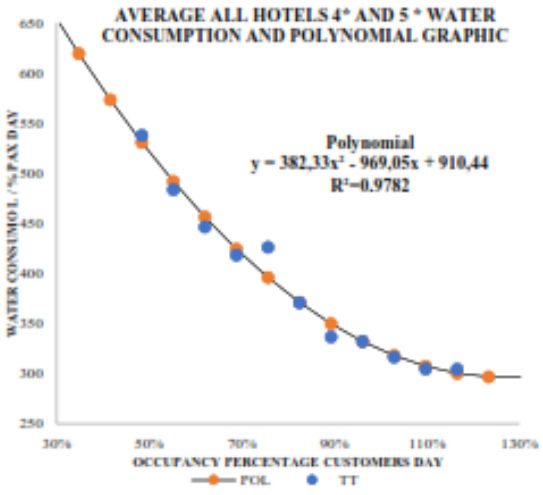


Figure 5. Representation of regression function between 30 and 130% occupancy with respect to the midpoints of the average consumption of water calculated for all hotels.

Reviewing the performance of the functions is found that the average data conform to the graphics generated, and can be used the functions potential and polynomial for the approach to water consumption values for four and five-star hotels with similar characteristics to the functions that we here studied. The approximate values monthly consumption, taking into account the daily average occupancy, air temperature for consumption of irrigation and specific consumption to produce desalinated water, are summarized in:

Irrigation consumption:

$$W_{irr} = (4,09(0,0379t - 0,0226)A_g)d$$

Total consumption without irrigation:

$$W_{TT} = (382,33x^2 - 969,05x + 910,44)d$$

Total consumption with irrigated

$$W_{TTirr} = \begin{pmatrix}(82,33x^2 - 969,05x + 910,44)\\ +(4,09(0,0379t - 0,0226)A_g)\end{pmatrix}$$

Where "x" is the percentage of average occupancy, "A_g" is the surface area of gardens, "d" is the number of days of calculation and "*t*" the average temperature in the area where the hotel is located on the islands.

CONCLUSIONS

Using the method described, a model of typical water consumption of a hotel of a certain segment, which may be reproduced for any other hotel in the sector and thus be able to check and compare the consumption thereof is obtained. With the application of statistical correlation functions are achieved and generate the optimum consumption patterns for a group of hotels, considering that the larger the number of data is increased the reliability of the generated models. The basic procedure followed and demonstrated, leaves the field open to research more complex and precise, applicable to any type of hotel supply field models.

With the different models studied correlation has been found that in most of the hotels studied the potential polynomial model or apply with very little difference between the rates of correlation. The calculated values from which we can consider similar approaches both models are between 40 and 120% of occupation of customers of the hotels, where to lower or higher occupations very large differences, which are no longer either equivalents. Has proven the importance of the average temperature for the consumption of irrigation, this being the main factor being the rainfall of the small islands, and taking into account the landscaped areas the use of recycled water for irrigation and decrease is necessary the dependence on water desalination plants on the islands also for irrigation.

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4.3. Artículo 2. Modeling of energy and water supplies in hotels in Lanzarote and Fuerteventura with and without desalination plant (SWROP)

4.3.1. Resumen

En este artículo se confirmar el modelo estudiado y desarrollado con anterioridad para los consumos de agua, para lo cual se prueba el modelo para todos los suministros de un grupo de hoteles con características similares y de categoría 4 estrellas. Los consumos estudiados han sido: energía total, electricidad y agua. Se realiza el procedimiento de modelización de los consumos para todos los suministros, mediante el cálculo de las funciones de regresión características respecto de la ocupación de clientes día, comprobando que también en este caso, los modelos potencial y polinómico son los que obtienen unos indicadores de correlación más ajustados para todos los hoteles, con validez para los establecimientos hoteleros con ocupaciones medias de clientes entre el 40% y 120. En el estudio realizado no se ha tenido en cuenta el consumo eléctrico producido por la generación industrial de agua mediante las plantas desaladoras de agua de mar de los establecimientos que contaban con estos equipos, para realizar un modelo de consumo energético y eléctrico que sea válido para todos los tipos de establecimientos, siendo el consumo producido por la desalación un extra adicional que solo lo tendrán los hoteles con desaladora propia y no todos.

Se demuestra nuevamente como los modelos basados en correlación son los indicados para los cálculos de suministros en hoteles o grupos de hoteles con características similares, para lo cual se obtienen algoritmos de cálculo para todos los consumos energéticos y de agua según la ocupación de los establecimientos. Se tiene en cuenta la variación de los establecimientos con desaladora propia con una función característica que describe sus consumos en este caso. Con las funciones obtenidas se pueden realizar simulaciones y pronósticos de consumos para hoteles con características similares a los estudiados que se encuentren en la misma zona geográfica.

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Modelling of Energy and Water Supplies in Hotels in Lanzarote and Fuerteventura with and Without Desalination Plant (SWROP)

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Abstract

Objectives: This article presents a comparative study of energy and water consumption in four-star hotels in the Canary Islands (Spain), specifically on the islands of Fuerteventura and Lanzarote, with and without desalination sea water reverse osmosis plants (SWROP), of order to define a pattern of consumption based on the average occupancy rates of different establishments. **Methods/Statistical Analysis:** The method used for regression calculations of the data obtained has been, initially the data collection and filtration, perform the mean arithmetic of the data according to the intervals calculated, perform calculations and generate the correlation graphs of the different models, change the occupancy rates to a percentage and use all the values for the total calculation as if it were a single hotel, calculate the final model of energy and water consumption for establishments, and create a valid algorithm using the calculated regression models. **Findings:** We demonstrate the validity of the potential and polynomial models of regression used to calculate the approximate values for consumption of water, electricity and energy, valid for most of the hotels with an average occupancy rate of between 40% and 120%, which are typically the average occupancy rates for hotels in the Canary Islands during various months of the year. Through a calculated and demonstrated system of analysis, approximate simulations of consumption can be performed for hotels with the same or similar characteristics and modelling of reduced energy consumption can be performed by simulating occupancy values to test the level of reduction. **Application/Improvements:** The article concludes with the functions for the approximate calculations of energy consumption, electricity and water per guest, per day for hotels with similar characteristics to those in the study.

Keywords: Energy, Efficiency, Hotels, Modelling, nZEB, SWROP, Water

1. Introduction

At a global level, two-thirds of emissions come from energy consumption, the tourism sector-being a major consumer of energy-contributing 5% due to the inefficiency of energy consumption that occurs in that sector. The tourist accommodation sector represents more than 20% of emissions from tourism and energy consumption from tourism overall[1] is equivalent to 1% of global emissions. For this reason, hotel buildings, which operate in geographical areas with a high concentration of tourism and intensive seasonal use, pose a major challenge to the sustainability of tourist destinations.

The European Union has set a goal of reducing energy consumption, as well as CO_2 emissions, by 20% by 2020 in comparison to 1990 levels, stipulating that 20% of total energy consumption must come from renewable sources and giving much importance has been placed on energy efficiency through the publication of several directives on it, as the directive directive 2010/31/EU [2] on energy efficiency in buildings, investigated their application in buildings in one study[3] and directive 2012/27/EU[4] on

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energy efficiency, which also highlights the importance of promoting energy efficiency in buildings, setting a time to achieve Zero Energy Buildings (ZEB) or near to Zero (nZEB), this being an obligation in new constructions for the year 2018 general government and by 2020 the other buildings, which has been studied their application in Lithuania[5].

The archipelago of the Canary Islands, belonging to Spain and located in the Atlantic Ocean near the coast of southern Morocco and the Sahara, north Africa, between coordinates 27°37' and 29°25' north latitude and 13°20' and 18°10' west longitude, with a total area of 7447 km^2 and an oceanic subtropical climate, has stable year-round temperatures mitigated by the sea in winter and in summer by trade winds. Currently the tourism sector in the Canary Islands represents 31% of the archipelago's GDP and generates 36% of employment on the islands[6], it being the main engine of the economy. It is the main engine of the economy and its labour mobility as demonstrated in the study of[7] on the labour market in the Canary Islands. At this location, there are 626 hotels that offer more than 244,000 hotel beds[8]. Annually, around 13,000,000 tourists visit and produce more than 100 million overnight stays in hotels on the islands. Energy consumption for hotels in the tourism sector accounts for 15% of total electricity consumption[9] and 11% of water consumption[10], with respect to the overall consumption of the islands. Taking into account the importance of tourism for the Canary Islands, the search for models of energy consumption and water sustainability is essential and valid for implementing energy efficiency strategies in hotels, which has become an essential aspect of European strategy for sustainable growth in 2020, and one of the most profitable ways to strengthen the security of energy supplies, as well as reduce emissions of greenhouse gases and other pollutants. It is very important to know the distribution of energy consumption in hotels so that it can be shown where improvements can and should be made in order to make reductions. Distribution varies according to geographical area and category of hotel, as can be seen by studies conducted in several countries, for example: in Britain, where the typical distribution is 47% on heating and 20% in Domestic Hot Water (DHW)[11]; in Greece, where the typical distribution is 35% on heating, 15% on refrigeration, and 22% on DHW[12]; hotels in the Balearic Islands is between 22 % for DHW , cooling 14% heating and 21%[13]; and the Canary Islands, where, due to its climatic characteristics, climatization is reserved mainly for air conditioning, with consumption at 31%,and, in second place, DHW at 22% [14]. Tourist associations, along with several universities, have conducted various studies on the consumption of hotels. The International Tourism Partnership (ITP), in conjunction with Cornell University, has published the results of the study "Cornell Hotel Sustainability Benchmarking" (CHSB)[15] to provide points of reference to hotels regarding energy and water consumption, and worldwide carbon footprint references for different types of establishments in various countries. The World Tourism Organization (UNWTO) has launched the project "Hotel Energy Solution", creating the E-Toolkit[16], a tool that allows small and medium-sized European companies in the hotel accommodation sector to make a comparative assessment of energy consumption, efficiency and carbon footprint, with similar companies on the continent. The Spanish Confederation of Hotels and Tourist Accommodation (CEHAT) and the Hotel Technological Institute (ITH) conducted an investigation of hotel consumption using the bench hotel mark tool, which generated a comparative report with hotels with similar characteristics, comparing energy and water consumption with hotels in Madrid[17] and the Canary Islands[18], but without creating a reproducible model for other hotels. All these studies give typical values, but have not generated reproducible models using occupancy as an indicator, which is paramount in actual tourist establishments.

Other research has been carried out by the scientific community, such as that performed in 2009[19] whereby a study of 29 energy intense hotels was conducted in Singapore, checking their linear correlation with various parameters of different hotels, such as the average monthly occupancy rate and average temperature. The average consumption of the hotels stood at 427 kWh/m^2/year. Heterogeneous samples of hotels concluded with the need to group the data into more homogeneous hotels for utility models in simulating energy consumption. In 2012[20], performed a comprehensive study on the basis of 200 hotels in four categories, checking the levels of energy consumption based on the category of hotels, among other factors. Energy consumption was between 280 and 143 kWh/m^2/year and average consumption per occupied room was between 26,7 and 9,4 kWh/room/nigth with 84% of the energy consumed being electricity. In 2012[21], conducted a study on the classification of hotels in Greece for their energy consumption, according to the climatic zone and type of hotel, in which they took into

account the size of the hotels but not their occupancy rates. The study in 2007[22]-roughly 184 hotels from the Hilton and Scandic chain in Europe - created a model of energy and water consumption in these hotels, taking into account multiple variables and modelling them by linearization of annual consumption. When basing a study on heterogeneous hotels, values are very generic and hardly usable for modelling all hotels, since there are large variations between them. In the study in 2011[23], to model water consumption in Acapulco, he found that the logarithmic model was the most appropriate for consumption of this type. In 2014[24], investigated the modelling of water consumption in hotels through regression models in order to obtain a hyperbolic model of water consumption in hotels of the type investigated here. In investigations[25] on the impact of tourism by type of accommodation, it means data for different countries and a global estimate is obtained per bed per night use 36 kWh/bed/night, with consumption water through very uneven, with values between 100 to 2000 l/bed/night so cannot generate reliable means of water consumption per customer per day.

Data published by the major chains should also be taken into account, since they provide general data on energy and water consumption in their hotels, motivated by environmental certifications and their corporate environmental responsibility policies, which can be useful for checking the average consumption of different establishments comparatively, albeit without any model of consumption or grouping of hotels with similar characteristics. Examples of annual data published include the NH hotel chain, which gives indicators for occupied rooms of 300 l/day/room and energy consumption of 51.43 kWh/day/room[26], or the Riu hotel chain, with shows an average consumption per guest of 371 l/day/guest and electricity of 15.31 kWh/day/guest[27].

For this research, we focused on hotels in the Canary Islands, specifically on 4-star hotels, both with and without desalination plants to provide their own water, on the islands of Fuerteventura and Lanzarote. These two destinations have an average of 2.3 and 2 million tourists a year and 18.7 and 16.5 million overnight stays respectively. The reason that the study focuses on 4-star hotels, is that they represent more than 55% of the hotels in the Canary Islands and more than 70% of the rooms[8], with which it is possible to realize an approximation of the consumption of most of the hotels on the islands.

2. Experimental

The data obtained from the corporate departments of the hotels from this study of total energy, water and electricity consumption, and number of guests staying a night (=overnight stays), was reviewed alongside the technicians responsible for each establishment, filtering out erroneous data - due mainly to failure to collect it or other chance events outside of normal operations (e.g., water leaks, renovations of facilities, breakage, etc.). With this list of definitive data, already filtered and reviewed, the calculation was performed for the histogram of the resulting data, generating the characteristic points grouped by frequency ranges. To calculate optimal ranges, the Sturges' formula[28] was used, which gives us the number of intervals depending on the amount of data obtained.

The next step was to perform the grouped distributions by intervals calculated, and once the values were grouped, the arithmetic mean of the data was performed in order to obtain the different characteristic points of consumption and perform the correlation calculations. The values are ordered by daily guest occupancy rates, which gives us a more accurate correlation than classic systems of monthly or annual consumption, because in this way, errors due to the different number of days in a month - which would provide an error of 6% in February and 3% in the months containing 31 days – are annulled, obtaining a distribution of values more tightly adjusted to their real values. With the data obtained from hotels, the calculations for total energy, electricity and water costs per guest per night were performed.

To test what kind of correlation resembled the models of consumption the most, correlation calculations were performed for linear, exponential, logarithmic, and polynomial of the second degree and potential models, testing their coefficient of determination and calculating their modelling function.

- Linear Regression whose shape fits: $y = ax + b$
- Exponential Regression whose shape fits: $y = ae^{bX}$
- Logarithmic regression whose shape fits: $y = a \ln x + b$
- Second order polynomial regression whose shape fits: $y = a + bx + cx^2$
- Power Regression whose shape fits: $y = ax^b$

The calculation of the values to find the function of the line of different value matrices was performed by the method of least squares[29]. With the lines generated, calculation of the correlation between the values can be performed, which indicates the degree of dependence between two variables, so we used the correlation coefficient of Karl Pearson[30]. To interpret the correlation coefficient of Karl Pearson, it must be taken into account that its value ranges between 1 and -1. Values closer to 1 imply a perfect positive linear relationship and -1 a perfect negative relationship. Values closer to 0 indicate a lower linear relationship[31].

To test the correlation between the data, the coefficient of determination R^2 was used to interpret the proportion or percentage of variation in the dependent variable, which is explained by the variation in the independent variable, i.e., the percentage of values that fit with the shape of the graph[32]. The functions calculated generate the various energy and water consumption graphs to test their shape and to generate a valid energy model.

This same methodology was used to calculate the correlations of all hotels for different total water, electricity and energy consumption levels. With data from all the establishments, and due to the different maximum capacities of each hotel, guests had to be averaged as a percentage of occupancy, which was necessary to make the relative comparison of the average daily occupancy rate and work with the data from all hotels as if they were a single establishment in order to generate the corresponding function for hotels of similar characteristics.

Figure 1 exhibits schematically the workflow that was followed to perform the correlation calculations, where a summary of the steps taken can be seen as follows: 1. Data collection and filtration, 2. Perform the mean arithmetic of the data according to the intervals calculated, 3. Perform calculations and generate the correlation graphs of the different models, 4. Change the occupancy rates to a percentage and use all the values for the total calculation as if it were a single hotel, 5. Calculate the final model of energy and water consumption for establishments, and 6. Conclusions.

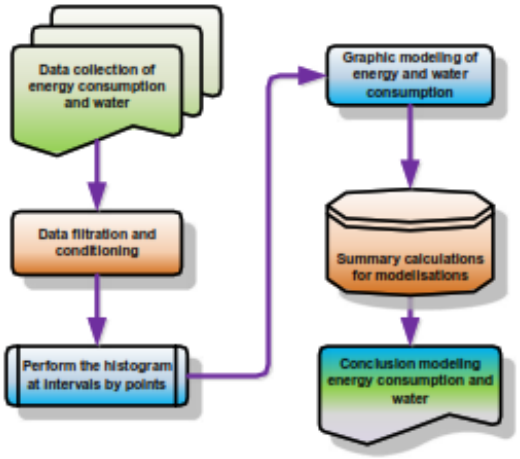


Figure 1. Diagram of the workflow for the research work. Source: Original.

To carry out the study of consumption in hotels, we chose several characteristic hotels in the Canary Islands, located on the eastern islands of Fuerteventura and Lanzarote, which have a peculiarity that distinguishes them from other hotels on other islands: their 100% reliance on desalinated water, due to the absence of hydrological resources for water distribution for general consumption on these islands. The hotels studied differ according to the way they supply water for human consumption, which is by producing water through a desalination Sea Water Reverse Osmosis Plants (SWROP) either located on the premises and belonging to the hotel or through a public water supply from a municipal plant located externally.

In the search for hotels with homogeneous characteristics, facilities were chosen that were less than 30 years old, had a 4-star rating, and fitted into the category 'holiday establishment', which implies a type of tourism where more of the hotel is enjoyed, such as the continual use of restaurants and swimming pools for the duration of the stay. All establishments have swimming pools and air conditioning, not counting heating. The gardens of the hotels are irrigated with desalinated or reclaimed water, which is motivated by the possibility of having

Table 1. Details of facilities and characteristics of hotels studied

DATES		HPE	HT	ESA	ECA	HTI	MSL
GENERAL	Location	Fuerteventura	Fuerteventura	Fuerteventura	Fuerteventura	Lanzarote	Lanzarote
	Construction date	2.000	2.004	2.003	2.007	1.997	1.988
	Land area	30.000	34.879	27.163	34.670	38.622	26.163
	Constructed area	25.912	31.132	22.710	28.307	34.112	24.507
	Rooms	333	354	266	346	329	343
	Beds	678	710	532	692	658	718
	Garden area	8.000	11.000	6.000	14.000	8.000	5.000
	Water source	SWROP	SWROP	Public supply	Public supply	SWROP	SWROP
	Irrigation source	SWROP	SWROP	Recycled	Recycled	SWROP	SWROP
POOLS	Nº Freshwater	2	1	2	1	8	1
	Area m^2	572	240	702	589	1.160	1.084
	Volume m^3	765	266	891	706	1.135	1.727
	Nº Climatized pool	1	3	1	2	2	2
	Heating system	Electricity	AC Recovery	Electricity	Electricity	Electricity	Solar panels
	kW heating	38	378	100	135	25	95
	Area m^2	86	232	331	439	85	120
	Volume m^3	130	240	298	487	95	110
Hot Water DHW	Combustible	LPG Propane	LPG Propane	Diesel oil	Diesel oil	LPG Propane + Diesel oil	Diesel oil
	kW heating	537	650	800	1.000	272+200	450
Renewable energy	Biomass heating kW					270	
	Nº Solar panels					168	92
	Solar panels m^2					340	795
Air Conditioner	HVAC System	1	2	2	2	1	1
	kW Total HVAC chillers	344	828	792	804	485	450
Desalination SWROP	kW Power (feed + plant)	65	65			52	120
	Production m3/hour	12	12			11	18
Years of date		2010-2013	2010-2015	2007-2012	2007-2012	2010-2015	2010-2015

their own treatment plant or external supply of reclaimed or desalinated water, since not all establishments have the possibility of irrigating with reclaimed water. The modelling calculations were performed regardless of the irrigation methods used in each hotel.

The hotels studied do not have the facilities to generate their own electricity, either for their own consumption or for sale, except for replacement generators in case of power failure from the grid, nor do they have their own cogeneration equipment. All electricity comes through an external supply network, being, in all cases, medium voltage with transformers located within the hotel facilities. Other fuels and power generation systems used by hotels, for which data are available are: LPG propane, diesel, biomass pellets and thermal solar panels.

Consumption data for the hotels was obtained between 2007 and 2015, depending on the facilities, with minimum values per hotel of 4 years and maximum of 6 years. During the years of study, diesel boilers have been replaced with biomass boilers, producing similar yields and allowing equivalent calculations to be performed by transferring all combustibles to the same unit of energy, i.e., kWh.

2.1 Data Analysis

Table 1 shows the general data of the establishments

studied, with their main characteristics and facilities being presented. The low use of renewable energy can be observed, present only in a few establishments for the heating of water for human consumption (DHW), as well as the lack of heating facilities. Due to the data protection of the hotels, we refer to each hotel with a code.

In considering a study of hotels with similar capacities and facilities, all feature gardens, swimming pools and have air conditioning in all rooms and public areas (restaurants, bars and lounges). The need be able to generate their own supply of water through desalination SWROP is also verified where there is an absence in the public supply, as is the case in some areas of the islands in this study, so it is necessary that hotels have their own desalination plants SWROP. With the main data from the hotels, a comparison was performed to check the average values of the facilities listed in Table 2. In this comparison of different facilities, the homogeneity of establishments can be checked.

Hotels in the Canary Islands, mainly those in the eastern islands of Fuerteventura and Lanzarote, have the peculiarity that they do not need heating in winter. The average winter temperatures do not require the use or installation of heating systems, which reduces the average consumption during the winter months, air conditioning not being required in most establishments either. The average temperature of the coldest months of December, January and February is close to 18°C, with a minimum average of 16°C and a maximum of 20°C[33], making heating and air conditioning unnecessary.

2.2 Consumption Water Performance

To perform the calculations of water consumption, the peculiarity of these establishments must be taken into account, counting two extra types of consumption that are independent of hotel occupancy and operations. These consumptions are the replacement of swimming pool water and the irrigation of gardens, which have been studied independently.

Consumption from irrigation has not been taken into account in the calculations of the total water consumption of the hotels, since irrigation water can be of two types: purified water which has specific rules[34] for its implementation, which was studied and compared with other European countries in 2015[35] and water for human consumption[36], both of which are incompatible with each other. Irrigation costs in respect to total water consumption can be seen in Table 3, reaching an average expenditure at 12% of total water consumption. Given the total surface area of the gardens, irrigation consumption is calculated as m2 of garden, with an average of 2.67 l/m2 and a standard deviation of 0.6 l/m2.

Table 2. Main indicators of the hotels studied

INDICATORS	HPE	HT	ESA	ECA	HTI	MSL	Average	Typical deviation
m²Construction / rooms	78	88	85	82	104	71	85	11
m²Gardens / rooms	24	31	23	40	24	15	26	9
% Gardens / land area	27%	32%	22%	40%	21%	19%	27%	8%
m² Pools / rooms	2,0	1,5	3,9	3,0	3,8	3,5	2,9	1,0
m³ Pools / rooms	2,7	1,6	4,5	3,4	3,7	5,4	3,5	1,3
kW Heating water / rooms	1,6	1,8	3,0	2,9	1,4	1,3	2,0	0,7
kW AC / rooms	1,0	2,3	3,0	2,3	1,5	1,3	1,9	0,7

Table 3. Total consumption, percentages and garden surface area for irrigation water

TYPE	HPE	HT	ESA	ECA	HTI	MSL	Total / Average
Total water consumption	453.535	468.617	423.494	397.289	424.167	467.479	2.634.581
Irrigation water consumption	46.286	79.232	25.480	77.285	38.263	37.388	303.934
% Consumption irrigation	10%	17%	6%	19%	9%	8%	12%
m²garden	8.000	11.000	6.000	14.000	8.000	5.000	52.000
Average daily consumption	21	36	10	42	17	11	139
L/m²daily	2,64	3,29	1,70	3,03	2,18	2,26	2,67

To perform a simplified approximation of the consumption of irrigation, taking into account only the air temperature and not considering go their factors, such as the type of flora, the similarity of the gardens, or the rainfall of the islands, annual accumulated average being the lowest in both the Canary Islands and Spain at 100 l/m² year[37]. With the average data of the percentage of consumption for irrigation in respect to the maximum value of the monthly irrigation values of the hotels shown in Table 4, a linear regression to test their dependence on the temperature was performed, proving that its coefficient of determination is very high and hence their dependence very strong, as shown in Figure 2.

Given that the annual average for daily consumption is 2.67 l/m2, corresponding to 80% of the value of irrigation, the maximum value, 100%, corresponds to 3.34 l/m2, which is the maximum value of daily irrigation. With the function calculated by linear regression, the function for calculating monthly consumption in litres for irrigation according to the surface area of the garden can be generated.

$$W_{irr} = \left(3,34(0,0371t - 0,0152)A_g\right)d$$

Where "A_g" is the area of garden in m², "d" is the number of days of the month of calculation and "t" the average monthly temperature in °C in the area where the hotel is situated on the islands.

With the consumption of water in swimming pools, which is another determinant factor in the cost of water, there are several variables involved in the daily renewal necessary to maintain the level of the swimming pools, which can be enumerated with the following factors: evaporation, leakage in the pool itself and the circuit, washing of filters, etc. Table 5 shows consumption data for hotel swimming pools, differentiating between the cold and heated pools. The importance of pool maintenance, which amounts to 13% of the water consumption of a hotel, can be checked, without taking into account maintenance of hot tubs, which are affected by the rules of legionella[38] and which mark the minimum amount of water maintenance of this type. It has been studied for this type of thermal pools[39]. Daily consumption of water for swimming pool maintenance, generically speaking, takes a daily value of 2.42%, with a standard deviation of 0.5%, which is considered sufficient to perform an approximate calculation for the water consumption of swimming pools, according to volume.

As hotel swimming pools use fresh water, this expense for modelling calculations of total water consumption has to be taken into account. In order to calculate approximations of monthly swimming pool water consumption in m3, taking into account the volume, the following function can be used to simulate an approximation of consumption:

$$Wp_m = \left(0.0242V_{Tp}\right)d$$

Where "V_{TP}" is the total volume of cold-water swimming pools, heated pools and Spas in m³, "d" is the number of days of the month of the calculation.

Table 4. Average air temperature and percentage of monthly irrigation water consumption

UNIT	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dic	Average
T°	17,9	17,9	18,9	20,2	21,7	23,2	24,8	25,5	24,9	23,8	21,3	19,1	17,9
% irrigation	63%	69%	72%	83%	78%	92%	94%	100%	93%	80%	78%	70%	80%

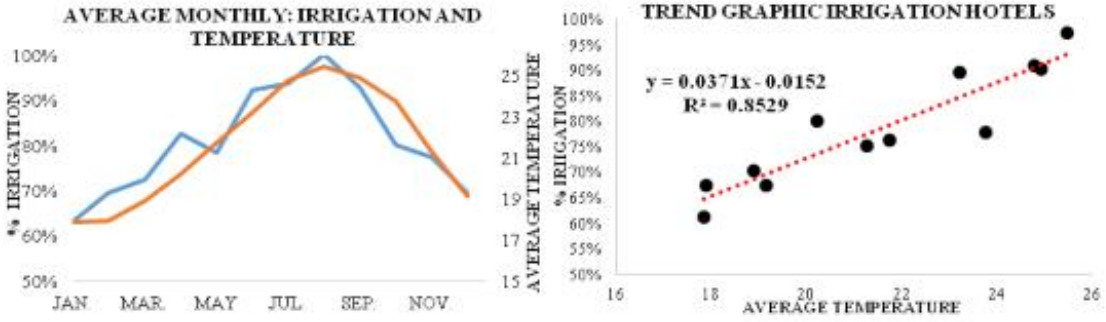


Figure 2. Average consumption of irrigation water and representation of the linear regression function. Source: Original.

Table 5. Water consumption in recreational and climatized pools

TYPE		HPE	HT	ESA	ECA	HTI	MSL	TOTAL
Total Year	Total water consumption	453.535	468.617	423.494	397.289	424.167	467.479	2.634.581
	Consumption water pools	53.929	26.342	49.930	66.824	40.976	113.899	351.900
	% consumption pool	12%	6%	12%	17%	10%	24%	13%
Cold pool	Volume water pool m³	765	266	891	706	1.135	1.727	5.490
	Average daily consumption	21	4	17	16	18	48	123
	% average daily consumption	2,76%	1,51%	1,91%	2,22%	1,55%	2,78%	2,25%
Climatized pool	Volume water pool m³	130	298	298	487	79	110	1.402
	Average daily consumption	3	7	7	19	2	6	43
	% average daily consumption	1,96%	2,47%	2,35%	3,85%	2,18%	5,44%	3,09%
Total	Volume water pool m³	895	564	1.189	1.193	1.214	1.837	6.892
	Average daily consumption	24	11	24	34	19	54	167
	% average daily consumption	2,64%	2,01%	2,02%	2,89%	1,59%	2,94%	2,42%

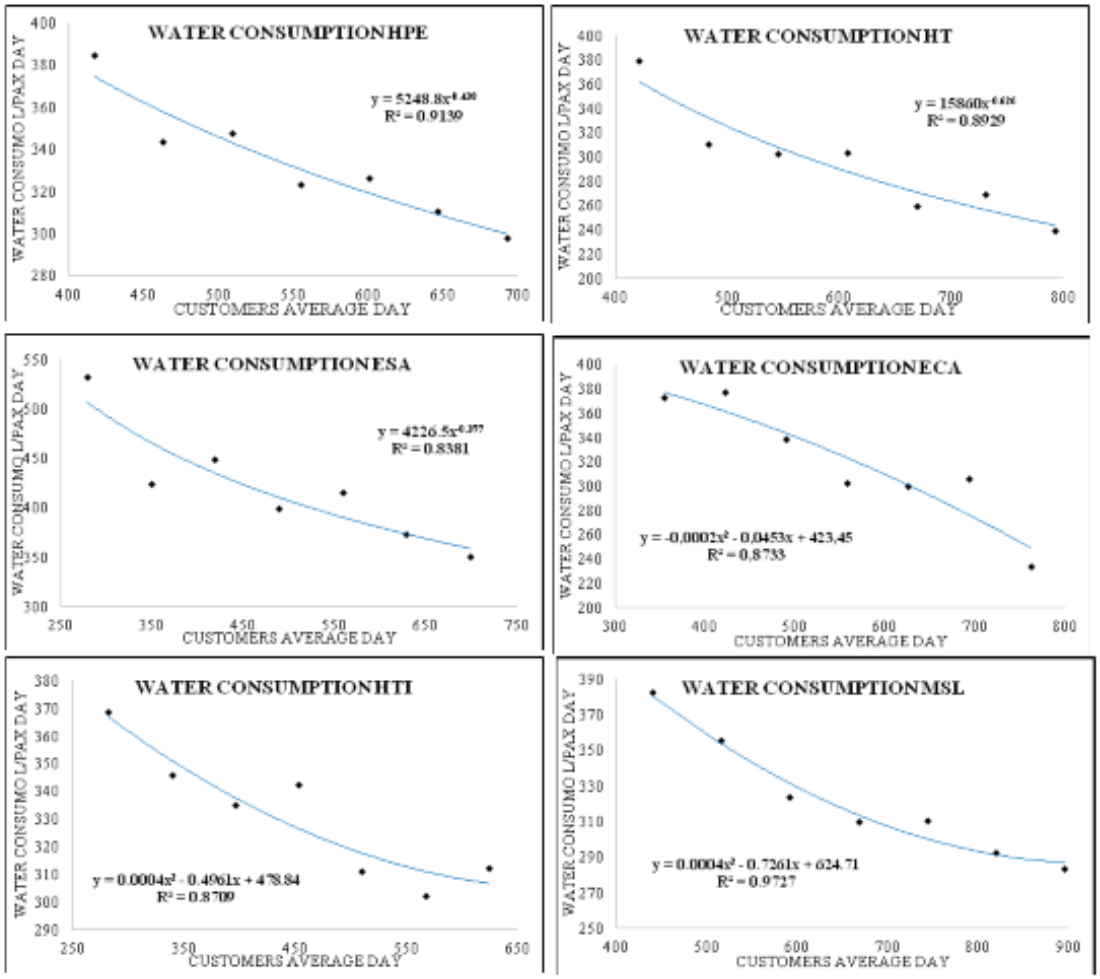


Figure 3. Characteristic function with the greatest correlation index for each hotel for different regression models for water consumption, without considering irrigation. Source: Original.

2.2.1 Water Consumption in Hotels without Irrigation

Having established the average consumption from swimming pools and irrigation, the correlation calculations of different levels of water consumption of hotels-recalling that the consumption of irrigation has not been taken into account, but the consumption of pools has-were performed. The following graphs show the different average points calculated for each hotel, according to the daily occupancy rate and daily average water consumption in litres per guest. In Figure 3 each hotel represents the characteristic function with a greater correlation index and a greater determination coefficient R^2 for different regression models.

Table 6 summarizes the calculation values of the functions of the investigated regression models, where the different values of the coefficient of determination can be checked, with the potential and polynomial correlation which best fit the graph. The increased potential of consumption is due to the declining number of guests. Since the minimum consumption of some facilities is independent of the number of guests, we consider the minimum fixed consumption to be maintained.

2.3 Electricity Consumption

Electricity in hotels is the main source of energy used in them, since most of the equipment and facilities work with this type of energy. Electricity consumption represents about 70% of the total energy consumption of hotels. In the hotels in this study, all electric power is supplied externally, not counting the establishments with any active generation or cogeneration system, so their external dependence is total. This external dependence clashes with the possibility of obtaining buildings with ZEB or nZEB, so it is necessary to model their consumption and check their behaviour according to occupancy rates, seeking alternatives to this external dependence through self-supply of electricity with different types of power generation systems based on renewable energy.

For comparison of electricity consumption, the use of water from the public supply or from the hotel's own desalination Sea Water Reverse Osmosis Plants (SWROP)

Table 6. Summary of functions and coefficient of determination of the different types of correlation for water consumption

CORRELATION TYPE		HPE	HT	ESA
WATER CUSTOMERS	Linear	y=-0,2687x + 483	y=-0,3148x + 486	y=-0,3466x + 590
	Linear R^2	0,8842	0,8496	0,7869
	Exponential	$y = 517{,}53e^{-8E\text{-}04x}$	$y = 552{,}06e^{-0{,}001x}$	$y = 619{,}13e^{-8E\text{-}04x}$
	Exponential R^2	0,9002	0,8758	0,8161
	Logarithmic	y = -147,9ln(x) + 1265,9	y = -188,7ln(x) + 1499,5	y = -163,3ln(x) + 1424,2
	Logarithmic R^2	0,9034	0,8784	0,8245
	Polynomial	$y = 0{,}0006x^2 - 0{,}8871x + 649{,}43$	$y = 0{,}0006x^2 - 1{,}0462x + 698{,}32$	$y = 0{,}0006x^2 - 0{,}8853x + 710{,}89$
	Polynomial R^2	0,9083	0,8854	0,8162
	Potential	$y = 5248{,}8x^{-0{,}438}$	$y = 15860x^{-0{,}626}$	$y = 4226{,}5x^{-0{,}377}$
	Potential R^2	0,9139	0,8929	0,8381
CORRELATION TYPE		ECA	HTI	MSL
WATER CUSTOMERS	Linear	y=-0,3142x + 494	y=-0,1759x + 411	y=-0,2056x + 460
	Linear R^2	0,8662	0,8380	0,9158
	Exponential	$y = 556{,}66e^{-0{,}001x}$	$y = 419{,}72e^{-5E\text{-}04x}$	$y = 487{,}92e^{-6E\text{-}04x}$
	Exponential R^2	0,8390	0,8377	0,9338
	Logarithmic	y = -165,4ln(x) + 1359,9	y = -77,36ln(x) + 801,65	y = -135,2ln(x) + 1198,2
	Logarithmic R^2	0,8403	0,8637	0,9554
	Polynomial	$y = -0{,}0002x^2 - 0{,}0453x + 423{,}45$	$y = 0{,}0004x^2 - 0{,}4961x + 478{,}84$	$y = 0{,}0004x^2 - 0{,}7261x + 624{,}71$
	Polynomial R^2	0,8733	0,8709	0,9727
	Potential	$y = 8995{,}3x^{-0{,}533}$	$y = 1352{,}2x^{-0{,}232}$	$y = 4582{,}4x^{-0{,}41}$
	Potential R^2	0,8013	0,8591	0,9653

has to be taken into account, which represent between 10% and 15% of hotels' total consumption. This can be seen in Table 7 of values from 2013, where the average energy consumption from desalinations about 4.77 kWh/m³, taking into account the SWROP and pumping brackish or saltwater from a catch pit.

To perform the calculations for modelling the consumption of electricity, the consumption of SWROP are not considered, as there are hotels without desalination plants. The following graphs Figure 4 shows the different average points for electricity consumption calculated for each hotel according to the average daily occupancy rates

Table 7. Consumption of electrical energy for desalination in hotels, 2013

TYPE (2013)	HPE	HT	HTI	MSL	TOTAL
ELECTRICITY	2.830.578	4.025.026	3.045.352	2.822.006	12.722.962
DESALINATION	357.115	391.600	292.212	420.801	1.461.729
% Desalination	13%	10%	10%	15%	11%
Desalinated water	68.676	78.320	76.898	82.510	306.404
Consumption kWh/m3	5,20	5,00	3,80	5,10	4,77

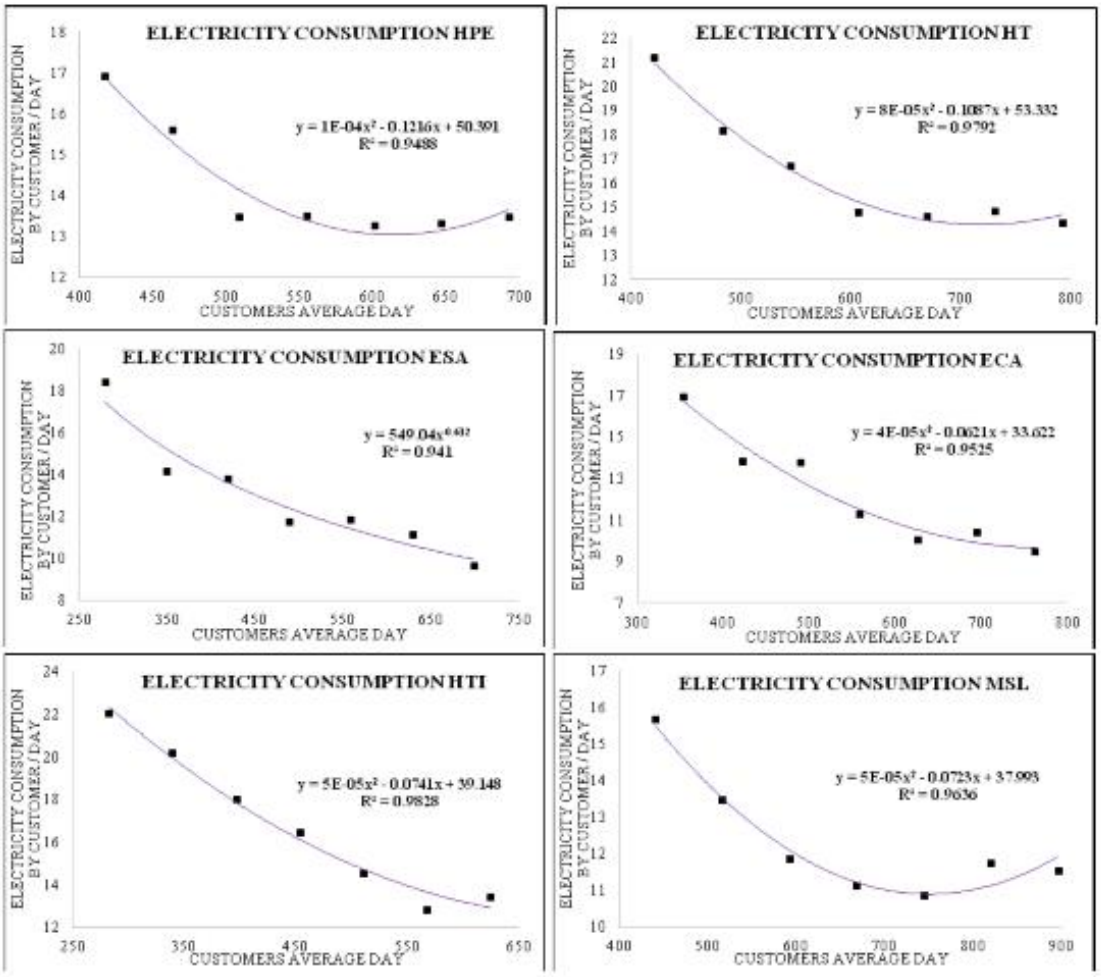


Figure 4. Characteristic function with the greatest correlation index for each hotel for different regression models for electricity consumption, without considering the desalination plant. Source: Original.

and the average daily electrical energy consumption in kWh per guest. They represent in all the graphs the line of tendency according to the correlation function with greater determination coefficient R^2.

Table 8 summarizes the calculations performed to obtain the functions of the regression models of consumption of electricity per customer per day, checking the different values of the coefficient of determination, which indicate the degree of correlation between data. The high correlation of the values of occupancy and consumption of electricity is tested, the polynomial correlation being the one which best fits in almost all cases, except in the case of ESA hotels.

2.4 Energy Performance

Hotels currently use multiple primary energy sources to meet their energy needs. To make comparisons, it is necessary to transfer such energy sources to a common unit of reference, in this case kWh, according to the values of energy conversion given in Table 9 provided by the IDAE[40–46].

The main types of energy used in hotels are:

- Electricity: generic use in all facilities. Between 60 and 75% of energy.
- LPG: kitchens, DHW heating and acclimatization of pools. Between 10 and 30% of energy.
- Diesel: DHW heating and acclimatization of pools. Between 10 and 30% of energy.

Table 8. Summary of functions and coefficient of determination of the different types of correlation for energy consumption

TYPE		HPE	HT	ESA
ELECTRICITY CUSTOMERS	Linear	y=-0,0117x + 21	y=-0,0169x + 27	y=-0,0174x + 21
	Linear R^2	0,6536	0,7952	0,8605
	Exponential	$y = 21{,}941e^{8E\text{-}04x}$	$y = 29{,}509e^{1E\text{-}03x}$	$y = 24{,}094e^{0{,}001x}$
	Exponential R^2	0,6578	0,8195	0,9083
	Logarithmic	y = -6,692ln(x) + 56,414	y = -10,36ln(x) + 82,512	y = -8,278ln(x) + 63,854
	Logarithmic R^2	0,7167	0,8607	0,9169
	Polynomial	$y = 1E\text{-}04x^2 - 0{,}1216x + 50{,}391$	$y = 8E\text{-}05x^2 - 0{,}1087x + 53{,}332$	$y = 4E\text{-}05x^2 - 0{,}0562x + 30{,}182$
	Polynomial R^2	0,9488	0,9792	0,9260
	Potential	$y = 240{,}9x^{-0{,}449}$	$y = 760{,}9x^{-0{,}603}$	$y = 549{,}04x^{-0{,}612}$
	Potential R^2	0,7202	0,8802	0,9410
TYPE		ECA	HTI	MSL
ELECTRICITY CUSTOMERS	Linear	y=-0,0172x + 22	y=-0,0275x + 29	y=-0,0079x + 18
	Linear R^2	0,8859	0,9505	0,5869
	Exponential	$y = 25{,}85e^{-0{,}001x}$	$y = 34{,}496e^{-0{,}002x}$	$y = 18{,}283e^{6E\text{-}04x}$
	Exponential R^2	0,9126	0,9555	0,5861
	Logarithmic	y = -9,445ln(x) + 71,674	y = -12,07ln(x) + 90,206	y = -5,493ln(x) + 47,902
	Logarithmic R^2	0,9293	0,9748	0,6821
	Polynomial	$y = 4E\text{-}05x^2 - 0{,}0621x + 33{,}622$	$y = 5E\text{-}05x^2 - 0{,}0741x + 39{,}148$	$y = 5E\text{-}05x^2 - 0{,}0723x + 37{,}993$
	Polynomial R^2	0,9525	0,9828	0,9636
	Potential	$y = 1320{,}6x^{-0{,}747}$	$y = 1235{,}8x^{-0{,}71}$	$y = 182{,}49x^{-0{,}417}$
	Potential R^2	0,9418	0,9657	0,6803

Table 9. Factors of conversion for combustible fuel energy in kWh. Source: IDAE

COMBUSTIBLE TYPE	ENERGY CONVERSION FACTORS	
DIESEL OIL	10,28	KWh/L
LPG PROPANE	12,75	kWh/kg
Wood Pellets (humidity<15%)	5,01	kWh/kg
Pellets generally	4,57	kWh/kg

Table 10. Summary of energy consumption from hotels in study from 2011

ENERGY TYPE	HPE	HT	ESA	ECA	HTI	MSL	TOTAL
ELECTRICITY	3.596.447	3.855.650	2.394.797	2.372.912	2.978.048	3.021.838	18.219.692
% Electricity	72%	68%	70%	63%	62%	67%	67%
LPG PROPANE	1.372.410	1.801.014	194.081	272.582	906.895	307.224	4.854.206
% LPG propane	28%	32%	6%	7%	19%	7%	18%
DIESEL OIL			822.400	1.099.960	544.316	441.989	2.908.664
% Diesel oil	0%	0%	24%	29%	11%	10%	11%
THERMAL SOLAR					350.842	739.200	1.090.042
% Thermal solar	0%	0%	0%	0%	7%	16%	4%
TOTAL ENERGY	4.968.857	5.656.664	3.411.278	3.745.454	4.780.100	4.510.250	27.072.603

- Biomass: DHW heating and acclimatization of pools. Usually replacing LPG or diesel oil boilers in the same proportion, representing between 10 and 30% of energy.
- Thermal Solar: DHW heating and acclimatization of pools. Between 5 and 20% of energy.

Table 10 lists the different types of energy consumption in 2011, where the importance of electricity consumption can be seen. Renewable energy does not yet represent a significant percentage of consumption. From 2014, HTI diesel cats switched to biomass, which means an increase to 15% of renewable energy, this value being too low to obtain ZEB or nZEB buildings.

Figure 5 can be used to check the distribution of energy consumption in percentages by energy type for the year 2011, highlighting the importance of electricity consumption in hotels, where it represents 67% of total consumption, and the low importance of renewable energies in that year, representing only 4% from thermal solar energy.

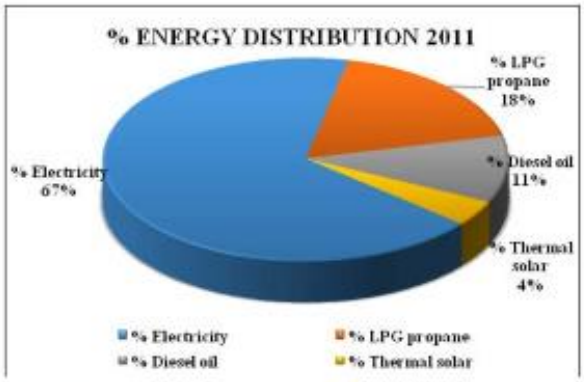


Figure 5. Distribution of energy consumption in hotels study 2011. Source: Original.

In the calculations of the modelling of energy consumption, the consumption of desalination plants is not taken into account. Figure 6 shows the average points of energy consumption calculated for each hotel according to the average daily occupancy rates and the average daily consumption of energy per guest in kWh. The line of tendency is represented in all the graphs, according to the correlation function with the greatest determination coefficient R^2.

Table 11 summarizes the calculations performed to obtain the functions of regression models of total energy consumption per customer per day, checking the different values of the coefficient of determination, which indicates the degree of correlation between the data. The high correlation values of occupancy and energy consumption is tested, the polynomial correlation being that which best fits consumption, except in the case of ESA, where it is the potential, and HTI, where it is the exponential.

2.5 Study Mathematical Model

Since the hotels in this study have different maximum capacities, the same number of clients translates to different percentages of occupancy. This requires changing the ratios of consumption per guest to consumption by percentage of occupancy, since, in this way, we can compare the occupancy rates of different hotels in balance with the conditions of occupancy. With the amount of data from all the hotels, it was found that the occupancy intervals used and on which we have data, cover occupancy values of between 45% and 120%. Once we divided by intervals and filtered them, we performed the correlation calculations for the calculated mean values.

With the calculations performed, Figure 9 was generated, representing the midpoints for consumption of

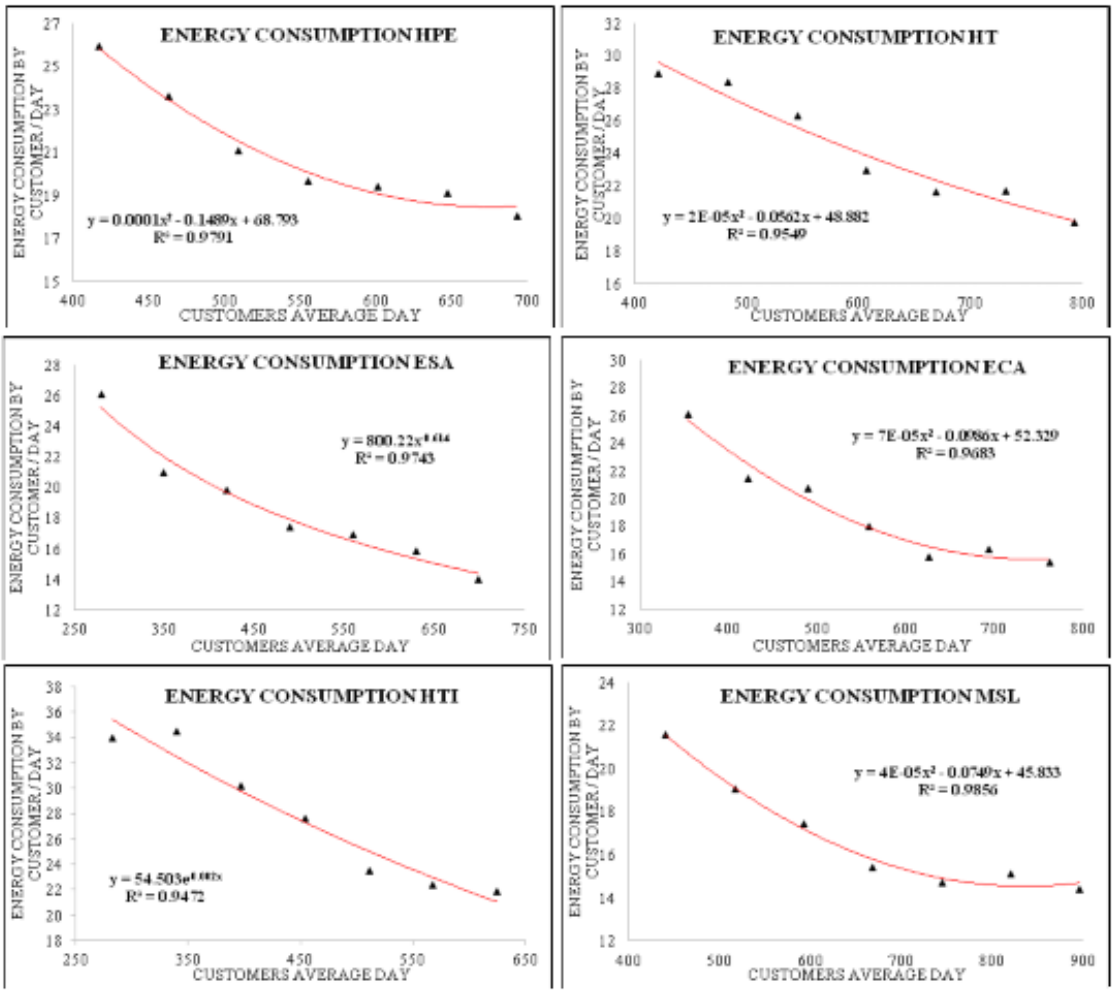


Figure 6. Characteristic function with the greatest correlation index for each hotel for the different regression models for total energy consumption, without considering desalination plants. Source: Original.

water, electricity and energy for all the hotels combined. The line of tendency is represented in all the graphs, according to the correlation function with the greatest determination coefficient R^2.

Table 12 shows the calculations performed to obtain the functions for the regression models of water, electricity and energy are summarized. A strong correlation was found between the consumption of water and energy, which fits almost perfectly with the potential function. The best fit for consumption of electricity is a type of polynomial function, although the potential function also has a high degree of correlation.

After verifying the strong correlation between the systems of polynomial regression in electricity and potential in water and total energy, the suitability of these functions can be confirmed, comparing the actual values of the averages for the hotels with values of the functions generated by the regression models. All the regression models have been compared on the same graph, calculating the values of the functions from an occupancy rate of 1% to 140%, which is shown in Figure 7. It can also be seen how the values of the regression functions have been paired for values of between 40% to 120% occupancy, for which, among these values - which are where the average occupancy rates for the hotels are usually found - the mean values of supplies with any of the functions can be approximated, although taking into account that the optimum fit has to use the potential or

Table 11. Summary of functions and coefficient of determination of the different types of correlation for total energy consumption. Source: Original.

TYPE		HPE	HT	ESA
ENERGY CUSTOMERS	Linear	y=-0,0267x + 36	y=-0,0262x + 40	y=-0,0252x + 31
	Linear R^2	0,8834	0,9452	0,9073
	Exponential	$y = 41{,}405e^{-0{,}001x}$	$y = 46{,}225e^{-0{,}001x}$	$y = 35{,}024e^{-0{,}001x}$
	Exponential R^2	0,9072	0,9514	0,9488
	Logarithmic	y = -14,84ln(x) + 114,53	y = -15,49ln(x) + 123,22	y = -11,9ln(x) + 91,935
	Logarithmic R^2	0,9226	0,9523	0,9566
	Polynomial	$y = 0{,}0001x^2 - 0{,}1489x + 68{,}793$	$y = 2E\text{-}05x^2 - 0{,}0562x + 48{,}882$	$y = 5E\text{-}05x^2 - 0{,}0748x + 42{,}206$
	Polynomial R^2	0,9721	0,9549	0,9615
	Potential	$y = 1571{,}9x^{-0{,}686}$	$y = 1386x^{-0{,}635}$	$y = 800{,}22x^{-0{,}614}$
	Potential R^2	0,9408	0,9511	0,9743
TYPE		ECA	HTI	MSL
ENERGY CUSTOMERS	Linear	y=-0,0247x + 33	y=-0,0421x + 47	y=-0,0151x + 27
	Linear R^2	0,8807	0,9405	0,8549
	Exponential	$y = 37{,}91e^{-0{,}001x}$	$y = 54{,}503e^{-0{,}002x}$	$y = 29{,}695e^{-9E\text{-}04x}$
	Exponential R^2	0,9085	0,9472	0,8758
	Logarithmic	y = -13,61ln(x) + 104,75	y = -18,17ln(x) + 138,32	y = -10,04ln(x) + 81,849
	Logarithmic R^2	0,9323	0,9354	0,9153
	Polynomial	$y = 7E\text{-}05x^2 - 0{,}0986x + 52{,}329$	$y = 3E\text{-}05x^2 - 0{,}0672x + 52{,}174$	$y = 4E\text{-}05x^2 - 0{,}0749x + 45{,}833$
	Polynomial R^2	0,9683	0,9442	0,9856
	Potential	$y = 1402{,}2x^{-0{,}685}$	$y = 1464{,}7x^{-0{,}655}$	$y = 683{,}88x^{-0{,}574}$
	Potential R^2	0,9472	0,9326	0,9286

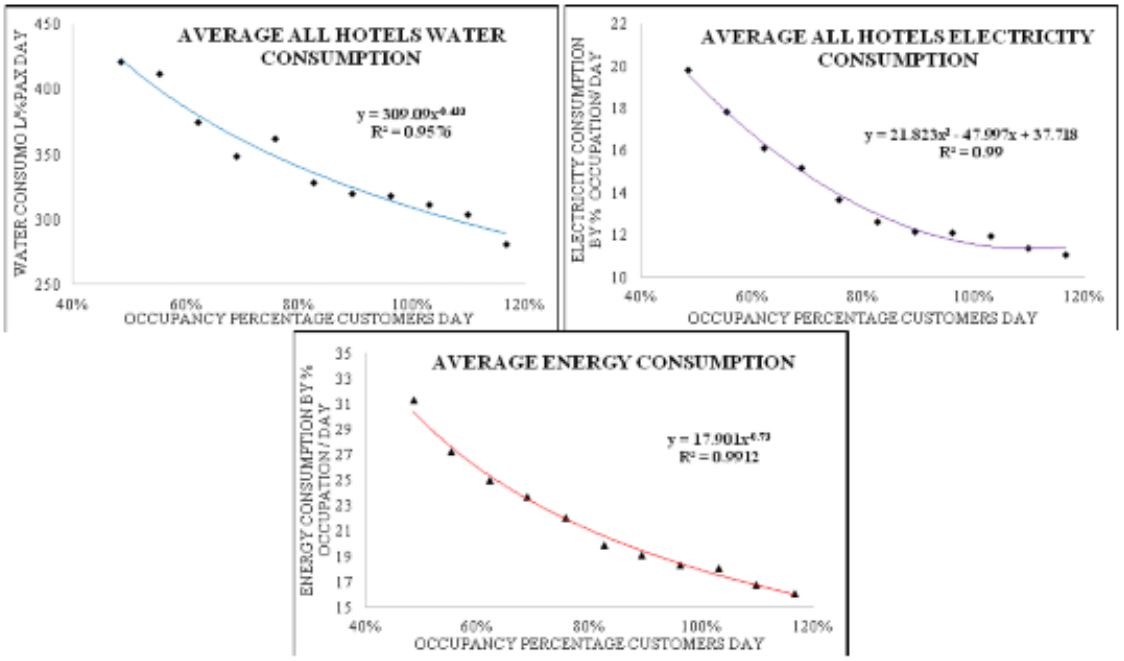


Figure 7. Characteristic function with the greatest correlation index for the consumption of water, electricity and energy of all hotels. Source: Original.

Table 12. Summary of functions and coefficient of determination of the different types of correlation for consumption of water, electricity and energy. Source: Original.

TYPE	DATA FOR ALL HOTELS		
	WATER CUSTOMERS	ELECTRICITY CUSTOMERS	ENERGY CUSTOMERS
Linear	y = -190,38x + 500,91	y = -11,988x + 23,879	y = -20,312x + 38,362
Linear R^2	0,9247	0,8838	0,9257
Exponential	$536{,}13e^{-0{,}347x}$	$y = 27{,}163e^{-0{,}828x}$	$y = 45{,}157e^{-0{,}919x}$
Exponential R^2	0,9412	0,9212	0,9647
Logarithmic	y = -151,6ln(x) + 309,16	y = -9,732ln(x) + 11,762	y = -16,33ln(x) + 17,868
Logarithmic R^2	0,9542	0,9476	0,9733
Polynomial	$y = 180{,}19x^2 - 487{,}69x + 615{,}18$	$y = 21{,}823x^2 - 47{,}997x + 37{,}718$	$y = 27{,}706x^2 - 66{,}027x + 55{,}931$
Polynomial R^2	0,9547	0,9900	0,9882
Potential	$y = 309{,}09x^{-0{,}455}$	$y = 11{,}803x^{-0{,}864}$	$y = 17{,}901x^{-0{,}73}$
Potential R^2	0,9576	0,9700	0,9912

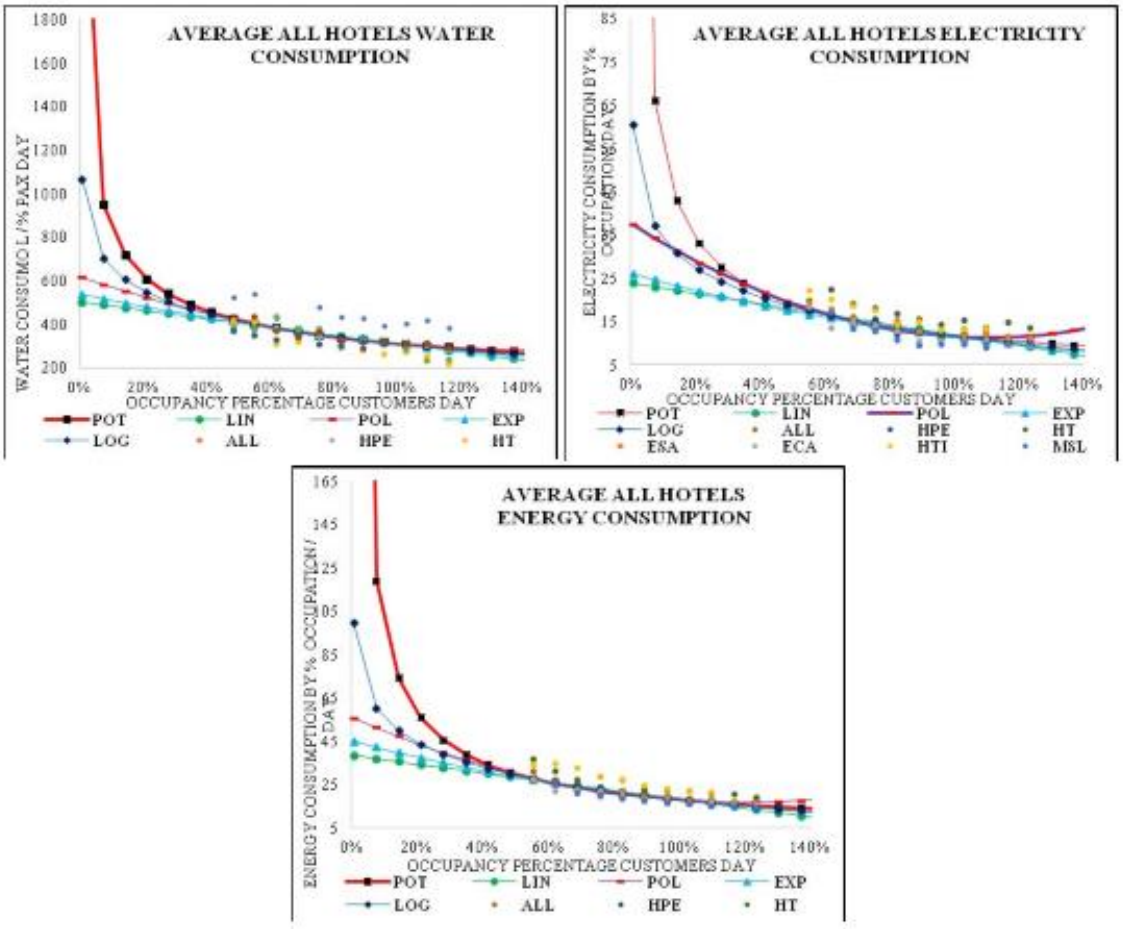


Figure 8. Representation of regression functions between 1 and 140% occupancy with respect to the midpoints of water, electricity and energy consumption of the different hotels.

polynomial function.

3. Results and Discussion

It was found that the values of the midpoints for the levels of consumption of the hotels approximately fit the values of the calculated functions. The next step was to check that the calculated mean values for all hotels fit with the generated function in order to demonstrate the validity of the models calculated for the average occupancy values, which range in a generic sense between 30% and 130%. Figure 9 represents functions of water, electricity and energy appear.

In reviewing the representation of the functions, it was found that the average data fits the graphs generated, so the potential function can be used for the approximation of the values of water and energy consumption, and the polynomial for electricity consumption for a group of four-star hotels with similar characteristics such as those studied here.

The functions that bring us the values of monthly consumption, taking into account the average daily occupancy, air temperature for water consumption for irrigation and desalinated water production for specific consumption, are summarized as follows:

- Water

Consumption without irrigation:

$$W_{TT} = (309,09x^{-0,433})d$$

Consumption with irrigation:

$$W_{TTirr} = \left((309,09x^{-0,433}) + \left(3,34A_g(0,0371t - 0,0152)\right)\right)d$$

- Electricity

Consumption without irrigation:

$$El_{TT} = (21,832x^2 - 47,997x + 37,718)d$$

Consumption desalination SWROP without irrigation:

$$El_{TTdw} = \left((21,832x^2 - 47,997x + 37,718) + (W_{TT}C_{dw})\right)d$$

Consumption desalination SWROP with irrigation:

$$El_{TTdwirr} = \left((21,832x^2 - 47,997x + 37,718) + (W_{TTirr}C_{dw})\right)d$$

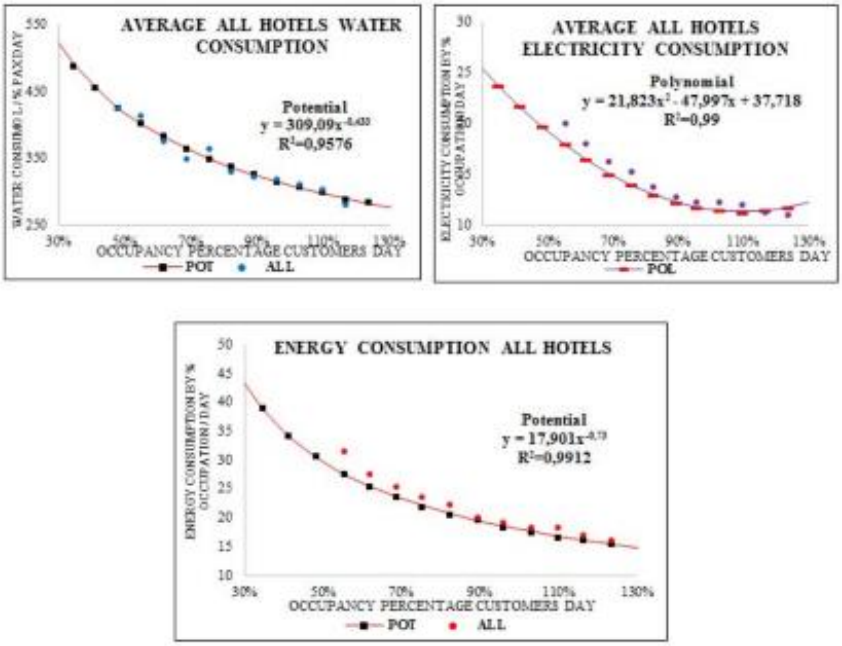


Figure 9. Representation of regression functions between 30 and 130% occupancy with respect to the midpoints of the average consumption of water, electricity and energy calculated for all hotels.

- Energy:

Consumption without irrigation:

$$E_{TT} = (17,901x^{-0,73})d$$

Consumption desalination SWROP without irrigation:

$$E_{TTdw} = \left((17,901x^{-0,73}) + (W_{TT}C_{dw})\right)d$$

Consumption desalination SWROP with irrigation:

$$E_{TTdwirr} = \left((17,901x^{-0,73}) + (W_{TTirr}C_{dw})\right)d$$

Where "x" is the percentage of average occupancy, "C_{dw}" is the specific consumption of the plant in kWh/m³ of water generated, "A_g" is the surface area of gardens, "d" is the number of days of calculation and "t" the average temperature in the area where the hotel is located on the islands.

The main reasons for the increase in specific consumption, even with decreasing occupancy, are related to the need for facilities to be in place and consuming energy or water at the hotel, with or without guests, since the sectorization of equipment or systems cannot be carried out in most of the hotels studied, implying that the minimum consumption is always due to the ongoing maintenance of facilities.

4. Conclusions

Using the method described, a model of the typical consumption of water, electricity, and energy for a hotel in a determined segment, which may be reproduced for any other hotel in the sector, was obtained, thus making it possible to check and compare consumption. With the application of statistical functions and correlation, optimum consumption models can be generated for a group of homogeneous hotels, taking into account that the more data obtained, the more reliable will be the generated models. The basic procedure followed and demonstrated leaves the field open to more complex and precise research, applicable to any type of supply for hotels.

With the different correlation models studied, it has been found that, in most cases, the potential or polynomial models is applicable, with very little difference between the correlation coefficients. The calculated values, from which we can consider similar approximations for both models, are between 40 and 120% occupancy, being that lower or higher occupancy rates have very large differences from which no equivalent can be made.

The peculiarity of hotels with a desalination seawater reverse osmosis plants SWROP where energy consumption is directly related to water consumption and influence the type of irrigation used - is studied. This proves the need to improve the efficiency of the desalination plants SWROP in reducing water consumption and irrigation in order to achieve a proportional energy reduction in the hotels.

The use of renewable energy is highly unrepresented in the hotels from the study. This can and should be improved, mainly through using renewable energy sources for domestic hot water (DHW), which represents 22% of energy consumption in hotels. In this way, external energy dependence could be reduced.

This study leaves open the way to further investigation into the importance of hotel occupancy rates, with the carbon footprint generated by energy consumption being due to the activity of tourist accommodation, as well as the importance of water desalination in hotels in the Canary Islands, which is a determinant factor in the consumption of energy.

By comparing the different methods and systems for energy efficiency and developing the method studied, improvements can be simulated for application in facilities in order to compare the most optimal and effective models to be adopted, verifying this as hotels get closer to energy independence and achieving the objective of becoming ZEB or nZEB hotels.

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4.4. Artículo 3. Comparative study of carbon footprint of energy and water in hotels of Canary Islands regarding mainland Spain

4.4.1. Resumen

La importancia económica del turismo a nivel mundial ha aumentado de forma considerable en los últimos años y en la zona de estudio de las islas Canarias también, siendo las estimaciones futuras a quince años muy positivas para este sector, pronosticando un aumento que duplicarán los valores actuales de pernoctaciones. Las emisiones debidas al turismo son un factor importante a tener en cuenta en las emisiones globales de CO_2 que representan el 5% de las mismas, siendo necesario actuar sobre ellas lo antes posible, mediante la aplicación de mejoras en la eficiencia energética y disminuir los consumos de agua, para conseguir reducir el binomio agua/energía asociado al turismo. Para poder realizar una estimación de las emisiones por categorías de hoteles en el destino de las Islas canarias, se tomó una muestra de 12 hoteles de 5, 4 y 3 estrellas situados en las islas orientales más áridas del archipiélago, que corresponde a Fuerteventura y Lanzarote, donde el agua para el consumo proviene de plantas de desalación de agua de mar mediante ósmosis inversa.

Para poder realizar los cálculos de emisiones de CO_2 inicialmente se calcularon los consumos energéticos de los hoteles, obteniendo unos valores promedio de 22,1 kWh/pernoctación (p), así como los consumos de agua con promedio de 295,6 L/p, estos últimos sin tener en cuenta consumo de riego ni piscinas. Una vez obtenidos de los consumos energéticos y de agua de los diferentes establecimientos por categorías y promedio, se realizaron los cálculos de la huella del carbono de alcance 1 y 2, generando la energía unas emisiones promedio 13,1 kg CO_2/p, y del agua un promedio de 1,14 kg CO_2/p para hoteles con planta desaladora propia y de 2,18 kg CO_2/p para hoteles con suministro de agua centralizado. Estos datos de los hoteles canarios se comparan con hoteles de las mismas características en la península, comprobando que las emisiones insulares de energía son superiores 1,27 veces a las peninsulares y las del agua, en el caso de desaladoras locales propias, son de 3,89 veces superior y si es centralizado son 7,87 veces superior a las peninsulares. Se finaliza con el algoritmo de cálculo de emisiones según el tipo de desaladoras para Canarias y el modelo único para la Península.

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Comparative study of carbon footprint of energy and water in hotels of Canary Islands regarding mainland Spain

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Abstract In this study, we estimate the emissions in terms of category of hotel, with the data of a sample of 12 hotels of 5, 4 and 3 stars in the Canary Islands (Spain), located in the most arid eastern islands of the archipelago, Fuerteventura and Lanzarote, where there are a total of 122 hotels and this sampling represents 10% of the hotels of these islands where water for consumption comes from desalination plants using seawater reverse osmosis (SWRO), which was chosen. Water consumption was measured not considering consumption due to irrigation and swimming pools and comparing the generation of water by means of desalination plants of the hotels or external plant centralized with public distribution. Considering the energy and water consumption of the hotels in the study, their carbon footprints, scope 1 and 2 and obtaining average values of emissions between 14.23 kg CO_2/person night (CO_2/p) for hotels with own SWRO and 15.16 CO_2/p for hotels with external water distribution. These data were compared to hotels with the same characteristics and consumptions in mainland Spain, proving that average emissions from the islands for the energy are 1.27 higher and for water production are 3.89 higher for own SWRO and 7.87 superior for distribution by centralized external SWRO. The Canary Islands, as a sensitive and vulnerable tourist destination, with their external energy dependence, their great

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ecological value, and their need for water desalination, make for a good laboratory to test the application of measures and improvements in the systems of industrial water generation, and in the conservation of energy in buildings, to try to turn these establishments into nearly zero energy buildings (nZEB).

Keywords Carbon footprint · Tourism · Desalination (SWRO) · Energy · Hotels · nZEB

1 Introduction

In recent decades, tourism has continued to boom, increasing in its economic significance and representing one of the biggest increases in global economic activity. As a global export category, tourism is in third place, behind only fuels and chemicals, and ahead of sectors such as food and the automotive industry. International tourism accounts for 30% of exports, and tourism's share in total exports of goods and services rose from 6 to 7% in 2015 (World Tourism Organization (UNWTO) 2016; Vega Altamira and Muñoz Vivas 2007). The general expansion of tourism has been beneficial in economic and employment terms of local economies (United Nations 2013). Globally, tourism accounted for 9% of world GDP in 2014, with revenues more than $ 1.4 billion (UNWTO 2015). The increase in tourism must be in line with the sustainability of destinations—especially those with high ecological value—through the adoption of a policy of responsible and efficient energy and water use. Furthermore, it is very important to maintain the biodiversity of tourist destinations (UNWTO 2010; United Nations Environment Programme 2011). Climate change forecasts, with increased temperatures and reduced rainfall, should be considered, given that the energy and water need of the tourism industry will increase considerably (World Tourism Organization and United Nations Environment Programme UNWTO-UNEP 2011). The demand for water/energy will continue to increase due to the need for water for human consumption, making desalination plants increasingly relevant as existing aquifers are depleted (Bates et al. 2008). It should be noted that the United Nations World Tourism Organization (UNWTO) projections in the general meeting of 2011 presented the tourist estimates up to 2030, with values for that year of 1800 million tourists (UNWTO 2011), almost double the values for 2010. Having ascertained the importance of the tourism sector for the world economy and its future expectations, its impact on greenhouse gas emissions and especially its carbon footprint must also be studied. In several studies carried out by the United Nations, together with the UNWTO and United Nations Environment Programme (UNEP) (World Tourism Organization and United Nations Environment Programme UNWTO-UNEP 2011), an estimation of the global emissions of the tourism industry was obtained for the year 2007, with contribution of tourism to global emissions of 5% of CO_2 emissions can here be verified, with the accommodation sector accounting for 21% of emissions and the transport sector 75%. These emission values are projected to increase by 97% by 2035 by the World Economic Forum (World Economic Forum (WEF) 2009), which is why it is necessary to act urgently on the sources of emissions.

To make the necessary improvements needed to reduce emissions in the tourist accommodation sector, it is necessary to know the distribution of its energy consumption, and, in this way, act on the most inefficient installations with the highest levels of specific consumption. Depending on the geographical location of the establishments, as well as their category and typology, the distribution of energy consumption varies widely. We find that the main source of energy, considering the average expenses of the hotel industry,

is electricity, since it represents between 55 and 85% of primary energy consumption (Monzón-Alejandro and Colmenar-Santos 2016; Shiming and Burnett 2002; Moiá-Pol et al. 2006; Hendrikx 2008). The results show great variation depending on the geographical area and category of establishment, such as data from several hotels in Greece (Karagiorgas et al. 2007), Taiwan (Wang 2012), Singapore (Priyadarsini et al. 2007) or Shanghai (Yao et al. 2015). The model of energy consumptions was also made for the occupation for 4-star hotels, which corresponded to a potential function (Díaz Perez et al. 2016). It is also necessary to take water consumption into account at the various tourist destinations, which varies substantially according to the country and category of establishment. Several studies have noted the great variation in consumption levels, highlighted mainly by category. In most of the Mediterranean (Grenon and Batisse 1989), it is approximately 250 litres/night (= l/p), in Morocco (European Commission, Eurostat 2009) between 300 and 600 l/p, depending on category, in Australia (Bohdanowicz and Martinac 2007) 750 l/p, in France (Langumier and Ricou 1995) over 175 l/p, on the island of Zanzibar (Gössling 2001) an average of 685 l/p, and on a global level (Gössling et al. 2012) it is estimated at around 284 l/p. The characteristic function of water consumption in hotels of 4 and 5 stars corresponding to a polynomial function (Díaz Perez et al. 2016).

Tourism emissions have been studied in several areas, with tourist accommodation being the most variable. The great variety in emissions at the destinations is due mainly to the different coefficients of emission of the fuels used and the generation of electricity, as well as to the efficiency of the installations. After investigations of hotels in Indonesia (Saputra et al. 2013), 55% of emissions were due to domestic tourism. Tourism emissions in Spain (Cadarso et al. 2015) showed that internal tourism is responsible for 11% of emissions. Another study of tourism in Wales (Munday et al. 2013), and one on the analysis of transport due to tourism activity in Lanzarote (Martín-Cejas and Sánchez 2010), is example of surveys of general emissions from tourism. Other studies, such as those carried out in various areas of the island of Menorca (Sanyé-Mengual et al. 2014), resulted in a mean emission of 14.6 CO_2/p, in Taiwan (Huang et al. 2015) with average emission values of 29 CO_2/p, in Great Britain (Filimonau et al. 2011) with emissions between 11.65 and 8.25 CO_2/p, or that performed for stays in hotels (Gössling et al. 2005) which calculated on average 20.6 CO_2/p, are studies that bring us closer to the problem of tourism emissions due to accommodation.

Once the importance of tourism, its emissions, energy consumption, water consumption and economic income for the recipient countries has been verified, we are able to study a high ecological value zone whose sustainability is very important and complicated, one such territory is the Canary Islands belonging to Spain and located in the Atlantic Ocean (Muñoz 2006), when tourism represents the main driver of the economy, accounting for 31% of the archipelago's GDP and generating 36% of the employment on the islands (Exeltur 2014) and the 63% (Government of the Canary Islands 2016) of the surface of the archipelago has been declared a Biosphere Reserve, which means that it is a space with a great singular value, both at an ecological level and in the capacity to implement development models compatible with its conservation.

2 Methodology

To carry out calculations of CO_2 emissions and energy and water consumption, the workflow shown in Fig. 1 shows the schema of the research performed. Initially the data were

collected from 12 hotels, located in the islands of Lanzarote and Fuerteventura, belonging Canary Islands and located in the Atlantic Ocean near the coast of southern Morocco and the Sahara, north Africa, with climate arid, with zones belonging to the desert climate and other zones belonging to the arid subtropical climate (Muñoz 2006). The data for research have an average period of 5 years, with data between 2007 and 2015, which is provided by

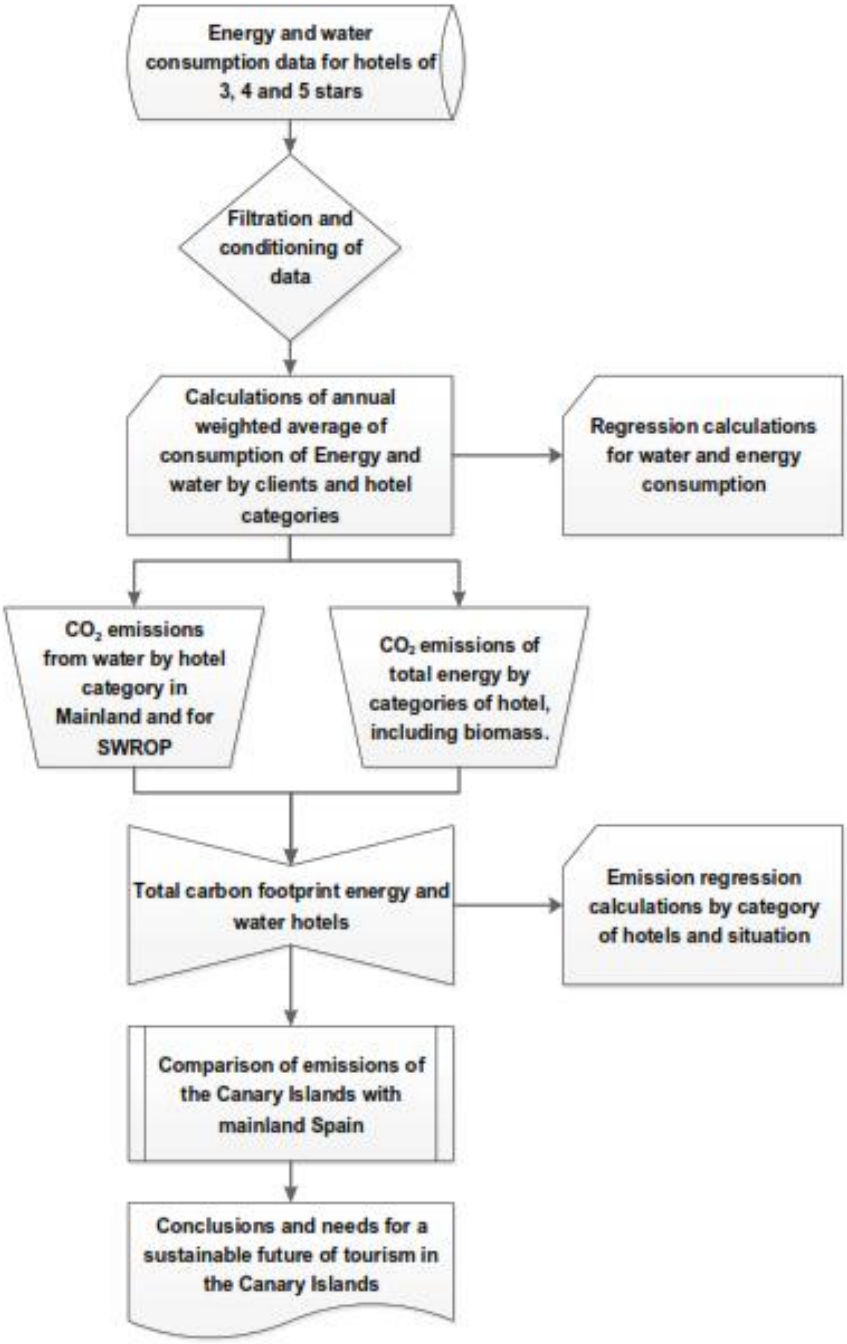


Fig. 1 Research flowchart

the hotel management and subsequently reviewed and filtered with the maintenance engineers of each establishment. Table 1 summarizes the characteristics of the hotels in the study, was chosen for their similarities of type of holiday hotels and with similar characteristics. These hotels have been chosen since they represent approximately the percentage of hotels by category of these islands that are: 5* represent 5%, from 4* 53% and from 3* 21% of the total of hotels. Due to the data protection of the hotels, we refer to each hotel with a code. The data, once filtered and revised with the maintenance engineers, were converted to the same unit of measurement that made possible the comparison between them—water in cubic meters (m^3) and energy to kWh—transforming the values of the different fuels, according to the factors of primary energy conversion for each of them (Institute for the diversification and saving of energy IDAE 2014; Government of Spain 2016). The calculation was made to produce water in private, establishment-owned SWRO plants or in external, centralized SWRO plants, with their corresponding specific ratios of water production in kWh/m^3. The weighted average hotel consumption by category was arrived at by summing up the total consumption values of the different fuels in each category, divided by the number of hotel stays in the category. For the total weighted average, we have added the values of the different consumptions of the hotels and divided by the total number of stays, which was then calculated by means of a regression. Finally, their emissions were checked according to the category of the different establishments, and a comparison was made of the emissions from the same types of hotel if they were in mainland Spain, considering the electricity emission ratios, which are different in both geographical zones, but keeping the ratios of the rest of primary energies used constant. The regression calculation of the emissions by categories was also done to verify the trend of the same ones.

2.1 Footprint calculations

To carry out the calculation of the carbon footprint of the different establishments, a procedure had to be chosen from within the multiple existing models and standards, seven of which have been analysed in depth by the European Commission to find a common model (Chomkhamsri and Pelletier 2011). The model chosen to perform these calculations is the

Table 1 Details of facilities and characteristics of hotels studied

Hotel code	Stars	Construction date	Constructed area	Beds	Water source
EPG	5	2.002	8.124	122	Public supply
ESH	5	2.006	35.888	532	Public supply
HPE	4	2.000	25.912	678	SWRO
HT	4	2.004	31.132	710	SWRO
ESA	4	2.003	22.710	532	Public supply
ECA	4	2.007	28.307	692	Public supply
HRP	4	2.001	46.297	1.286	SWRO
HTI	4	1.997	34.112	658	SWRO
MSL	4	1.988	24.507	718	SWRO
ECE	3	1.998	12.968	507	Public supply
ESJ	3	1.997	33.421	1.170	Public supply
PPC	3	1.993	9.165	284	Public supply

Greenhouse Gas (GHG) Protocol (2009), widely used by organizations around the world, where three ranges are distinguished for the carbon footprint:

- Scope 1: direct GHG emissions, which are controlled or owned by hotels: boilers, ovens, vehicles, etc.
- Scope 2: indirect GHG emissions associated with electricity.
- Scope 3: other indirect emissions, which are those due to the activities of the company.

Scopes 1 and 2 were calculated for the hotels in the study to have a view of the complex emissions, which can be directly acted upon since those of scope 3 are external factors that cannot be directly acted upon by the management of the hotel. Biomass, which was treated independently, according to the new GHG corporate standard, was also calculated in this study. To quantify the emission factors, the conversion coefficients of the different fuels converted to kWh were used based on Table 2 provided by the Institute for Diversification and Energy Saving (IDEA) (Institute for the diversification and saving of energy IDAE 2014), using emission factors approved and updated by the Spanish government (Government of Spain 2016). The electricity emission factors are very different from year to year and from month to month, due to which—to be able to estimate the emission factor—it was decided to consider the last 9 years of emissions (Spanish Electricity Network (REE) 2016), the period from 2007 to 2015. Calculations were taken in a generic way, so that all the hotels had their own transformer, with a medium voltage supply, whose losses for the calculations are estimated by regulation (Government of Spain 2008) to be within 6% of the medium voltage.

The energy consumed by the desalination plants of the hotels is not added to the total energy calculation of the hotel. The desalter consumption is used to calculate the carbon footprint of water generation for these hotels with its own desalination plant.

Emissions due to water also have a direct dependence on the type of supply and its origin, as an example, the values from Aragon (Mainland Spain) of 0.788 kg CO_2/m^3 (General Direction of Environmental Quality and Climate Change DGCACC 2010) for waters from a natural source, or those from the Canary Islands, which depend directly on desalination plants and the distribution network, may be able to reach values in old SWRO plants of 6.44 kWh/m^3 (Feo-García et al. 2016), implying very high emissions of 5.30 kg CO_2/m^3—not considering the leaks in the water distribution network.

Table 2 Factors of conversion and emission of different fuels. *Source*: IDAE, Government of Spain and own

Combustible type	Energy conversion factor	CO_2 emission factor (kg/kWh)
Diesel oil	10.28 kWh/l	0.311
LPG propane	12.75 kWh/kg	0.254
Pellet generally	4.57 kWh/kg	0.018
Electricity Canary	1 kWh	0.838
Electricity mainland Spain	1 kWh	0.282

3 The carbon footprint of tourism in the Canary Islands

3.1 Carbon footprint of energy

Initially, the weighted averages energy per client overnight was calculated: the energy was converted to kWh and the energy of the different years was added and divided by the number of overnight stays of those years, generating the ratio of kWh per night stay (kWh/p). The years calculated for the weighted averages are those that for which there is data from each hotel, which is between 3 and 6 years. In the following Table 3, we can verify the weighted average consumptions per overnight stays of the hotels according to category, and the weighted average for consumption of each category, which has been calculated using the same procedure. In these weighted averages, the consumption of the SWRO desalination plants in the hotels that have them has been subtracted. The footprint and emissions of desalination were calculated in the section on water.

With the data compared, it is possible to observe the high consumption of the higher star-rated hotels, with 69.9 kWh/p—that being more than five times the value of lower star-rated hotels, with values at 12.2 kWh/p. This is due to the various, additional facilities and services provided as the category of the hotel rises, such as the obligation to provide air conditioning, heated swimming pools, live kitchens, equipment in the rooms. The weighted average value of all hotels is 22.1 kWh/p. With all the calculated data, a regression study was carried out, where it was verified that the energy consumption has an exponential tendency with respect to the hotel category variable, which is represented in Fig. 2.

Considering the weighted average consumption per category and the primary energy data of the hotels, the details of the proportional distribution of the same were taken to calculate the distribution of the percentage share of each type of fuel used as can be seen in Table 4. It must be considered that in these consumption data, the consumption of the own desalination plants is not taken into account, so that the values of the hotels without desalination plant can be compared correctly. These desalter energy consumption data are used to calculate the carbon footprint of water.

Table 3 Energy consumption per guest, per day, not considering expenses from own desalination

Total energy without SWRO kWh/p				
Hotels	5*	4*	3*	Total
EPG	50.6			
ESH	73.7			
HPE		18.7		
HT		22.5		
ESA		18.4		
ECA		18.2		
HRP		22.7		
HTI		23.1		
MSL		15.8		
ECE			13.7	
ESJ			12.9	
PPC			9.3	
Weighted average	69.9	20.5	12.2	22.1

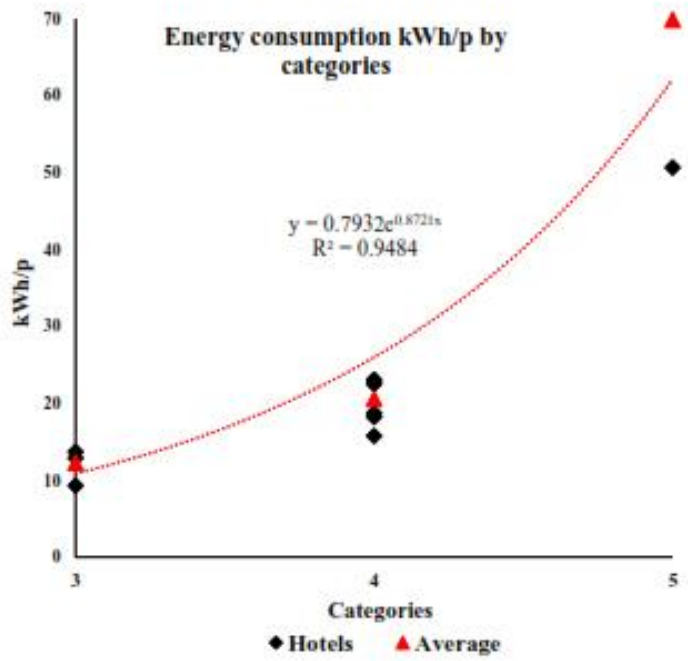


Fig. 2 Regression graph of average consumption of hotels by category

With the energy distribution and the specific energy consumption per night (kWh/p), according to each category of establishment and regardless of the consumption of the SWRO, the calculations of emissions and the carbon footprint of the overnight stays of tourists at hotels, for the scope 1, 2 and biomass (Díaz Martín et al. 2015), were carried out. The percentage of each of the fuels used in hotel energy consumption was calculated, and by multiplying the calculated energy corresponding to each fuel by its emission coefficient, for both the Canaries and mainland Spain. The sum of the emissions gave us the value of the total emission per stay, always without considering the consumption of the SWRO. The following Table 5 shows the calculations of CO_2 emissions for hotels in the Canary Islands and for equivalent hotels with the same consumption and characteristics in mainland Spain. Average emissions on the mainland, at 5.8 CO_2/p, are 55% lower than those of the hotels in the Canaries, with average emissions of 13.1 CO_2/p, considering the differences between hotels categories. We observe as the electricity represents 57.8% of the energy of hotels in the Canary Islands, but the emissions from it represent 83.6% of the total and in a hotel in mainland Spain with equivalent consumption, the emissions from electricity would represent 63.2%.

Table 4 Distribution of energy by category without considering private desalination plants SWRO

Energy	5* (%)	4* (%)	3* (%)	Total weighted average (%)
Electricity without SWRO	43.2	61.5	54.4	57.8
LPG propane	8.1	17.0	14.6	15.3
Diesel oil	48.7	7.7	21.7	15.8
Biomass		10.9		8.1
Thermal solar		3.0	9.2	3.0

Table 5 Distribution of energy emissions in $kgCO_2/p$ without SWRO in the Canaries and mainland Spain

GHG	Category	5*	4*	3*	Weighted average	Weighted average (%)
Scope 1	LPG propane	1.3	1.2	0.5	1.1	8.7
	Diesel oil	10.2	0.4	0.9	1.0	7.6
Scope 2	Electricity Canary	26.8	10.7	5.5	10.9	83.6
	Electricity Mainland	9.0	3.6	1.9	3.7	63.2
Other	Biomass		0.02		0.01	0.1
Weighted average kg CO_2 Canary		38.3	12.4	6.9	13.1	
Weighted average kg CO_2 Mainland		20.5	5.3	3.2	5.8	

For the energy consumption and emissions values, we made the regression calculation per stay was performed according to the category of the establishment and the zone (Canary Islands and mainland Spain), with the weighted average data of the different hotels and categories, for calculating the emissions per night. Both regression curves obtained follow an exponential model, which is show in Fig. 3, and it is possible to verify the characteristic curves of the emissions of the hotels in the study, proving the exponential increase is more pronounced in the hotels of the Canary Islands than in those of the mainland.

3.2 Carbon footprint of water

The carbon footprint of water is very important nowadays at any tourist destination, but it becomes more important in destinations that lack sufficient water resources, as is the case on the aridity islands of Lanzarote and Fuerteventura (Tejedor et al. 2013), where water for human consumption must be produced industrially through desalination plants. At these destinations, there are two production cases: through small desalination plants installed at the establishment's premises, which usually produce between 50 and 1000 m^3/day, and centralized facilities for multiple consumers, producing between 1500 and 67,000 m^3/day. According to data from 2013 (Suarez 2013), there are 319 desalination plants in the Canary Islands. In the study carried out, irrigation data have not been considered, since the water is from a different source, and may be desalinated water or reused water, which has other characteristics and applicable regulations (Spanish Ministry of the Presidence 2007), as well as coefficients of different emissions. The water consumption of hotels is calculated by means of the consumption per room, without considering the irrigation and swimming pool consumption. With the data from the various hotels and their occupancy rates, the weighted average consumption can be calculated, which gives us a value of about 296 L/p. Table 6 shows the weighted average values of water consumption per guest of hotels and weighted average by category.

The data for weighted average consumption per night are studied by means of a regression analysis, grouping the values by category and checking how the water consumption in hotels conforms to an exponential regression curve, where the values of the higher star hotels reveal a level of consumption 94% higher than those with a lower star rating. Figure 4 shows the regression graph of the average hotel data by category, as well as the trend

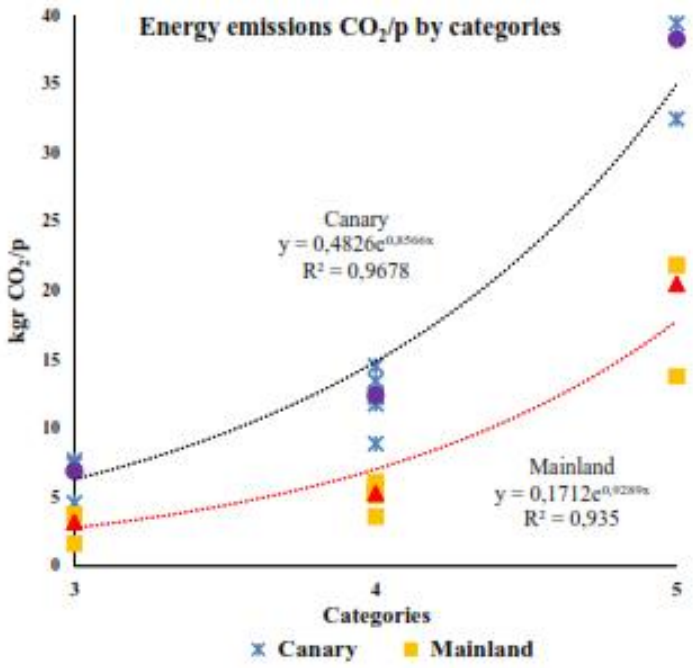


Fig. 3 Regression graph of average emissions by category for the Canary Islands and mainland Spain

curve of the same. A characteristic feature of the graph is that the consumption is so high within the sample of 5-star hotels, with relatively few accommodation places, whose total costs are influenced by the low occupancy rate and few places, causing the level of consumption to deviate greatly.

With the main data of consumption per guest already calculated, the study of the water emissions in hotel establishments can be carried out by category. The water for the complexes is provided either by private or external centralized SWRO. The private plants there are small and medium, and the consumption has ranges from 6.4 to 3.61 kWh/m^3,

Table 6 Average water consumption per night without considering irrigation water or swimming pools

Hotels	5*	4*	3*	Total
EPG	926.2			
ESH	449.6			
HPE		280.5		
HT		255.2		
ESA		365.6		
ECA		292.6		
HRP		296.7		
HTI		279.8		
MSL		239.0		
ECE			341.8	
ESJ			291.9	
PPC			154.6	
Weighted average	526.5	289.5	270.9	295.6

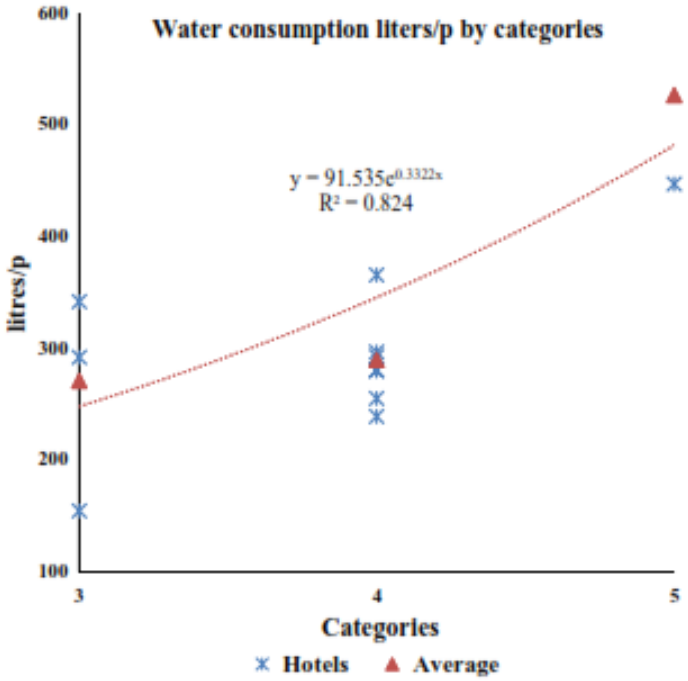


Fig. 4 Water consumption by category

which generates a weighted average calculation for the plants that we used in the study of 4.6 kWh/m^3. In the centralized plants for multiple users, consumption is highly variable giving average production values of 5.98–3.79 kWh/m^3 (Feo-García et al. 2016), and with an average value for the plants that we used in the study of 5.1 kWh/m^3. The main current problem of centralized water supply systems is losses in the supply and distribution network. For Fuerteventura, the losses are at 35.8% (Government of the Canary Islands 2014), and for Lanzarote losses are 42% (Government of the Canary Islands 2015). To carry out an emission calculation, the average of the losses for both islands would be 38.9%. Emission data are calculated by considering the emissions from electricity and with the emissions generated by water in the mainland, using the data from the emission factor of the water in the mainland, 0.788 kg CO_2/m^3 for water consumed, calculated by the government of Aragon (Spain) (General Direction of Environmental Quality and Climate Change DGCACC 2010). The following Table 7 shows the data for emissions, consumption and the losses for the various distribution and generation systems. The calculation of the emissions has taken into account the losses of the supply networks.

We calculate the emissions per night bearing in mind the weighted average costs of water per night according to the category of hotel. The different systems of water supply in the Canary Islands were compared with the supply in the Spanish mainland. Table 8 shows the per capita emissions data from producing water for human consumption, without taking into account the consumption of swimming pools and irrigation These data show that the emissions from the local desalination plants are 45% lower than the average emissions from a centralized desalination plant and emissions from the mainland are 9 times lower than the average for a centralized plant, corresponding to a figure for emissions of 88.7%, and about 5 times lower than the average for hotels' private desalination plants, which represents 79.6% lower emissions.

Table 7 Distillation emissions of distributed water, by generation and by geographical area

Type	Energy kWh/m^3	Lost network distribution (%)	CO_2 emissions kg CO_2/m^3
SWRO Hotel	4.6		3.855
SWRO Lanzarote	5.1	42.00	7.369
SWRO Fuerteventura	5.1	35.80	6.657
SWRO Central Average	5.1	38.90	6.995
Emissions mainland			0.788

Table 8 Water emissions in kgCO_2/p without irrigation and pools, by type of supply and category

Type	5*	4*	3*	Weighted average
SWRO Hotel	2.03	1.12	1.04	1.14
SWRO central average	3.68	2.03	1.90	2.07
Mainland	0.41	0.23	0.21	0.23
% Decrease in Mainland with respect to SWRO hotel				**79.6%**
% Decrease in Mainland with respect to SWRO central				**88.7%**

Once the average emissions of the different categories are calculated, the next step is to calculate the emissions of each hotel for the three models studied: in a hotel desalination plant, a central desalination plant, and if it were located on the mainland. By performing the regression calculations with the calculated emission values, we find that all curves have an exponential function, as is the case with energy. In Fig. 5, we can see the characteristic curves of the emissions of the hotels in the study.

3.3 Total carbon footprint of accommodation

Table 9 shows the summary of the emissions from the different establishments, the weighted averages by category, and of all the hotels. We note the significance of energy in the overall emissions of hotels, which represent, on weighted average, 92% of emissions from hotels with their own desalination plant, and 86% from hotels which use an external, centralized supplier. In the mainland, energy represents 96% of total emissions, as can be seen in Fig. 6 where you can also see the importance of energy in relation to water graphically. Comparing equivalent hotels in mainland Spain and the Canary Islands gives us a result for emissions of between 57 and 60% lower for overnight stays at hotels on the mainland than for hotels in the Canary Islands, depending on the water source.

With the calculated data of emissions, the regression calculation of the values of total emissions of the hotels and weighted averages by categories can be made. Figure 7 shows the result of the regression calculations applied, proving that the resulting function also corresponds to an exponential function, in all three models studied, which implies that the higher star-rated hotels are the biggest polluters and must be the focus of greater efforts

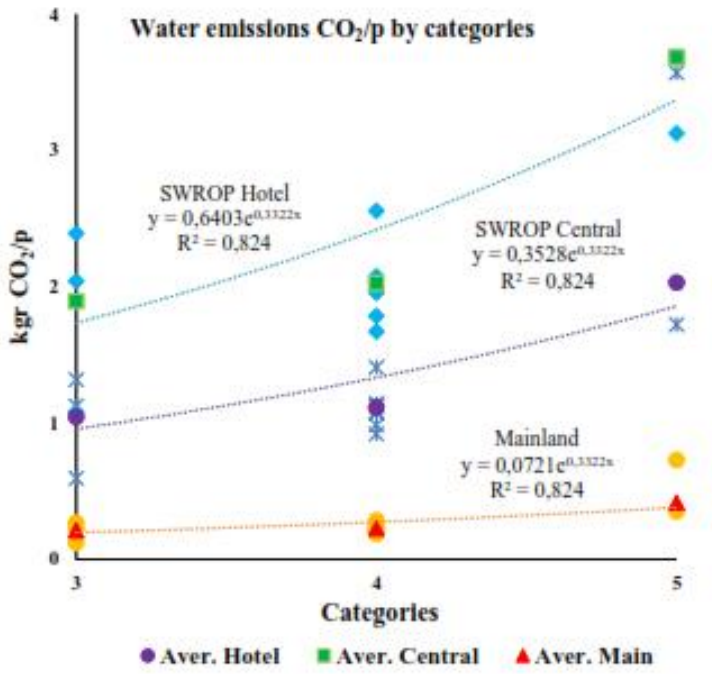


Fig. 5 Graph of regression calculations for water consumption by category

to achieve a higher level of efficiency in reducing consumption and emissions generated through the operation of these establishments.

Finally, the calculation of the total emissions of a hotel can be realized knowing the stays of clients and the category, and we can be calculated using the following calculation algorithms:

- Hotel Canaries with private SWRO: $\mathbf{E_{TTP} = (N_c \cdot (0.4826e^{0.8566 \times C} + 0.6403e^{0.3322 \times C}))}$
- Hotel Canaries supplied by centralized SWRO: $\mathbf{E_{TTex} = (N_c \cdot (0.4826e^{0.8566 \times C} + 0.3528\, e^{0.3322 \times C}))}$
- Hotel in mainland Spain: $\mathbf{E_{TTp} = (N_c \cdot (0.1712e^{0.9289 \times C} + 0.0721e^{0.3322 \times C}))}$

where "N_c" is the number of stays during the timeframe of the calculation, and "C" is the category of the establishment.

4 Conclusions

Considering future projections, it is necessary to act now to reduce CO_2 emissions, by increasing energy efficiency and reducing water and energy consumption in the establishments. For establishments to achieve successful conversion and reach a sustainable future, they need to experience a great reduction in energy and water consumption, with the realization of more efficient and sustainable installations.

It has been shown that the higher star-rated hotels have consumption levels and emissions triple those of lower star-rated ones, and five times that of the lowest. Emissions due to electricity consumption account for more than 83% of energy consumption emissions, while representing only 58% of the energy consumed, with the emission coefficients for

Table 9 Summary of hotel emissions

Type		Energy		Water			Total CO_2		
Hotel	Stars	Canary CO_2/p	Mainland CO_2/p	SWRO Hotel CO_2/p	SWRO Central CO_2/p	Mainland CO_2/p	SWRO Hotel CO_2/p	SWRO Central CO_2/p	Mainland CO_2/p
EPG	5	32.47	13.80	3.57	6.48	0.73	36.04	38.95	14.53
ESH	5	39.43	21.85	1.72	3.13	0.35	41.15	42.56	22.20
HPE	4	12.27	5.12	1.08	1.96	0.22	13.35	14.23	5.34
HT	4	14.56	6.14	0.98	1.79	0.20	15.54	16.35	6.34
ESA	4	12.39	5.28	1.41	2.56	0.29	13.80	14.94	5.57
ECA	4	11.76	5.27	1.13	2.05	0.23	12.89	13.81	5.50
HRP	4	12.53	5.42	1.14	2.08	0.23	13.67	14.61	5.65
HTI	4	13.44	5.75	1.08	1.96	0.22	14.52	15.40	5.97
MSL	4	8.89	3.60	0.92	1.67	0.19	9.81	10.56	3.79
ECE	3	7.39	3.66	1.32	2.39	0.27	8.71	9.79	3.93
ESJ	3	7.70	3.78	1.13	2.04	0.23	8.83	9.74	4.01
PPC	3	4.60	1.63	0.60	1.08	0.12	5.20	5.68	1.75
Weighted average 5*	5	38.27	20.51	2.03	3.68	0.41	40.30	41.96	20.92
Weighted average 4*	4	12.40	5.27	1.12	2.03	0.23	13.52	14.43	5.50
Weighted average 3*	3	6.90	3.24	1.04	1.90	0.21	7.94	8.80	3.45
Weighted average total		13.09	5.83	1.14	2.07	0.23	14.23	15.16	6.06

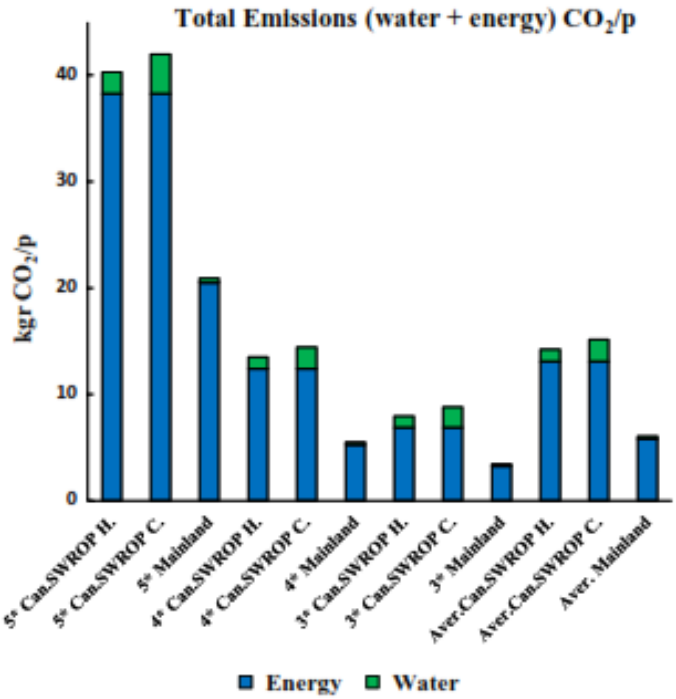


Fig. 6 Comparative graph of total energy and water emissions by type of desalination plant in the Canary Islands and on mainland Spain

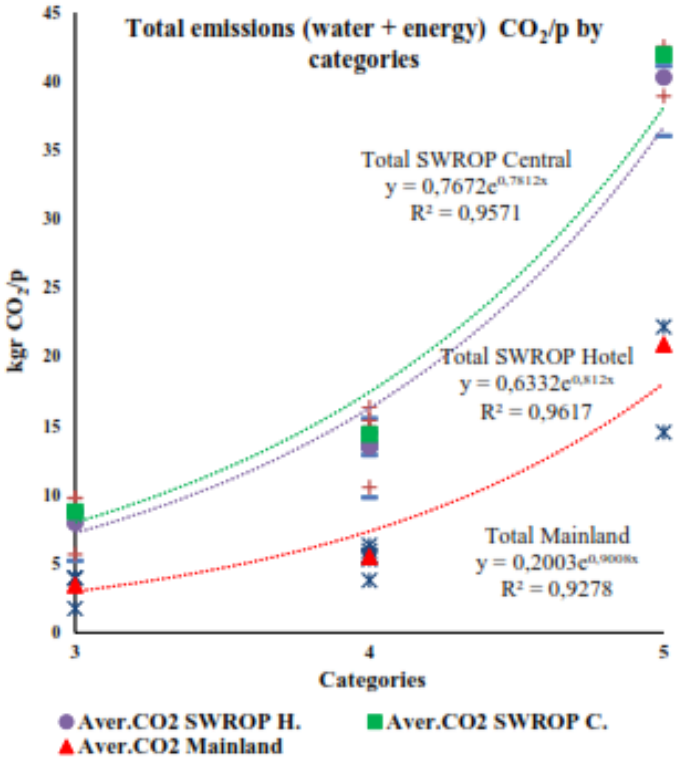


Fig. 7 Regression calculation graph for total hotel emissions by water source and geographic area, and by category

the Canary Islands being about three times higher than those for the mainland. The hotels must be converted, installing self-generating equipment to reduce electrical emissions and dependence on external suppliers. Although it is an effective current model to obtain drinking water, it is necessary to modernize the existing SWRO water desalination plants to reduce their consumption level and reduce the binomial water/energy that in the Canary Islands is united by the need to use energy to desalinate to get water. Through the use of renewable energy generation in the hotels themselves, through mini wind generators or photovoltaic solar plants can reduce emissions caused by the production of water for human consumption.

The Canary Islands, as a sensitive and vulnerable tourist destination, with their external energy dependence, their great ecological value, and their need for water desalination, make for a good laboratory to test the application of measures and improvements in the systems of industrial water generation, and in the conservation of energy in buildings. In this way, in future research, we must study the possibility and way to reduce the energy consumption of existing facilities to levels that could be considered zero energy buildings (ZEB) to nearly zero energy buildings (nZEB), through methods of reducing consumptions, increase in efficiency of systems and equipment, and the installation of electric generation plants based on renewable energies for own consumption in the establishments.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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4.5. Artículo 4. Energy and water consumption and carbon footprint in tourist pools supplied by desalination plants: case study, the Canary Islands

4.5.1. Resumen

En este artículo analizamos los consumos de agua producidos por una de las principales instalaciones de los establecimientos turísticos vacacionales, que son las piscinas turísticas, y como afecta este consumo a las necesidades de agua de los destinos, así como se realiza el cálculo de la huella del carbono que genera la producción de esta agua por métodos industriales. Mediante los datos de consumos de agua de 42 piscinas turísticas de 14 establecimientos turísticos de diferentes categorías del archipiélago de las islas Canarias, investigamos los gastos de las mismas mediante métodos de regresión simple y lineal multivariable respecto del volumen y la superficie de las piscinas, obteniendo la función característica que define el consumo de agua de las piscinas turísticas de Canarias, la cual es una función potencial de la variable del volumen de la piscina. Con la función de consumo obtenido y los datos oficiales de las características de todas las piscinas turísticas de la región que se obtuvieron del sistema nacional de control sanitario de piscinas, se calcularon las necesidades de agua para el conjunto de estas instalaciones en Canarias.

Teniendo en cuenta, que más del 90% del agua potable suministrada en Canarias procede de plantas desaladoras de agua de mar mediante osmosis inversa, se plantea la hipótesis de que todo el suministro se satisfaga mediante este tipo de instalaciones de generación y con dos modelos de suministro, con desaladoras locales en los propios establecimientos y mediante sistemas centralizados con distribución por las canalizaciones y redes de suministro actuales. Calculamos las necesidades energéticas y la huella del carbono de alcance 2, producida por la generación del agua necesaria para cubrir los consumos de todas las piscinas del archipiélago y comparamos ambos modelos de suministro. Comprobamos que la huella del carbono es un 28,16% superior mediante la producción centralizada y su posterior distribución, respecto de los sistemas con producción y distribución local, debido a las grandes pérdidas en las principales redes de suministro de las islas.

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Energy and Water Consumption and Carbon Footprint in Tourist Pools Supplied by Desalination Plants: Case Study, the Canary Islands

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ABSTRACT We analyze the consumption of water and energy produced by tourist swimming pools and how it affects the water needs of the destinations, as well as the carbon footprint generated by the production of this water by industrial methods. By means of the data of water consumption from 42 tourist swimming pools on the Canary Islands (Spain), we investigate the expenses associated with them by means of simple and multivariate linear regression methods, obtaining the characteristic function that defines the water and energy consumption. With the algorithm obtained and the data of all the tourist swimming pools in the region, the water needs for the collective whole of these facilities were calculated. Considering that more than 90% of the drinking water supplied in the islands comes from desalination plants using seawater reverse osmosis (SWRO), it is hypothesised that all supplies will be satisfied through these types of installation, calculating the energy requirements and the Scope 2 carbon footprint of generating the water needed to meet the requirements of all swimming pools. It can be observed that the carbon footprint is 28.16% higher through centralized production, compared with local production, due to large losses in the supply networks. The generation of the water necessary for tourist swimming pools through SWRO would represent between 0.089% and 0.114% of all emissions in the region, according to the type of supply, local or centralized, respectively—extremely significant values and equivalent to the biological treatment of all solid waste from the islands.

INDEX TERMS Canarian tourism, carbon footprint, emissions, energy, GHG, swimming pools, SWRO.

I. INTRODUCTION

The importance of tourism is increasing year on year and is currently ranked third as a global export category [1]. It has become an important pillar in job creation and local economic improvement [2]. The increase in tourism also brings with it higher energy and water requirements [3], due to the consumption of establishments and the need for the industrial generation of water through the desalination of sea water thanks to overexploitation of aquifers and climate change [4], which is reducing surface drinking water. The global projections for 2030 are double the number of tourists compared to 2015 [5], which will lead to a clear increase in energy and water supplies to tourist establishments to cope with this growth in tourism.

Global consumption of drinking water due to tourism is very difficult to quantify because of the lack of real data [6], but it has been estimated to represent 0.04% of total consumption of drinking water [7]. The consumption of drinking water in relation to the total of the region varies greatly according to the destinations and the geographical areas [8], the consumption per overnight stay also being different according to the type of hotel and the destination. Examples include 175 litres per overnight stay (L/p) in France [9], 1802 L/p in the Philippines [10], and between 300 and 850 L/p in various areas of the Mediterranean [11]. The impact of tourism on water consumption has also been studied in a number of areas, such as Hawaii [12], where the importance of the number of golf courses and resort pools over total consumption was verified,

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the Canary Islands (Spain) [13], [14], where water and energy consumption were modelled in hotels, Malta, where consumption from swimming pools and spas in establishments represents 38% of the total water costs of the island [15], and the island of Mallorca (Spain), where the significance of swimming pools in the water consumption of hotels was evidenced [16]. Carbon footprints and tourism emissions were also studied in several destinations - for example, the investigations carried out to verify the differences between tourism emissions and those of residents in Spain [17], to study the impact of tourism on the island of Menorca (Spain) [18], and also for the average of 58 luxury hotels in Taiwan [19] and several hotels in Britain [20] - showing us the variability of emissions according to destinations and establishments.

The consumption of water in swimming pools due to evaporation alone has been studied by multiple authors, through physical methods and adjustments of experimental correlations, obtaining the typical values of indoor and outdoor swimming pools. The form of the characteristic function of these studies is as follows:

$$T = (\alpha + \beta v)(P_w - P_a)$$

Where "T" is the evaporation rate per unit of water surface, "α" and "β" are the coefficients of the correlation, "v" the mean air velocity, "P_w" partial vapor pressure of the air saturated to the water temperature, and "P_a" partial vapor pressure of the air. These evaporative models have been extensively studied, the most widely-used function being the one proposed by Carrier [21] in 1918, which is recommended in the application books of the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) [22]. Other authors have also carried out investigations, considering other variables of calculation, such as the number of bathers in the swimming pool, which can increase consumption between 40% and 70% compared to one which is unoccupied and still [23], [24], depending on the type of surroundings of the swimming pool (e.g., if it is indoors) [25], or air velocity a combined with the number of users [26]. Shah also performed studies for indoor swimming pools, considering air density [27], as well as for all types of swimming pool vessels, obtaining different correlations according to their characteristics [28]. For outdoor swimming pools, losses due to solar heating have also been studied according to the irradiation of the geographical location [29]. Neuronal analysis methods have also been used for calculations of the evaporation of indoor pools [30].

All of these studies only calculate losses by evaporation, without taking into account the other losses suffered by swimming pools over the course of their operation, which, as estimated, in California (USA) [31] is extremely significant, evaporation being responsible for only 56% of the water refills, while the cleaning filters correspond to 23%, and various other losses the remaining 21%, proving the importance and necessity of carrying out studies that take into account all the water losses, and not just evaporation. The water demands of swimming pools with respect to the destination has also been studied for several regions, such as on the island of Mallorca (Spain) [32] and in Cape Town (South Africa) [33], [34], highlighting the importance of these facilities in the total consumption of drinking water in these regions, and the need to reduce it.

Based on the literature review of previous research, the need to carry out a study on the water consumption of tourist swimming pools is highlighted, taking into account not only losses due to evaporation, but also the whole set of losses that are generated by a swimming pool, such as those produced by filter cleaning, pipe and vessel losses, occupancy, maintenance, etc., the optimum form of calculation being by means of a statistical system with data from actual tourist pools in continuous operation. To carry out this research, the archipelago of the Canary Islands (Spain) located in the Atlantic Ocean [35] was chosen, where the tourism sector is the main driver of the economy, representing 31% of gross domestic product (GDP) and generating 36% of the employment on the islands [36]. 63% of the area of the archipelago has been declared a Biosphere Reserve by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) [37]. At this destination, tourist swimming pools are those in hotel establishments (hotels, apartment complexes, hostels etc.) and represent more than 57% of the total number of swimming pools on the islands, not counting those owned privately by individual homeowners. In addition, 43% of the surface area of the archipelago is considered as arid [37]. Therefore, it is necessary that most of the drinking water consumed is generated industrially in desalination plants using seawater reverse osmosis (SWRO) [39].

II. METHODOLOGY

To obtain the calculations for consumption, we collected the data from 42 tourist swimming pools on the archipelago, which was provided by the management of the establishments. The sample period varies from a minimum of 6 months to a maximum of 10 years, from 2007 to 2016. ***Table 1*** summarises the characteristics of the pools studied. The names of the establishments have been codified for data protection.

The research process was as follows:

1. Collection of data from the various pools in the study and official data on the total number of pools on the archipelago (except private).
2. Review, filter and verify that the study data is correct. Convert the values of recycled water per pool to monthly refill values of m^3/month and daily of m^3/day.
3. For each pool, calculate the daily weighted averages of water losses, with all the monthly data for each pool, and obtain a percentage of the volume of daily water refill with respect to the total volume of the pools. Calculate the weighted average percentage of consumption for all swimming pools studied in relation to the refill volume.
4. Calculate the multivariate linear and simple correlation regression functions for the volume and surface

TABLE 1. List of researched pools and their main features.

HOTEL	NAME	VOLUME m^3	SURFACE m^2	TYPE	PLACE
ECA	Grande	706	589	Cold	Outdoor
ECA	Clima	459	356	Cold	Outdoor
ECE	Infantil	20	30	Cold	Outdoor
EPG	Infantil	12	20	Cold	Outdoor
ESA	Grande	841	599	Cold	Outdoor
ESA	Clima	298	331	Heated	Outdoor
ESH	Grande	756	619	Cold	Outdoor
ESH	Clima Int	135	125	Heated	Indoor
ESJ	Infantil 1	8	10	Cold	Outdoor
ESJ	Infantil 3	8	10	Cold	Outdoor
ESJ	Grande 2	185	162	Cold	Outdoor
ESJ	Grande 1	300	195	Cold	Outdoor
EVE	Grande	90	77	Cold	Outdoor
HC	Infantil	14	30	Cold	Outdoor
HC	Grande	970	613	Cold	Outdoor
HC	Clima	220	157	Heated	Outdoor
HC	Clima Int	120	100	Heated	Indoor
HOS	Grande 1	350	250	Cold	Outdoor
HOS	Clima	215	171	Heated	Outdoor
HPE	Infantil	30	50	Cold	Outdoor
HPE	Grande	735	525	Cold	Outdoor
HPE	Clima Int	130	86	Heated	Indoor
HRP	Calimera	179	440	Cold	Outdoor
HRP	Cascada	262	215	Cold	Outdoor
HRP	Cocoloco	622	429	Cold	Outdoor
HTI	Redonda	385	590	Cold	Outdoor
HTI	Grande	450	450	Cold	Outdoor
ORM	Infantil 3	16	8	Cold	Outdoor
ORM	Infantil 4	16	8	Cold	Outdoor
ORM	Infantil 5	16	8	Cold	Outdoor
ORM	Infantil 7	16	8	Cold	Outdoor
ORM	Infantil 9	16	8	Cold	Outdoor
ORM	Infantil 1	77	280	Cold	Outdoor
ORM	Tobogan	115	105	Cold	Outdoor
ORM	Oasis3	187	262	Cold	Outdoor
ORM	Oasis4	187	262	Cold	Outdoor
ORM	Oasis 7	187	262	Cold	Outdoor
ORM	Oasis 9	187	262	Cold	Outdoor
ORM	Olas	668	540	Cold	Outdoor
ORM	Clima Reces	320	330	Heated	Outdoor
PPC	Infantil	32	80	Cold	Outdoor
PPC	Clima	185	137	Heated	Outdoor
TOTAL	42	10,725	9,789		

variables of the swimming pools, and for both combined. Check the model that best fits by the value of R^2 and the square root of the mean square error (=RMSE), as well as its possible autocorrelation.

5. With the regression algorithm of best fit obtained, the estimation of water consumption for all tourist swimming pools in the Canary Islands - daily, m^3/day and annually, m^3/year - is made.
6. Considering the energy consumption ratios for water production in kWh/m^3, calculated by means of the weighted average of the data from the SWRO plants of the islands, and considering the losses in the distribution system of the supply networks per island, we calculate the necessary energy consumptions in kWh to generate the value of all the water consumed in the supply of the tourist pools.
7. Calculate the carbon footprint of Scope 2 for the generation of the water required to cover the needs of the pools, considering the emission factor of electricity for the Canaries, in kgCO_2/kWh.
8. Conclusions of the research and future needs for the reduction of water and energy consumption.

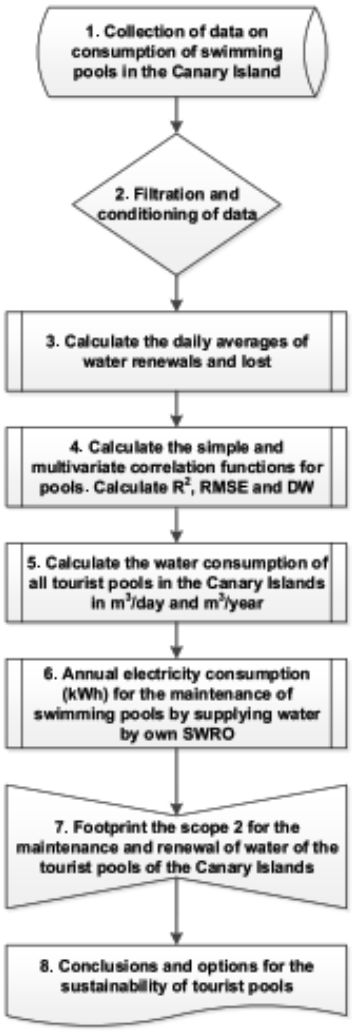


FIGURE 1. Research flowchart.

To calculate the CO_2 emissions of electricity, due to the change in the emission factors of the monthly electricity generated, the annual weighted average coefficient of the emissions from 2016 were used, this being the year chosen as the basis for the calculation of the kgCO_2/kWh of energy consumed - data supplied by Spanish Electric Network (REE) [40]. ***Figure 1*** shows the research flow for this study of water consumption and emissions in tourist swimming pools.

TABLE 2. Distribution of swimming pools in the Canary Islands by type.

POOL TYPE Volume > 5 m³			TOTAL POOLS	TOURIST POOLS	% TOURIST OVER TOTAL
Outdoor	Cold	Pools	2,089	1,039	49.7%
		Volume	529,671	267,281	50.5%
	Heated	Pools	1,073	812	75.7%
		Volume	318,790	212,889	66.8%
Indoor	Cold	Pools	8	0	0.0%
		Volume	831	0	0.0%
	Heated	Pools	147	39	26.5%
		Volume	45,093	4,120	9.1%
Total pools		**Pools**	**3,317**	**1,890**	**57.0%**
		Volume	**894,384**	**484,290**	**54.1%**

III. ANALYSIS OF DATA

In Spain, public and private swimming pools in communities must be authorised and registered by the National Swimming Pool Information System (SILOE) [41], which is the sanitation information system that collects all data on swimming pools and water quality. For the development of this research, the data from all the swimming pools in the autonomous region of the Canary Islands (Spain) has been obtained, showing a total of 3,565 swimming pools, of which only the swimming pools with volume greater than 5 m^3 are considered, given that those with a volume equal or inferior to this number have a negligible level of consumption to impact the total for this investigation. The total number of swimming pools larger than 5 m^3 is 3,317; a volume of stored water of 894,384 m^3. Within this number of swimming pools, we study only the ones belonging to tourist establishments, which represent 57% of the total, with 1,890 pools, and 54.1% of the volume of stored water, with a total of 484,290 m^3. In the following ***Table 2***, the distribution of swimming pools by type - climatized, cold, internal or external - appear.

A. CALCULATIONS OF WATER LOSSES

With the consumption data obtained from all swimming pools, once filtered and conditioned, the calculation of the weighted average consumption of each installation is performed, obtaining a value of water consumption per day in m^3, and in the daily percentage of water consumed from the total volume of the pool. With these values obtained, we performed the simple and multivariate linear regression calculations, regarding the volume and the surface of the pools, comparing the obtained values using the regression index R^2 of Karl Pearson [42] to justify their greater or lesser correlation [43], [44]. We compared the precision of the different regressions calculated by calculating the RMSE. To verify possible autocorrelation problems, we also performed the Durbin-Watson index (DW) [45]–[47]. The functions used are as follows:

$$DW = \frac{\sum_{t=2}^{T} (u_t - u_{t-1})^2}{\sum_{t=2}^{T} u_t^2}$$

$$RMSE = \left[\frac{1}{t} \sum_{i=1}^{t} (u_p - u_o)^2 \right]^{1/2}$$

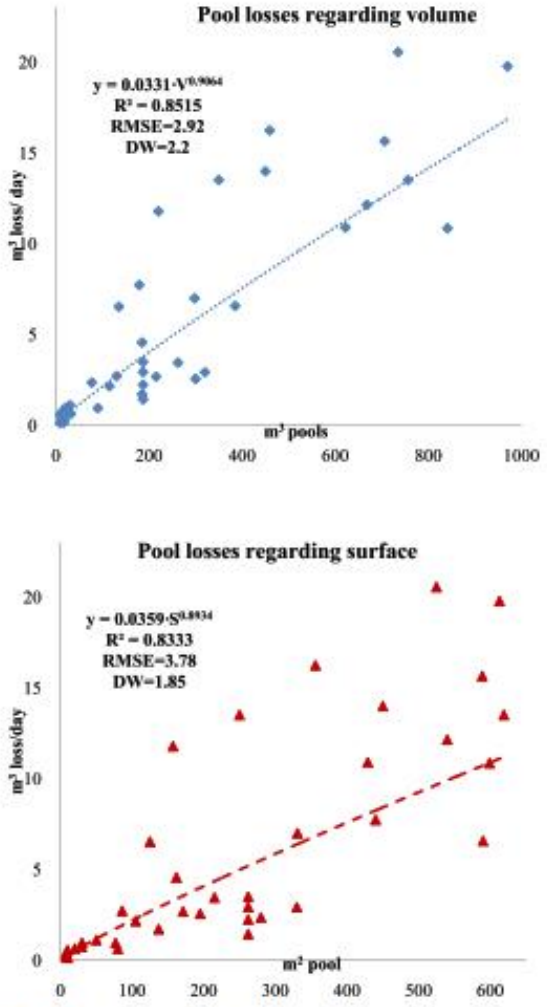


FIGURE 2. Simple regression trend line graphs.

Where "t" is the number of observations, "u" is the residuals of the estimates, the subscript "p" being the predicted residue and "o" the observed residue.

With the data obtained, the following simple regression graphs shown in ***Figure 2*** were generated, where the trend lines and distribution of the points of dispersion of the daily water losses are observed, with respect to the volume or surface area of the swimming pools. We observed how the volume is the main factor for the calculation of water consumption, with a potential characteristic function that is adjusted in 85.15% of cases with an RMSE value of 2.92, while the function of the surface is adjusted to 83.33% of the cases and with an RMSE value of 3.78 - this value being higher than that of the volume variable, which is rejected. Both DW statistics are close to 2, which implies that there is no problem of autocorrelation. It is important to note that in these total loss calculations, consumption is the sum of all possible losses, not only evaporation, which depends mainly on the surface exposure, but also on leaks in pipes and vessels,

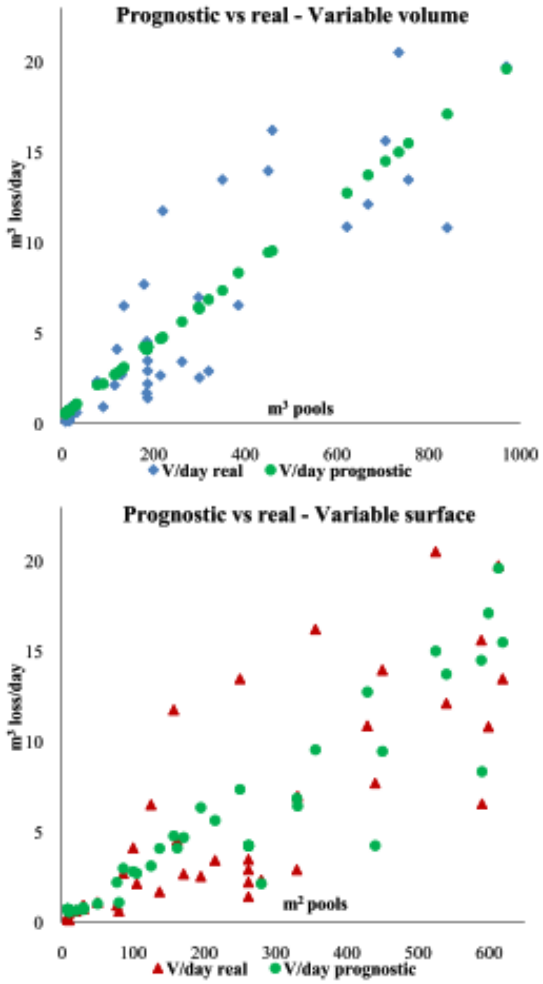


FIGURE 3. Multiple regression predictive graphs.

maintenance, filter cleaning, etc., which is why the volume of the pool and not the surface area is the determining factor in the total losses, as could be foreseen.

The multivariate linear regression calculations have given us some prognostic graphs with respect to the real values shown in ***Figure 3***, where the dispersion of the values is observed. The calculated correlation index R^2 has a value of 0.7730, which is lower than those calculated for the simple regression, while the RMSE value is 2.78. The value of the DW statistic is 2.33, which means that there is no autocorrelation problem there either. It can be verified in the graphs that the values predicted with the volume variable have a lower dispersion, while with the surface variable, they have a higher and more erratic dispersion, which does not fit with the observed levels of consumption in most of the cases.

Table 3 summarises the calculated values for the simple regressions of the linear, exponential and potential models, as well as for multivariate linear regression. We verified how the potential function with respect to the volume variable has higher correlation indexes than the rest, while the RMSE value is very close to the value of the linear function for the volume or the multivariate. However, we decided to use the potential for the greater percentage of values adjusted to this characteristic function. We took the characteristic algorithm of daily water consumption for the tourist swimming pools in the Canary Islands - the one defined by the simple regression potential with respect to the volume, as shown below:

$$P = 0.0331 \cdot V^{0.9064}$$

Where "P" represents total swimming pool losses in m^3/day, "V" represents the total volume of water in m^3.

The calculation of the estimated daily losses is done by means of the algorithm previously shown, from which, together with the pool data from the different islands, we obtain the water needs per island and the total of the archipelago. ***Table 4*** shows consumption by island, both daily and annually, where it is verified that the water requirements for the maintenance of the swimming pools are higher than 3.3 Hm^3 per year - with 66% of the consumption being for the islands of the province of Las Palmas and the remaining 34% for the islands of the province of Tenerife. It should be noted that the islands of Fuerteventura and Lanzarote, whose combined annual water needs for swimming pools total almost 1.2 Hm^3, currently come directly from SWRO desalination plants, since there are no surface or underground aquifers for use. With the data calculated, considering that the produced and billed drinking water in the Canaries for 2014 was 138.59 Hm^3 [39], and given that all the water was produced and supplied by external, centralised desalination, representing 2.39% of the total water produced, the need for an increase in current production is implied - in the case of wanting all production supplied through centralised SWRO.

B. CALCULATION OF ENERGY TO PRODUCE THE WATER

The drinking water consumed in the Canaries is generated mainly by the desalination of sea water, reaching 90.5% of the total supplied and billed for 2014 [39] - this percentage varying among the different islands of the archipelago. For the remaining irrigation or industrial supplies, groundwater and surface water are mainly used - although desalinated water is also used on islands lacking these resources. Due to the low refill rate of underground aquifers, which in recent years have suffered a decrease in natural reserves of 36.4% in Gran Canaria and 35.3% in Tenerife [48], this type of supply is also migrating towards desalination through SWRO.

To calculate the energy consumption of water production, we hypothesised that all water will be supplied by SWRO desalination plants, with two delivery models: centralized for multiple users through distribution through existing pipelines, and local desalination plants located in or near tourist establishments. To obtain this data, we considered the energy consumption of desalination plants according to the coefficient of generation in $kW_{consumed}/m^3_{generated}$, for which we have the values of several medium local plants with a production level of less than 500 m^3/day, and large

TABLE 3. Summary correlation index for daily losses in tourist swimming pools.

REGRESSION MODELS FOR ALL POOLS						
Type Regression	**Variables**	**Model**	**Calculated function**	**R^2**	**RMSE**	**DW**
Simple	**Volume (V)**	Lineal	$P = 0.0199V + 0.4275$	0.7740	2.78	2.31
		Exponential	$P = 0.8136 \cdot e^{0.0044V}$	0.6534	7.75	1.06
		Potential	$\mathbf{P = 0.0331 \cdot V^{0.9064}}$	**0.8515**	**2.92**	**2.20**
	Surface (S)	Lineal	$P = 0.0237S - 0.0164$	0.6546	3.44	2.35
		Exponential	$P = 0.6295 \cdot e^{0.0058S}$	0.7011	4.77	2.16
		Potential	$P = 0.0359 \cdot S^{0.8934}$	0.8333	3.78	1.85
Multivariate	**V, S**	Lineal	$P = 0.0192V + 0.0009S + 0.4277$	0.7730	2.78	2.33

TABLE 4. Daily and monthly consumption of water for Tourist swimming pools in the Canary Islands.

ISLAND	Pools	Pool volume m^3	Lost water pools m^3/day	Lost water pools m^3/year	% Lost water over total
Gran Canaria	662	139,395	2,667	973,349	29.4%
Fuerteventura	312	94,756	1,748	638,119	19.3%
Lanzarote	314	84,230	1,560	569,470	17.2%
Tenerife	519	143,888	2,678	977,292	29.5%
La Palma	49	16,390	298	108,834	3.3%
La Gomera	29	5,092	100	36,537	1.1%
El Hierro	5	538	11	4,101	0.1%
Total Canary Islands	**1,890**	**484,290**	**9,062**	**3,307,702**	

TABLE 5. Consumption and production plants SWRO.

NAME	kWh	m^3	kWh/m^3	m^3/day
PRO	29,882,434	7,795,324	3.83	21,299
GTA*	6,126,023	986,526	6.21	2,695
COR	3,600,157	1,173,025	3.07	3,205
Weighted average SWRO Large	**39,608,614**	**9,954,875**	**3.98**	**27,199**
HPE	342,168	78,853	4.34	215
HT	399,693	83,270	4.80	228
HRP	602,621	177,243	3.40	486
HTI	304,737	80,194	3.80	220
MSL*	434..15	85,199	5.10	233
Weighted average SWRO Medium	**2,083,734**	**504,759**	**4.13**	**1,382**

*They are SWRO plant that does not have energy recovery

centralised production plants greater than 2500 m^3/day [49]. With the generation data of the SWRO plants, we calculated the weighted average of all of them, obtaining the consumption ratios characteristic for each model of plant and type of supply. With these values obtained, they were used as a base for all desalination plants in the Canary Islands. In ***Table 5***, the calculation data of the various SWRO plants are shown. Plant data has been supplied by the managers of each facility; the names of each plant are coded for data protection. With the coefficients of energy consumption to produce water of the two types of SWRO plant, we calculate the values of the energy consumption necessary to supply the water to the swimming pools.

Table 6 summarises the calculations made, showing consumption by island, where the losses from the supply networks of each island were considered in the calculations of centralised plants; taking the official data for losses, the various hydrological plans approved for Fuerteventura [50], Lanzarote [51], Gran Canaria [52], Tenerife [53], La Gomera [54], La Palma [55], and El Hierro [56]. We can verify that production at local desalination plants compared to the centralised ones - not taking into account losses within the supply network - is 3.6% higher. However, considering the losses within the supply network, consumption from the centralised plants is 28,16% higher than from the local plants.

C. CALCULATIONS OF CO_2 EMISSIONS

To carry out the calculation of the carbon footprint of the water production, the GHG Protocol [57] was chosen from within the multiple existing procedures and standards [58], this model being the most widely-used by organisations worldwide. In the GHG protocol, three Scopes are distinguished for the carbon footprint, of which we will only calculate in Scope 2 - that is due to the indirect emissions of GHG associated with electricity, for which we need the emission coefficient of the electrical energy consumption ($kgCO_2/kWh$) for the islands, once we have the total energy consumption.

The archipelago of the Canary Islands, among its peculiarities, has a very important one, which is the configuration of its electrical system, constituted as it is of six independent subsystems, one per island - minus the islands of Fuerteventura and Lanzarote, which are interconnected by submarine cables [40]. This uniqueness means that electricity production systems cannot take advantage of the economy of scale to vary and adjust the load between the different generating systems, and they must have a greater capacity of generation to be able to cover all the possible variations of load. In addition, the current production technology in the Canary

TABLE 6. Distribution of energy consumption by island to produce water through SWROP.

ISLAND	% Lost water distribution	kWh Central SWRO with lost distribution	kWh Local SWRO	% Local SWRO consumption over central
Gran Canaria	23.0%	4,764,931	4,019,930	-18.53%
Fuerteventura	35.8%	3,448,932	2,635,432	-30.87%
Lanzarote	42.0%	3,218,417	2,351,911	-36.84%
Tenerife	35.0%	5,250,992	4,036,217	-30.10%
La Palma	43.0%	619,420	449,486	-37.81%
La Gomera	24.0%	180,319	150,899	-19.50%
El Hierro	48.7%	24,268	16,935	-43.30%
Total Canary Islands		**17 507 278**	**13 660 811**	**-28 16%**

Islands is based on non-renewable fossil fuels, which produce 92.1% of the total energy [59], generating a large external energy dependence, and very high average CO_2 emission coefficients of 0.777 kg CO_2/kWh. Considering the emission factors and the total emissions generated at the generation points, the calculation for the point of consumption - which in these cases are SWRO desalination plants, either centralised or local - must be considered to explain losses in the electrical grid, which in Spain are legislated for [60]. 6% are considered for medium voltage supplies with local transformers, leaving us an emission value for Canarian electricity of 0.824 kg CO_2/kWh consumed.

The characteristic algorithm that defines the daily emissions of the tourist swimming pools in the Canary Islands is represented by the following function:

$$Ew = \frac{0.0331 \cdot V^{0.9064} \cdot Ee \cdot Ws}{1 - Lc}$$

Where "E_w" represents emissions associated with swimming pools in kg CO_2, "V" is the total volume of water in the pool in m^3, "E_e" is the value of the emissions from electricity in kg CO_2/kWh, "W_S" is the characteristic value coefficient of generation in $kWh_{consumed}/m^3_{generated}$, and "$L_c$" is the losses in the pipelines of the water supply network.

With the previously calculated data of the necessary electrical energy and the emission coefficient, we can already calculate Scope 2 and check the carbon footprint of the water used for swimming pools. ***Table 7*** below summarises the calculations of the total island emissions computations for centralised SWRO, considering the losses of the water supply network and for local SWRO. The great difference between emissions from local and centralised desalination plants is observed, with the reason being that the losses in the supply networks have very high values. ***Figure 4*** shows the emissions by island, depending on the type of desalination system used, as well as the percentage difference of emissions between the centralised or local models, the smaller islands being those which have greater differences, since their networks of distribution are older and often obsolete, with higher water losses.

Taking into account the hypothesis presented, where all the water for tourist swimming pools is generated by SWRO desalination plants, and with the current data of generation and emissions of electricity, the electrical consumption

TABLE 7. Distribution of CO_2 emissions by islands for centralized or local desalination SWRO.

ISLAND	kg CO_2 Local SWRO	kg CO_2 Centralized SWRO
Gran Canaria	3,312,423	3,926,304
Fuerteventura	2,171,596	2,841,920
Lanzarote	1,937,975	2,651,975
Tenerife	3,325,843	4,326,817
La Palma	370,377	510,402
La Gomera	124,341	148,583
El Hierro	13,955	19,997
Total Canary Islands	**11,256,508**	**14,425,997**

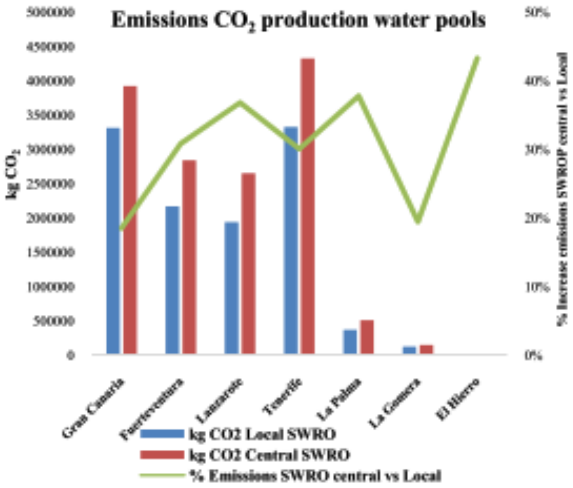


FIGURE 4. Distribution of CO_2 emissions by islands.

necessary for the generation of water for the maintenance of swimming pools would represent 0.156% of the annual electricity generation for local desalination plants; 0.2% over the total for the centralised desalination plants, according to data from the year 2016 [40]. The emissions produced by SWRO for the generation of swimming pool water would be of great importance within the total CO_2 emissions of the Canary Islands [61], [62], as it would account for 0.089% of total emissions for local desalination plants and 0.114% for centralised desalination plants, which are very important values, being higher than the equivalent to emissions due to

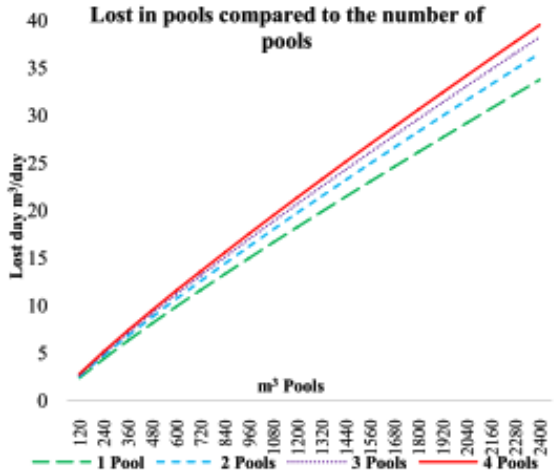


FIGURE 5. Lost in pools at equal volume according to number of pools.

the treatment and elimination of all solid waste by biological treatments in the Canaries. With these results, the importance of reducing water costs in swimming pools and increasing the percentage of electricity generation by means of renewable energies is verified, which would help to achieve a considerable reduction in the emissions that are due to the production of water for the maintenance of the tourist swimming pools in the Canary Islands.

IV. DISCUSSION

Swimming pools are an important, and almost essential, facility in current tourist establishments, so that the number of them and the water consumption due to their maintenance will continue to increase in the future, motivated by the ongoing, continuous growth in tourism.

It has been shown that the function that best defines consumption in swimming pools is a potential function, depending on the volume, due to the sum total of consumptions due to evaporation, filter cleaning and various other losses, which are defined by the following function:

$$P = 0.0331 \cdot V^{0.9064}$$

With this data, it is possible to verify the importance of the construction methods used in swimming pools, and the need to reduce the number of pools per establishment, as well as to group existing ones in a single vessel, since the consumption of several isolated pools is superior to a single one of the same total volume equivalent, average consumption being 4.28% higher for each pool than for a single, large one, as shown in ***Figure 5***, which shows the water losses of a swimming pool, and the equivalent of dividing the total volume of this into several smaller swimming pools.

The water consumed by the swimming pools in the Canary Islands must be obtained through industrial production, since they cannot count on the underground or surface resources, which cannot be maintained in time due to the insufficient refill rates of the aquifers, the SWRO desalination system being the chosen one. The alternatives proposed are through local desalination plants, which will be applicable to installations whose proximity to the sea makes it possible to install them, since energy consumption and emissions are 28.16% lower than for centralised plants, due to losses in the supply network, which vary according to the islands. It is also necessary to modernise existing plants by replacing membranes or installing energy recuperators, which can reduce the energy consumption of plants by up to 41%.

The emissions due to water production are also very substantial, considering that the emission factors of the Canary Islands are very high because of the lack of generation by means of renewable energies. It is therefore necessary to obtain a water/energy binomial based on sources of clean primary energy to reduce the carbon footprint of tourist swimming pools, which would represent up to 0.114% of the entire carbon footprint for centralised desalination plants in the Canary Islands.

Summarising the actions needed to achieve these energy and emissions decreases for tourist swimming pools, considering that they are facilities belonging to tourist establishments which need to be transformed into zero - or nearly zero - energy buildings (ZEB, nZEB), they can be classified in the following way:

- External or indirect improvements: the establishment cannot act directly, but, rather, they can influence the energy consumption and the global carbon footprint of the area and of the establishment itself:
  - Repairs, decreasing water losses in pipelines and supply networks.
  - Increase production through clean and renewable energies of the electrical supplies of the islands.
  - Modernisation of desalination plants to increase their efficiency.
  - Decentralise water production through small SWRO plants with reduced distribution lines to fewer clients.
- Internal or direct improvements: to be carried out by the establishments, directly influencing their energy consumption and carbon footprint.
  - Reduction in the total volumes of the tourist swimming pools by limiting the depth and reducing the total surface area, but without affecting the comfort of the client.
  - Group several swimming pools into one of equal or lesser total volume.
  - Produce the water through high efficiency SWRO desalination plants, located on the establishments' own premises.
  - Use renewable sources to produce the energy needed to generate the water.
  - Substitution of the type of pool water, changing the potable water currently used for salt water by means of water pumping from wells of marine infiltrations.

- The implementation of policies and models to reduce water consumption by utilising appropriate technologies that reduce losses through evaporation, frequency of filter cleaning, and other causes and practises within the establishments.

In future research, the importance of losses due to evaporation, cleaning and other causes, and emission reduction systems through alternative desalination and water generation technologies must be studied.

V. CONCLUSIONS

The impact of tourism on greenhouse gas emissions, focused on a specific aspect of water use, has been determined through the indirect analysis of water management in hotel swimming pools. It is concluded that water consumption associated with swimming pools is in function of power usage, depending on the volume.

The emissions due to energy to produce the water necessary for maintaining swimming pools are significant in the Canary Islands, where the generation of energy depends almost exclusively on fossil fuels. In addition, hotels located along the coastline near the sea have the possibility of installing local desalination plants with energy consumption and emissions lower than centralised plants. The annual emissions associated with swimming pools, according to their volume, are estimated to be 3.4 $kgCO_2/m^3$ in local desalination systems, and 4.36 $kgCO_2/m^3$ in centralised desalination systems.

In areas with limited water resources, high external energy dependence, and fragile ecosystems - as is the case with the archipelago of the Canary Islands - this study on the maintenance of tourist swimming pools contributes to sustainable tourism planning for the environment.

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He is currently involved in several EEC projects on climate change, energy, and immigration.

* * *

4.6. Artículo 5. Estimation of solar radiation of clear sky using non-linear methods. Case study: Fuerteventura (Spain)

4.6.1. Resumen

En los últimos años la energía solar fotovoltaica ha conseguido mucho protagonismo como productora de energía eléctrica para la venta y el autoconsumo así como por su faceta medioambiental como reductor de gases de efecto invernadero (GEI). Esto hace necesario, que se puedan realizar predicciones de producción lo más ajustadas posibles a la realidad y de esta forma, poder evaluar su viabilidad económica y las mejoras medioambientales conseguidas por la reducción de emisiones. En este artículo analizamos un método de cálculo de la irradiación incidente basado en la estimación de la misma en un área geográfica sin datos conocidos o fiables, mediante la producción de energía eléctrica generada por instalaciones solares fotovoltaicas conocidas y en uso, que estén instalados en la zona geográfica de estudio. Con los datos de varios años de tres instalaciones con características iguales de inclinación, modelo de paneles solares fotovoltaicos, y área geográfica de instalación, se realizan los cálculos mensuales de irradiación basados en los datos de producción total eléctrica mensual. Se realiza un estudio matemático de los mismos, utilizando el modelo ARIMA, también conocido como Box-Jenkins, con el programa de cálculo matemático SPSS Statistics, así como también se realizó el estudio utilizando el modelo de descomposición de series de Fourier. En ambos modelos se han obtenido las funciones características de irradiación para la zona geográfica de estudio.

Se realiza la verificación de la validez de los métodos mostrados para ambos modelos de predicción de irradiación mediate una comparación de los errores de pronóstico con los indicadores de error de la raíz cuadrada de la media (RMSE), del error porcentual absoluto medio (MAPE) y del índice del coeficiente de regresión R^2. Se ha demuestra la validez del método expuesto para ambos modelos matemáticos de predicción de irradiación y comprobamos que los mejores resultados se obtienen para el modelo de descomposición de Fourier.

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Estimation of Solar Radiation of Clear Sky using Non- Linear Methods Case Study: Fuerteventura (Spain)

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Abstract

The knowledge of irradiation in a geographical area is very important for multiple areas for the development of the area. Current calculation systems are based on statistical models of measurements of ground stations, or by external radiation calculations by satellite models. In this paper we show another method of calculation, based on the estimation of the incident radiation in a geographical area, through the production of electric energy generated by known photovoltaic solar installations. With the data of several years of three installations with equal inclination, model of solar panels, and in the same geographical area, the island of Fuerteventura, in the Canary Islands (Spain), we perform monthly irradiation calculations based on the total production of each month. With the calculated irradiation data, we performed a statistical study of them, using the ARIMA model with the SPSS Statistics software and we also carried out the study using a Fourier series decomposition model. With the two models, we made a comparison by measuring the forecast errors with the indicators of the root-mean-square error (RMSE) the mean absolute percentage error (MAPE) and its regression coefficient R^2. We verify the validity of the method shown for both statistical models of irradiation prediction and verify that the best results are obtained for the Fourier decomposition model.

Keywords: solar energy, irradiation, ARIMA, Fourier.

INTRODUCTION

The calculations of the global irradiation on the terrestrial surface become indispensable for multiple human activities, being the current one that more boom is taking, the one based on the applications of solar photovoltaic generation, for which the knowledge of the radiation is essential. The studies are multiple to be able to calculate the function that can represent the radiation in a geographical place. From the first expressions of regression treated by Angström in 1924 **[1]** that relates the average daily solar radiation per day for clear days and the radiation for a given place by the average of the fraction of the hours of measured solar brightness and the theoretical duration of the day, which later they were modified by multiple investigators which are summarized in the work of Bakirci **[2]**, where the different models of this type, are shown and which covers the study of the 60 different models based on the Angström original. The most widespread calculation systems are the statistics by measuring the irradiation in different areas, which have been generated Atlas of radiation for specific geographical areas **[3,4,5]**. Through statistical calculations, different irradiation studies have been carried out in the Canary Islands **[6]**, for the main irradiation databases in Turkey **[7]**, Tibet **[8]**, India **[9]** and many other countries **[10,11]**, the validity of their calculations has been verified. The realization of these studies has the problem of the high cost of measuring equipment and the large amount of data needed to be able to make forecasts and estimates with a certain validity, which according to the studies of Festa and Ratto **[12]** should be a minimum of 25 years for the case of hourly calculations, this is the reason why these studies become very complicated in many geographical areas.

The meteorological factors, like temperature and rainfall must also be considered in the estimates of solar radiation **[13,14]**. On the way through the atmosphere, solar radiation interacts with atmospheric constituents such as molecules, ozone, water vapor, aerosols, and cloud particles, which attenuate solar radiation by absorption or dispersion **[15]**. The distribution of cloud particles and aerosols can be difficult to predict with a high degree of accuracy, and cloud particles especially can reflect a large fraction of incoming solar radiation. Different approaches have been used to predict the radiation of the solar surface, depending on the time scale of the prognosis. Used cloud motion vectors derived from consecutive satellite

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imagery to forecast very short-range solar radiation (30 minutes to 2 hours). At forecast intervals of more than 6 hours, numerical weather prediction models (NWP) have been found to be superior to other alternatives. Apparently, the complete coherent system of equations describing the evolution of the atmosphere is necessary for these longer forecast ranges **[16,17].**

Estimates of global irradiation estimation, considering direct and diffuse irradiation **[18,19,20]** and the other methods discussed, become very complicated to have data from all the locations that are necessary, due to their associated expenses and the amount of data needed. Complexity of the commented systems, requires a simple and efficient model that can be adapted to multiple geographical areas, and taking into account that currently photovoltaic solar installations have a large expansion in many geographical areas, taking into account the monthly generation of the same in a space of several years we can calculate a real approximation of the irradiation of the area, and whose model of easy development can be applied to any geographical area that have data of the production of the photovoltaic installation and the type of solar modules installed.

METHODOLOGY

To calculate the irradiation, it is necessary to know the angle of incidence of sunlight, due to its movement of translation around the sun of the Earth and the decline of the axis of rotation, produces a difference in the incidence of solar radiation with respect to the reference latitude, and for the calculations of this angle we use the well-known Cooper equation **[21]**, which gives the value of the approximate decline of the reference point at solar noon of the day considered

$$\delta(n) = 23,45 * sen\left[360 * \left(\frac{284 + n}{365}\right)\right]$$

"n" is the chosen day counting from January 1 to the day in question.

We can also use calculation tables to estimate the values according to the latitude and angle of the collectors or calculating the values of the three components of direct, diffuse and albedo radiation must be found, with several methods for obtaining and estimating them **[22,23,24]**. There are multiple irradiation databases **[25,26,27,28]**, for convert the values irradiation at 10º to 0º for our model of approximation, we obtain the calculation factor "k" that passes the irradiation of the 10º of the study stations to 0º , for what we use the global irradiance values of the European PVGIS - Helioclim data **[29,30]**, as starting data to 10º and 0º, where the multiplying factor of the irradiance value is obtained for flat surfaces, and will give us the approximate result for the inclined surfaces **[31],**

$$G(\beta) = k * G(0^{o})$$

Where "k" is the multiplying factor for the irradiation of surface inclined to flat surface 0º is the latitude of the place, and "G (0°)" is the irradiance value for flat surfaces at 0°.

To obtain the calculations for generation, we collected the data from 3 photovoltaic generation facilities, which was provided by the management of the establishments. The sample period varies from a minimum of 3 years to a maximum of 5 years. ***Table 1*** summarises the characteristics of the facilities studied. The names of the establishments have been codified for data protection.

Table 1: List of researched facilities and their main features.

Name	Latitude	Longitude	Mark	Peak power W	Tilt angle
FEM	28º25´53"	13º52´28"	SolarWorld	88.000	10º
INP	28º31´26"	13º50´18"	SolarWorld	441.600	10º
HIE	28º31´32"	13º50´25"	SolarWorld	552.000	10º

Monthly irradiation calculation

To calculate the irradiation of the installations, we start with the monthly electric generation of the generating station, it is necessary to consider the electricity generated monthly, the peak power of the generator and the total losses, which are included in a total efficiency index known as "Performance ratio" (PR) **[32]**. With the following function we calculate the global monthly irradiation that affects the installation.

$$G(\beta, \mu) = \frac{E_{red}}{PR * P_{pp}}$$

"G (β, μ)" is the mean irradiance according to declination and a given azimuth, "PR" is the global loss index that encompasses all losses of the system, and "Ppp" is the maximum power of photovoltaic generators. The calculation of the PR is made considering all the losses of the generating system, which are given by the function:

$$PR = (1 - (L_T + L_D + L_R + L_p)) * L_E * L_{In} * L_V$$

Where, "L_T" are the losses by temperature that we calculate them by the method of Otherworld **[33]**, "L_D" are the losses by dispersion of parameters, "L_R" are losses by angular and spectral reflectance , "L_r" are losses due to dust on the modules, "L_E" are losses in electrical wiring, "L_{IN}" are losses due to the efficiency of the inverter, what we used the European efficiency value of the inverter **[34]** given by the manufacturer and "L_V" are other losses that were not previously considered. **Table 2** shows the data of the calculation parameters for the coefficients of the different losses.

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Table 2: List of coefficients of the different losses.

Name	Description	Value
L_T	Temperature losses	Calculate
L_D	Lost by dispersion	3,00%
L_P	Lost dust and dirt	2,00%
L_R	Lost reflectance	3,00%
L_{in}	European Investor Efficiency	96%
L_E	AC and DC circuit efficiency	97%
L_V	Efficiency due to other losses	95%

Arima

The ARIMA methodology aims to extract the regularities observed in the past behaviour of the variable, and if the structural conditions that make up the series remain constant, predict its behaviour in the future. This model is known as Box - Jenkins for being its creators **[35,36]**. It is widely used for economic series analysis, as well as in hydrology, medicine, and meteorology, although the field in which the ARIMA methodology finds its main role for prediction purposes is with short-term prediction and in series with a seasonal component. The theory of stochastic processes, the ARIMA processes, provides a general methodology for the analysis of a single variable in the series that shows a clear dependence between present and past values.

The generic name ARIMA derives from its three components: Self-regressive (AR), Integrated (I), of Mobile Averages (MA). The ARIMA model presents an explicit equation that allows us to describe an observation from the series as a linear function of previous data and errors due to chance, which may also include a cyclical or seasonal component which describes each of the components that can be part of the model, as well as the notation usually used to describe them, which will be used in this study. The general function **[37,38]** represented by the ARIMA model (p,d,q) is as follows:

$$\emptyset(\boldsymbol{\beta})(\mathbf{1}-\boldsymbol{\beta})^{\boldsymbol{d}}\boldsymbol{Xt}=\boldsymbol{c}+\boldsymbol{\theta}(\boldsymbol{\beta})\boldsymbol{\varepsilon t}$$

where "Xt" is the study variable, "c" a constant and "εt" is the error or residue term, which follows a normal distribution of zero mean and constant variance. The term $(1-\beta)^d$ is applied to the original series to make it stationary, and "d" corresponds to the order of part I of the ARIMA model. Ø(β) and θ(β) are polynomials of order p and q that depend on the delay operator "B".

We have used to calculate the mathematical software of IBM SPSS Statistics **[39]**, calculating the different factors through the expert model and through the Box-Jenxisn methodology of three steps that is extended to 6 by later studies **[40]** to be able to estimate the corresponding parameters of the model. 1 Data collection of the series, 2 Analysis of the stationarity and possible transformation of the series, 3 Identification of the model, 4 Estimation of model coefficients, 5 Validation and selection of the model and 6 Prediction.

Fourier

The Fourier transform is the mathematical procedure to analyze periodic functions through the decomposition of said function in an infinite sum of much simpler sinusoidal functions, with combination of sines and cosines with whole frequencies **[41,42]**. The function initially defined at time f(t) is the transform to the domain of the frequency F(w). This new function F(w) is called the Fourier Transform **[43]**, or Fourier Series, when the function is Periodic. Fourier determined that it was possible to express a function as the sum of Sines and Cosines signal of different frequencies and amplitudes until the original function was determined. This procedure was initially implemented for periodic functions, but can be extended to non-periodic. Fourier showed that virtually any periodic function can be represented as a sum of sines and cosines by assigning each a weighting coefficient.

The harmonic analysis is a type of analysis of any function, continuous within a range, can be represented by an infinite series of sine and cosine functions. This series is called the Fourier series, and the method of finding Fourier analysis functions. If there is only a finite number of points in the interval to be analysed, a finite number of sines and cosines will be able to account for all observations. This technique is adequate for investigating the harmonics of an identifiable frequency under the assumption that the time series is genuinely periodic. Each harmonic can (but need not) have a different physical meaning. Recall that if f (x) is infinitely differentiable at x = a, then the Taylor series **[44,45]** of "f" is defined as:

$$e^{x}=1+x+\frac{x^{2}}{2}+\frac{x^{3}}{6}+\frac{x}{24}^{4}$$

we have a "representation" of the function "f". We know from experience that representations of the Taylor series are useful in many ways. In the same way, there are other types of representations which are very useful. In this work we are concerned, specifically, with the representation of the periodic function by trigonometric series of the form:

$$Y_t=\frac{a_0}{2}-\sum_{K=1}^{k-1}A_n\cos\left(\frac{2\pi t}{T}\right)-B_n sen\left(\frac{2\pi t}{T}\right)$$

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Harmonic analysis means the computation of the coefficients "A_n" and "B_n". Now, with the coefficients computed according to equation is called the Fourier series of "f"; the coefficients A_0, A_1, …. , A_n, and B_0, B_1, …. , B_n are called the Fourier coefficients off, and the individual terms are generally referred to as harmonic. Since the data are typically taken at integer times $t_j = t_0, t_1, t_{N-1}$, a discrete version of the Fourier transform must be considered. The easiest case to treat, and the only one we will consider, is the case of equal time samples N, $T_j = j_{\Delta t}$ $j = 0,1,2, .. N - 1$.

Here Δt is the time between two neighbouring data points in the time series and $fs = 1/\Delta t$ is the sampling frequency - the number of samples taken per second. The discrete-time Fourier transform (DTFT) for a data set of discrete time of finite length's (0), X (Δt), X ($2\Delta t$), ..., X ((N-1) Δt).

Analogous to the series, the Fourier transform decomposes the signal into sines and cosines of different frequencies and amplitudes. Fourier showed that virtually any periodic function can be represented as a sum of sines and cosines by assigning each a weighting coefficient.

Methods

The method used to compare the real data and calculate the characteristic feature of irradiation according to the electrical energy generated by the photovoltaic generating stations is:

1. Initially the data of electric power generation of the different production plants of the study plants supplied by the facilities' managers were obtained.
2. We calculate the irradiance value of the generating plants, according to the monthly generation obtained. The calculated irradiation values are for the inclination of the solar panels of 10º.
3. We convert the irradiance value of the inclined surface from 10º to flat surface according to the calculated factor "k" of the solar DB, for all the stations.
4. With the monthly irradiation data, we calculate the characteristic function of the forecast with the ARIMA method and by the Fourier series decomposition
5. We compare the data obtained and compare it with the real values of the stations to check which system is best adjusted considering the term of RMSE, MAPE and R^2.

Figure 1 shows the flow diagram of the research carried out to obtain the actual irradiation data of the installations and their comparison with the data of the different photovoltaic generating stations.

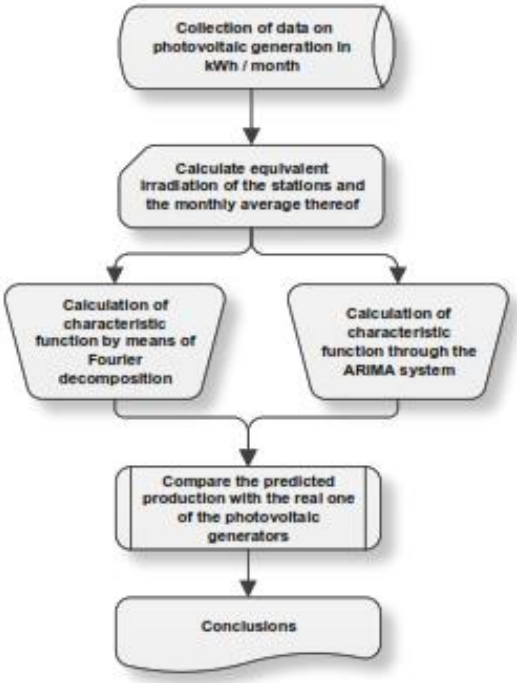


Figure 1: Research Flow Diagram.

ANALYSIS DATA

We take the values of the energy data produced from the different generating photovoltaic stations, with all the monthly production values of 3 and 5 years according to the generating station. With the obtained values, the transformation is carried out to calculate the irradiation of the different years and stations, filtering the values due to the failure of the measurements or the maintenance of the facilities. With the step coefficients "k" obtained from the PVGIS - Helioclim irradiation DB, the irradiation values for the inclined surface of the photovoltaic solar panels are calculated from 10 ° to the flat surface of 0 °. These values are shown in the following ***Figure 2***, which shows the irradiation calculated by months for flat surfaces of 0º.

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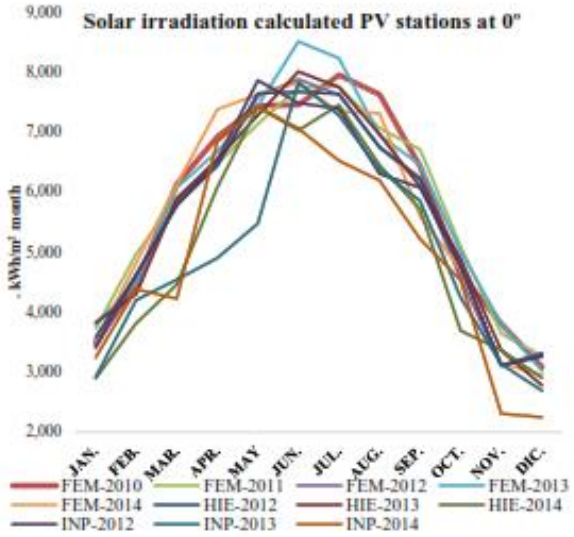


Figure 2: Solar irradiation calculated for 0°.

The monthly irradiation data depend on the solar height calculated for each geographical area and the average daily hours of insolation, that in the following ***Figure 3*** we can observe the distribution of the irradiation according to the hours of insolation and verify how it has a linear tendency with a high correlation index R2 of the irradiation with respect to the hours of insolation as expected.

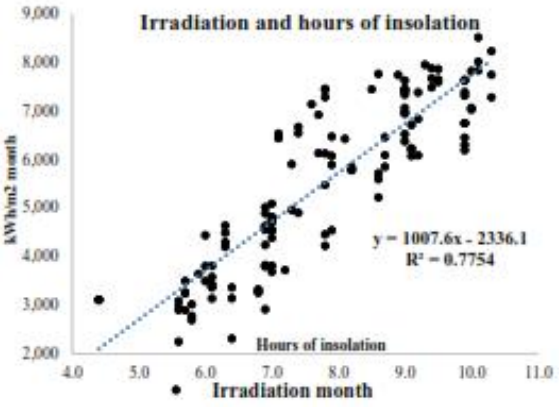


Figure 3: Distribution of the irradiation according to insolation

RESULTS

With the data obtained from monthly irradiation, we carried out the forecast calculations for the ARIMA model according to the Box-Jenkins methodology using the IBM SPSS Statistics v.23 mathematical modeling software. The modeling is done in two different ways, first the calculations are made through the SPSS expert modeling module, showing in ***Table 3*** the results obtained according to the models suggested by the software for each station. The calculations have also been made following the steps for the calculation of coefficients according to the Box-Jenkins procedure, with which another type of ARIMA modeling (p, d, q) was obtained, giving us an ARIMA model (2,0,1), which is an ARMA model (2.1), checking the results in ***Table 4***. With the obtained data, the comparison is made using the regression index R^2 of Karl Pearson **[46]** to justify their greater or lesser correlation **[47]** We compared the accuracy of the different regressions calculated by calculating the RMSE **[48,49]** and by MAPE **[50]** which is an indicator of the prognosis that measures the size of the error (absolute) in percentage terms, which gives us a relative measure of the error. The functions used are as follows:

$$RMSE = \left[\frac{1}{t}\sum_{i=1}^{t}(u_p - u_o)^2\right]^{1/2}$$

$$MAPE = \frac{100}{t}\sum_{i=1}^{t}\left|\frac{G_r - G_f}{G_r}\right|$$

Where "t" is the number of observations, "u" is the residuals of the estimates, the subscript "p" being the predicted residue and "or" the observed residue, "Gr" is the calculated real irradiation and "Gf" is the estimated irradiation according to the forecast model analysed.

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Table 3: Models and forecasts for expert mode of SPSS

SPSS expert modeling - ARIMA				
Station	**Model ARIMA (p,d,q)**	**R^2**	**RMSE**	**MAPE**
FEM	(3,1,0)	0,846	672,3	10,68%
HIR	(0,2,0)	0,755	858,0	13,89%
INP	(1,1,0)	0,642	1.030,3	17,37%

Table 4: Models and forecasts for the Box-Jenkins procedure

Box-Jenkins system modeling - ARIMA				
Station	**Model ARIMA (p,d,q)**	**R^2**	**RMSE**	**MAPE**
FEM	(2,0,1)	0,918	501,2	7,24%
HIR	(2,0,1)	0,889	600,8	9,13%
INP	(2,0,1)	0,816	761,8	11,65%

It is verified with the obtained results, with the model calculated by the Box-Jenkins procedure gives better results than by the expert module of the SPSS Statistics, with very high adjustment characteristic values in the three indicators of prediction R^2, RMSE and MAPE. ***Figure 4*** shows the results for the calculations for the autocorrelation function (ACF) and partial autocorrelation (PACF) plots of the differenced series, we can tentatively identify the numbers of AR and MA terms that are needed. The plots vary within the 95% CI bounds.

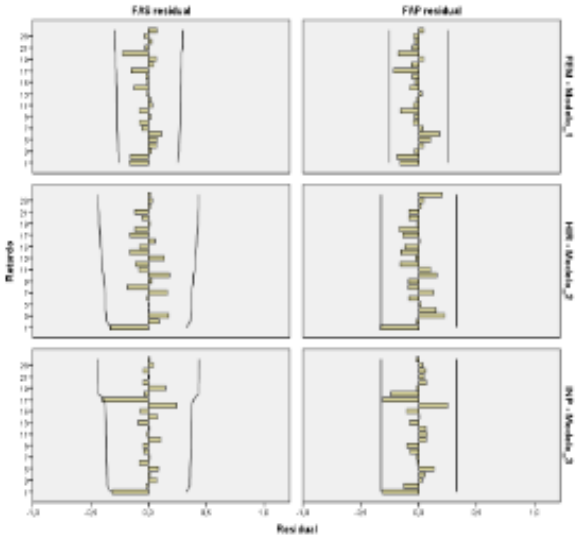


Figure 4: ACF and PACF of the residual error for the AR (2) and MA (1) models.

With the predicted values, we can observe in the following ***Figure 5*** the comparison of the irradiation of the three stations studied according to the years that we have data, with respect to the forecasts we calculate using the ARIMA model and real values calculated according to the monthly generated electricity production. We can observe the few differences that are between the real and forecasted values.

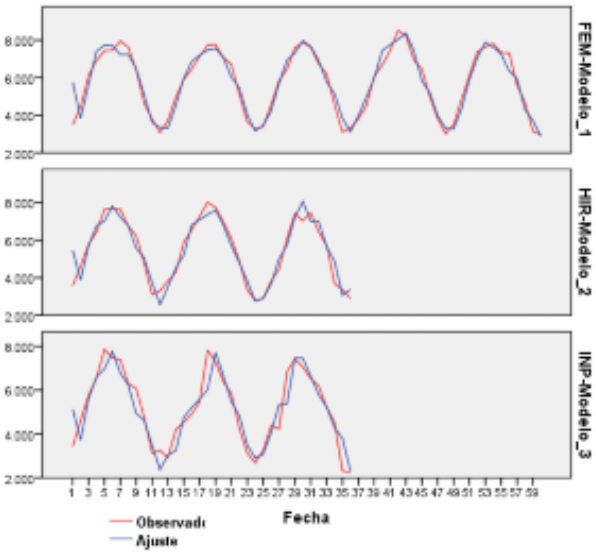


Figure 5: Real irradiation curve and predicted by ARIMA model

The characteristic function of the ARIMA model (2,0,1) calculated for the irradiation of one of the example photovoltaic stations, FEM, would be the following:

$$Y_t = 5.755{,}98 + 1{,}17Y_{t-1} - 0.979Y_{t-2} + 0.995\varepsilon_{t-1}$$

The prediction calculations according to the Fourier decomposition have given us very good values, with some indicators for the three photovoltaic stations far superior to the ARIMA model, being very close to a perfect correlation of predicted values with respect to the real ones. In the following ***Table 5*** the values of the different calculated indicators are shown.

Table 5: Models and forecasts for the Fourier decomposition

FOURIER			
Station	**R^2**	**RMSE**	**MAPE**
FEM	0,988	263,8	4,00%
HIR	0,980	338,6	5,75%
INP	0,953	505,2	8,09%

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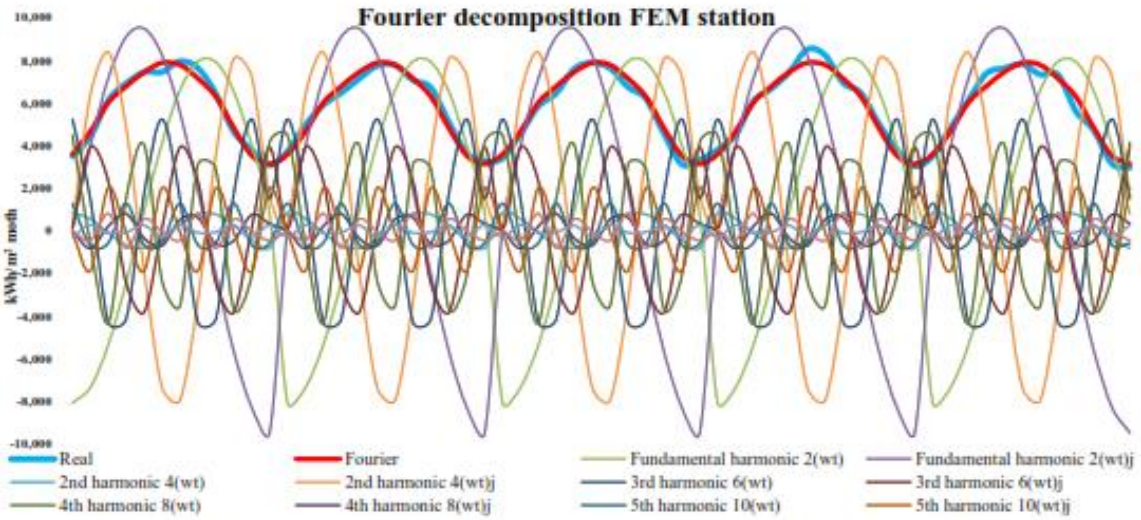


Figure 6: Fourier decomposition and characteristic harmonics together with real irradiation curve and prediction for FEM station.

The Fourier decomposition that we have done has been until the 6th harmonic, being the real function for an adjustment to the perfect formed by the harmonic infinities. ***Figure 6*** shows the decomposition of a sum of simple, sinusoidal functions whose periodic frequency. The component of the Fourier series whose frequency coincides with the fundamental (n=1) is called the fundamental component:

$$a_1 \cos(wo_t) + b_2 \sin(wo_t).$$

We can see how the adjustment of this function is superior to that of ARIMA, with a value for this station represented by R^2 = 0.998, and how the forecast data is almost the same as the real calculated.

The characteristic function that the irradiation represents will is composed by the harmonic components, so the harmonic of order n or nth would be that whose frequency is n times the fundamental. The values of a0/2 represent the average value of the function f (t) over a period and are called the continuous component. The sample function for the FEM station is shown below:

$$Y_t = 5.748,17 - 8.097,12 \cos(\tfrac{2\pi t}{T}) - 9.545,59 \operatorname{sen}(\tfrac{2\pi t}{T}) + 836,86 \cos(\tfrac{4\pi t}{T}) - 8.432,06 \operatorname{sen}(\tfrac{4\pi t}{T}) + 5.229,29 \cos(\tfrac{6\pi t}{T}) - 4.075,64 \operatorname{sen}(\tfrac{6\pi t}{T}) + 4.475,47 \cos(\tfrac{8\pi t}{T}) + 837,37 \operatorname{sen}(\tfrac{8\pi t}{T}) + 1.266,38 \cos(\tfrac{10\pi t}{T}) + 2.251,80 \operatorname{sen}(\tfrac{10\pi t}{T}) - 302,21 \cos(\tfrac{12\pi t}{T}) + 852,41 \operatorname{sen}(\tfrac{12\pi t}{T})$$

The following ***Figure 7*** shows the comparison of the two ARIMA and FOURIER non-linear models according to the R2 and MAPE indicators, verifying how in all cases the Fourier model gives better results.

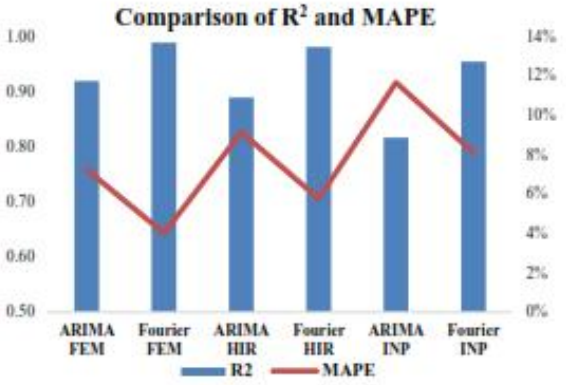


Figure 7: Comparison of ARIMA and FOURIER non-linear models according to the R2 and MAPE indicators.

DISCUSSIONS AND CONCLUSIONS

The calculation model of forecasts that we have developed for solar irradiation estimation, considering the generation of electric energy by photovoltaic solar panels (PV) is applicable to multiple destinations, provided that we have sufficient monthly data of several years and the characteristics of the PV. With the ARIMA model or the Fourier decomposition model, we obtained very good estimations and forecasts of irradiation, with R^2 values higher than 0.81 in all cases. We have also verified that using the mathematical software SPSS Statistics it is better to enhance the calculation by the Box-Jenkins procedure than by integrated expert modeling. The

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most recommendable model is the Fourier decomposition, with which we get better forecast indicators and a correlation index R^2 in all cases greater than 0.95.

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4.7. Artículo 6. Reduction of energy consumption in hotels with aerothermal energy. Case Study: Canary Islands (Spain)

4.7.1. Resumen

En este artículo se presenta un modelo de gestión y control de eficiencia energética en hoteles adaptado a los patrones de consumo que aseguran las exigencias de confort de los clientes e integrándose en el entorno de un complejo turístico inteligente. Se realiza un análisis del ACS de dos hoteles en funcionamiento de las islas Canarias con relación a su ocupación, obteniendo una solución basada en EERR mediante un sistema de bombas de calor de alta temperatura con disipación por aerotermia que debido a sus características se puede considerar como equipo basado en EERR y apoyadas por las calderas de GLP propano existentes. El control por autómatas programables está integrado en un sistema de control y adquisición de datos optimiza los sistemas para mantener la máxima energía acumulada durante los periodos de tarifa eléctrica más barata, mediante un sistema de apertura y cierre de válvulas hidráulicas que consigue ajustar la demanda del consumo de ACS para conseguir la mayor acumulación de energía durante los horarios con tarifa eléctrica más barata.

El resultado después de dos años y medio de registro de la actividad es un retorno de la inversión más rápido debido a la gestión energética optimizada del sistema, mediante el control de horarios de funcionamiento ajustados a las necesidades de los clientes y a la tarificación horaria. También se ha pronosticado que durante los 12 años de duración estimada del sistema se habrá ahorrado más de 1.179.737 € y 8.780.005 kWh térmicos en un hotel y 1.315.104 € y 9.522.301 kWh térmicos en el otro hotel por hotel. Este modelo mostrado se puede comprobar cómo es económica y energéticamente muy eficiente y el dinero ahorrado se puede reinvertir en seguir con mejoras en las instalaciones o directamente como beneficio de explotación del establecimiento.

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Research paper

Reduction of Energy Consumption in Hotels with Aerothermal Energy. Case Study: Canary Islands (Spain)

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Abstract

This article presents a management model and control of energy efficiency in hotels adapted to the consumption patterns that ensure the comfort requirements of customers and integrated into the environment of an intelligent tourist complex. The analysis of the hot water system (DHW) of two hotels in the Canary Islands (Spain) in relation to their occupation, yields a solution based on renewable energies using high temperature heat pumps with aerothermal dissipation and supported by boilers of existing LPG propane. The control by programmable automatons (PLC) integrated in a system of control and acquisition of data (SCADA) optimizes the systems to maintain the maximum accumulated energy during the periods of cheapest electric tariff, by means of a system of opening and closing of hydraulic Valves that It manages to adjust the demand of DHW consumption to achieve the highest energy accumulation during the hours with the cheapest electricity tariff. The result after two and a half years of activity registration is a faster return on investment due to the optimized energy management of the system, through the control of operating hours adjusted to the needs of customers and the hourly rate. It has also been predicted that during the estimated 12 years of the system will have saved more than € 1,179,737 and thermal 8,780,005 kWh in a hotel 1 and € 1,315,104 and thermal 9,522,301 kWh in the hotel 2. This model shown can be seen how economically and energetically very efficient.

Keywords: *DHW, energy efficiency, hotels, aerothermal energy, SCADA, PLC.*

1. Introduction

The constant increase of tourism in Spain is a fact, and this past year 2017 has again increased by 4.4% tourist GDP, now standing at 11.5% of total Spanish GDP ***[1]*** and giving work to 13 % of the employed population, which has led the sector to outstanding positions in the Spanish economy and enables both hotel and extra hotel accommodation have begun to remodel their facilities and equipment. Within these initiatives of improvements, and due to the new awareness of customers towards the environment, great efforts have been made in favour of the sustainability of the tourist destination and energy efficiency of the facilities. The hotel companies have worked in recent years, in the implementation of energy saving and efficiency measures in multiple facilities, betting on the reduction of consumption and greenhouse gas emissions (GHG), through the implementation of energy management methods and of information and communication technologies in monitoring and control systems. This new "green revolution" of the tourism business is well encouraged by the European Union (EU), defining goals in reducing CO_2 emissions to 20% by the year 2020 compared to the 1990s and establishing that 20% of the Total energy consumption is supplied by renewable energies (EERR) ***[2]***. In addition, new objectives have already been established for future stages ***[3]***, setting a reduction of 40% in emissions by 2012, compared to 1,990, 27% of EERR, increase in energy efficiency by 27-30% and 15% electric interconnection, that is, that the electricity generated in the EU can be transported to other member states. By the year 2050, the EU has imposed an 80-95% reduction in greenhouse gas emissions compared to 1990 levels. With these guidelines for improvement in energy management and saving, the tourism sector has launched a "green revolution", based on the implementation of technologies to reduce consumption and the certification of establishments and destinations, which leads to an increase in the different certification systems and certified companies, as can be seen in ***Table 1*** , where the main current environmental management and energy management certifications are being applied is the hotel establishments.

Table 1. Main environmental and energy certificates.

Name	Certificator
Ecolabel Europa ***[4]***	European Comission
Aito Star ***[5]***	Association Of International Tour Operators
Biosphere ***[6]***	Biosphere Responible Tourism
Earthcheck ***[7]***	Ec3 Global
Emas ***[8]***	European Comission
Green Globe ***[9]***	Green Globe Ltd
Iso 14001 ***[10]***	International Organization For Standardization (Iso)
Iso 50001 ***[11]***	Iso
Leed ***[12]***	U.S. Green Building Council
Travelife ***[13]***	Travelife Ltd
Step ***[14]***	Sustainable Travel Internationsal
Ecolideres ***[15]***	Tripadvisor

The importance of these changes is due to two clear reasons. The first is the need to reduce the energy consumption of the facilities, meeting the expectations of customers without reducing the services offered. The second is due to the change in mentality of

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customers, who begin to value destinations and establishments in response to the environmental sustainability of their facilities and services. Within these tourist destinations, we have taken as example two establishments in the Canary Islands (Spain), where the tourism sector is the main engine of the economy, representing 34.3% of GDP in 2016 and generating 39.7% of GDP. % of employment in the islands ***[16]*** and being an important factor in their labour mobility ***[17]***. Tourist stays have increased by 27% from 2010 to 2016 ***[18]*** in an archipelago where 63% of its territory is declared a biosphere reserve by UNESCO ***[19]***. In this singular tourist area, we focus our attention on the study of the DHW systems of two hotel establishments on the island of Fuerteventura.
The reason is that it has been proven in multiple investigations as the sum of the air conditioning and the DHW are the main energy consumers, depending on the percentage of each of the geographical area of study. For example, in Caribbean hotels, 48% of electric power is consumed in air conditioning (AA) ***[20]***, in Hong Kong AA accounts for 45% of electricity consumption ***[21]***, in hotels in the Balearic Islands the total energy consumption is between 22% for the DHW, the AA 14% and the heating 21% ***[22]***, in the hotels in the United States the consumptions are divided in a general way with the air conditioning 31% AA the 15% and the DHW 17% and the rest for other uses ***[23]***, in Britain the typical distribution is 47% in heating and 20% in DHW ***[24]***, and in Greece the typical distribution is 35% in heating, 15% in AA and 22% in DHW ***[25]***. Considering the consumption of customers per day, which vary according to zones and type of hotel, we can verify the importance of reducing these consumptions on the total energy needed for a hotel, which has been studied by several authors ***[26, 27, 28, 29, 30].***

2. Methodology

The installations analysed belong to two four-star hotels of 333 and 354 rooms, designated as H1 and H2 respectively, as they cannot be named due to the data protection of both companies, where their DHW-based heating systems have been replaced, propane LPG boilers, by systems based on aerothermy technology of high temperature heat pumps. The data that are initially counted are the annual occupation and the total consumption of LPG propane. By means of the studies of previous facilities of hotels of the same category and climatic zone, and of the norms of calculation ***[31]***, it has been verified that the average consumption of the clients is of about 70 L/day of DHW, and the percentage of consumption of total LPG propane by the DHW with respect to the remaining consumers -furniture and laundry according to cases- is between 60% and 75% of total consumption ***[32]***. With this starting data and once the possible heating systems were chosen, the possibility of using a system based on aerothermy and biomass was studied, whose forecasts of operating expenses and initial investments can be checked in ***Table 2***, where it was calculated a theoretical coefficient of performance (COP) for heat pumps of 2.4, much lower than the real one. To make forecasts as accurate and real as possible, it is necessary to have the greatest number of exact values and not estimates, for which the energy management of the establishments is fundamental to be able to perform these calculations of energy system improvements
The chosen result of the alternatives analysed has been aerothermy as a system to be implemented in both hotels, considering the number of companies that know these technologies and that the biomass fuel in the Canary Islands is not yet widespread and its performance is reduced due to transport, as has been demonstrated in several studies ***[33,34,35]***. The solution consists of high temperature heat pumps of 151.2 kW and 201.6 kW in the H1 and H2 hotels respectively, which are supported in a timely manner by the existing boilers and regulated by a PLC-based control system with connection to a computer through a SCADA system.

Table 2: Projection of consumption and installation expenses.

Previous	***Hotel H1 (333 Rooms)***	***Hotel H2 (354 Rooms)***
Total Hotel Lpg Expenditure In Kg/Year	*100,455 Kg*	*142,260 Kg*
Total Glp Expense In Dhw In Kg/Year	*70,318 Kg*	*99,582 Kg*
Thermal Needs Dhw In Kwh/Year	*801,839 Kwh*	*1,135,531 Kwh*
Lpg Cost €/Year	*123.057 €*	*174.268 €*
Projected	***Heat Pump***	***Heat Pump***
Necessary Investment	*135.000 €*	*145.000 €*
Consumption Electric In Kwh/Year	*334.100 Kwh*	*473.138 Kwh*
Cost Of Electricity	*30.069 €*	*42.582 €*
Saving Compared Lpg	*92.988 €*	*131.686 €*
Amortization In Years	*1,45*	*1,10*

For the calculations of the system so that it complies with the current regulations, the European Commission's guidelines for estimating values that can consider energy from renewable sources in operation of heat pumps according to dissipation systems have been considered ***[36]*** and considering the data on the efficiency of the equipment that regulates the seasonal yield factor (SPF) ***[37]***. For its part, the Institute for Energy Diversification and Saving (IDAE) has a document (it does not replace the standard) and according to this ***[38]***, the SPF will be calculated multiplying its nominal benefits (COP) by a factor called representative weighting factor (FP) and by a correction factor (FC) for the different technologies and applications of electrically driven heat pumps.

3. Calculus

Initially we performed the calculations of the total COP of the equipment considering the operating temperature and the environmental dissipation for Fuerteventura and in the tables of the manufacturer the values of electric consumption and thermal generation are obtained. Considering the system used for high temperature heat pumps with dissipation by aerothermy, which are formed by an external LG brand machine, model ARUN 160 LTE4, unit capacity of 50.4 kW, EER 4.30: SEER 7.27; COP 4.42 and 2 internal units of hydrokit brand LG model ARNH 08 GK3A2, with 25.2 kW of heat power, 80ºC of maximum water outlet temperature, and in each hotel is formed by 3 or 4 systems to get the 151.2 kW or 201.6 kW thermal.

$$COP_{60ºC} = E_{Thermal} / (E_{Elect\_inside} + E_{Elect\_outside}) \quad (1)$$

$COP_{60ºC}$ = 50.4 kWt / (7.68 + 2 x 4.87) kWe = 50.4 kWt / 17.42 kWe = 2.89

To determine the SPF of the heat pump we need to know the corresponding FP and FC. The FP will be obtained in the tables of the IDAE ***[38]*** 4.1 according to the climatic zone of the hotel site and to the type of heat pump used and the FC in the table of the IDAE 4.2 with a COP calculated for 60ºC. Fuerteventura is an area of climatic severity in winter A ***[39]*** and the type of heat pump is aerothermal. Centralized equipment, so FP = 0.87. The temperature chosen for the preparation of the ACS is 60 ° C, so FC = 1.

$$SPF = COP_{nominal\ 60ºC} \times FP \times FC \quad (2)$$
SPF= 2.89 x 0.87 x 1 = 2.51

Once it has been verified that the SPF of the pump exceeds the minimum of SPF = 2.5, it can be considered that the heat produced by the pump comes from a renewable source of both facilities. Now the amount of renewable energy is calculated, in accordance with the decision of the commission on calculation guidelines ***[40]*** is calculated with the following formula:

$$E_{res} = Q_{useful} \times (1-1/SPF) \quad (3)$$

$$Q_{useful} = H_{hp} \times P_{rated} \quad (4)$$

Where are you the amount of renewable energy supplied by heat pump technologies, Q_{useful} estimated total useful heat provided by

heat pumps [GWh], H_{hp} equivalent hours of full load operation [h] and P_{rated} power of installed heat pumps, considering the duration of the different types of heat pumps [GW].
Values for hotel H1:

$Q_{useful1}$ = 1170 x 151.2 x 10-6 = 0.176904 GWh
E_{res_min1} = 0.176904 x (1-1/2,5) = 0.106142 GWh
E_{res1} = 0.176904 x (1-1/2,51) = 0.106424 GWh
Percentage of renewable energy = 0.106424 / 0.176904 = 60.16%

Values for hotel H2:

$Q_{useful2}$ = 1170 x 201.6 x 10-6 = 0.235872 GWh
E_{res_min2} = 0.235872 x (1-1/2,5) = 0.141523 GWh
E_{res2} = 0.235872 x (1-1/2,51) = 0.141899 GWh
Percentage of renewable energy = 0.141899 / 0.235872 = 60.16%

Fig. 1 shows the operating scheme of the hotel's DHW system, with both hotels being the same. The systems consist of 5 accumulators of 5000 L - three for direct heating by boilers / heat pumps and 2 for preheating by recovering air conditioning (AA) -, the corresponding exchangers and circulation pumps. The primary boiler circuits are 2 boilers 280 kW in the H1 hotel and 2 boilers 290 kW in the H2. The circuits of the heat pumps in the H1 hotel are 3 heat pumps and in the H2 it is formed by 4 heat pumps as well. The principle of operation is as follows: priority to the heat pumps for the heating of the 3 DHW, ACS 3, 4 and 5 accumulators, and in case 45 min did not reach the set temperature (61ºC) they would enter the boilers as a support system, motivated by Legionella control regulations ***[41]***. The AA recovery system preheats the 2 ACS 1 and 2 accumulators. Two motorized valves have been added to this system, which are indicated in the diagram as "night valves", which are activated when the AA system is not operating and in the most economical electricity tariff schedule P6, to accumulate the largest amount of water at the working temperature, for which the operating temperature setpoint of the high temperature heat pumps (2nd set point) is also increased, at 65ºC, in order to accumulate in the 5 existing accumulators the maximum possible energy during the periods of lowest price of the same and in this way, reduce the average price of the useful electric kWh used for the heating of the DHW of the establishments. In the SCADA you can put the different the different pump controls, system temperatures, access to the programming of the operating hours and the operating status of the equipment.

4. Results and Discussion

The systems were launched in the hotels in September and December 2015 at the H1 and H2 hotel respectively. The results, after two and a half years of activity, have been very satisfactory, with a return on investment faster than initially projected. Also, be checked as by means of the possibility of adjustments, of times, hours of operation and temperatures can be obtained greater savings with a correct management of the parameters as it is carried out in the hotel H1 with respect to the H2. ***Fig. 2*** shows the graphs of energy consumption and expenditure per client-day of ACS of the hotels, graphically checking the decrease of these in 2016-2017 due to the new installation of aerothermy. With these new equipment, a drastic reduction of energy consumption in ACS has been achieved, as well as the emissions associated with LPG boilers, with higher savings in the H1 hotel compared to the H2 due to the adjustment of the system by the equipment hotel maintenance.

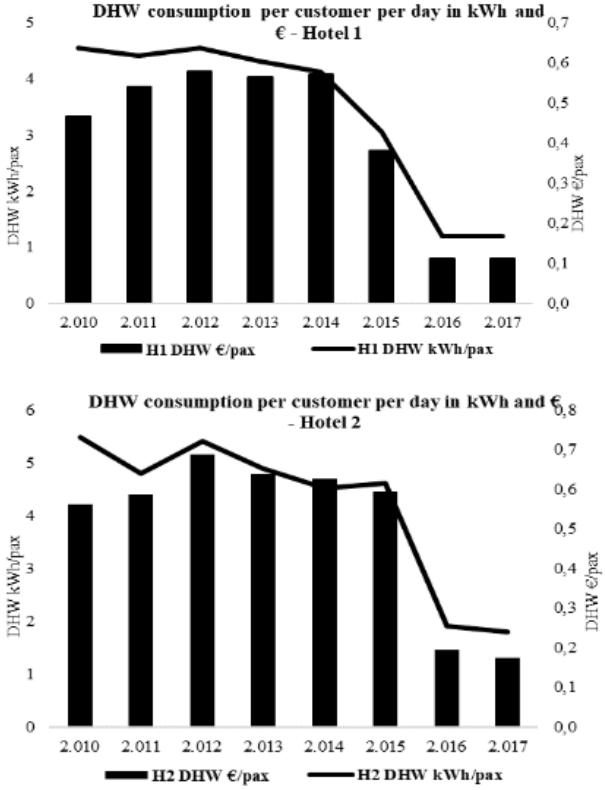


Fig. 2. Graph of decrease of energy consumption and economic expense in DHW per night customer.

Table 3 shows the evolution of energy and economic costs of the establishments, with a result of a reduction in energy consumption to produce the ACS between 72.7% and 63% per hotel respectively. It also shows that the average spending on ACS per client hosted in recent years (2010-2014) compared to the 2016-2017 year has decreased by 79.4% and 70.3%, from an average of € 0.54 / customer night (=pax) and 0.62 € / pax has gone to 0.11 € / pax and 0.19 € / pax for each hotel respectively. We compare the sav-

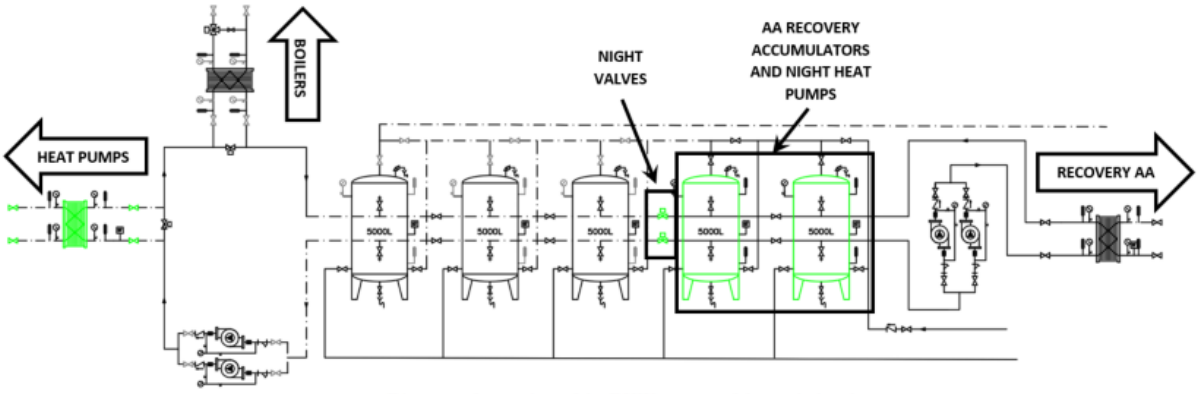


Fig. 1. Diagram of operation of the DHW system of the study hotels.

ings data for the years 2010 to 2014, since 2015 was launched at the end of the year, it is verified that due to the price of the kg of LPG, the amortization of the equipment has taken place in less time than the one that it was estimated, since also the actual consumption has been lower than projected due to PLC control that optimizes the operation by schedules. As a result, the installation has already been amortized in the time it has been running and is currently generating benefits. The total energy saving in annual kWh is greater than 600,000 kWh in both systems. The approximate consumption of LPG by the support boilers has been considered 5% of the total gas consumption in the H1 hotel and of 15% in the H2, due to the excessive punctual consumption of DHW in peak hours, mainly during the mornings between 8:00 a.m. to 9:00 a.m. hours and afternoons between 6:00 p.m. to 7:00 p.m., with the support of the boilers being necessary so as not to oversize the installation of heat pumps. The difference in gas consumption is due to the use of more optimized control systems in the H1 hotel than the H2, with a difference of more than 35.5% between the energy consumed per client of one hotel with respect to the other.

Table 3: Values of energy and economic consumption per customer and day obtained.

H	Type	2010	2011	2012	2013	2014	2015	2016	2017
1	kWh/pax	4.54	4.40	4.54	4.30	4.13	3.06	1.20	1.20
	€/pax	0.47	0.54	0.58	0.56	0.57	0.38	0.11	0.11
2	kWh/pax	5.47	4.79	5.41	4.88	4.52	4.60	1.91	1.80
	€/pax	0.56	0.59	0.69	0.64	0.63	0.59	0.19	0.18

With the data obtained, the following ***Table 4*** of expenses and savings produced by this change in the energy model is generated. Considering that the equipment has an average life of 12 years of the system will have saved more than € 1,179,737 and thermal 8,780,005 kWh in a hotel 1 and € 1,315,104 and thermal 9,522,301 kWh in the hotel 2 for which it is expected to have saved more than € 1,100,000 and in the H1 hotel and more than € 1,300.00 in the H2 hotel.

5. Conclusions

The investment in the reduction of energy consumption is the way forward to maintain current quality and environmental standards, without reducing services to customers and without increasing operating expenses. It has been proven how the amortizations are very fast, and the savings produced can be reinvested in further modernizing other facilities or offering more services to customers. The investment in high efficiency systems and based on heat pumps leave the possibility to get water heating systems with zero emissions if they are made with joint supplies of photovoltaic solar panels, which would achieve autonomous systems without dependence on external energy. its operation. It is in the hands of the owners or operators of the hotel facilities, the mentalizing and making these improvements in their facilities, as well as in the institutions to legislate and inform about these technologies and their application to the current buildings, in search of the long-awaited building of energy almost zero (ZEB) or almost zero (nZEB).

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Table 4: Expenses to annual savings and forecast during the useful life of the heat pump system

H	TYPE	2.010	2.011	2.012	2.013	2.014	2.015	2.016	2.017	Forecast in 12 years
H1	Annual expenditure €	90.841	117.518	123.715	115.877	120.113	82.324	26.109	25.311	**308.518**
	Annual savings €							99.096	97.527	**1.179.737**
	Annual savings kWh							738.647	724.687	**8.780.005**
H2	Annual expenditure	117.148	143.198	167.936	154.324	152.271	142.567	48.434	44.064	**554.985**
	Annual savings							107.342	111.842	**1.315.104**
	Annual savings kWh							793.194	793.857	**9.522.301**

5.

DISCUSIÓN Y FUTURAS LÍNEAS DE INVESTIGACIÓN

5.1. SÍNTESIS

En este capítulo se realiza la síntesis del desarrollo realizado, resaltando las contribuciones y poniendo de manifiesto la relevancia del conocimiento generado dentro de un confinado campo de la ciencia. Por lo tanto, se establece como objetivo de este capítulo la integración de los diversos temas tratados en los capítulos anteriores, resaltando los hallazgos ya establecidos con comentarios adicionales sobre el significado de las observaciones, pronosticando las implicaciones consecuentes del estudio y planteando posibles líneas de trabajo abiertas para futuras investigaciones.

Es inicialmente asumido por hipótesis, que entre los factores determinantes de los modelos de cálculo económico que pronostican la rentabilidad de los establecimientos turísticos basados en las ocupaciones futuras, los gastos imputables a los suministros energéticos y de agua son prioritarios para poder mejorar estas predicciones económicas. Los resultados analíticos vertidos en este estudio de investigación constituyen el fundamento para crear herramientas de cálculo fiables, que faciliten las predicciones necesarias para poder acometer los ajustes necesarios sobre las mismas. Teniendo en cuenta las proyecciones futuras, que duplican el número de pernoctaciones mundiales a quince años, es necesario poder contar con herramientas de cálculo fiables y sencillas, sobre las cuales poder realizar las predicciones necesarias y poder acometer los ajustes precisos sobre éstas.

Como arranque del proceso investigador se formularon unos interrogantes de la investigación, cuyas respuestas han ido apareciendo en el desarrollo de las diferentes publicaciones. Se han encontrado los indicadores claves y factores del consumo energético de los establecimientos hoteleros, definiendo modelos de comportamiento de ocupantes en cuanto a los consumos energéticos y de agua. Ha quedado establecida la relación funcional entre los consumos energéticos y emisiones de CO_2 en los establecimientos hoteleros, entre ellos, el consumo de aguas en piscinas se destaca como factor relevante, con grandes diferencias entre el suministro de agua centralizado y el local. También se ha demostrado como los modelos de generación eléctrica del archipiélago respecto a la península, influyen de forma considerable en la proporción de las emisiones de GEI. Por último, en cuanto al autoabastecimiento energético, se han encontrado modelos para la realización de pronósticos o simulación de aprovechamiento de la energía solar fotovoltaica.

5.2. CONTRIBUCIONES

Las principales contribuciones al conocimiento aplicado a la industria hotelera se pueden resumir en los siguientes temas principales:

A) Modelo de consumo de agua en hoteles.

Se obtiene un modelo en el estudio comparativo del consumo de agua en hoteles de cuatro y cinco estrellas en las Islas Canarias, al identificar los patrones principales de consumo. El modelo obtenido se verifica mediante diferentes técnicas de regresión, para seleccionar y ajustar el algoritmo óptimo, para poder obtener la función de calculo que define a estos consumos.

En este estudio queda demostrado que los modelos de correlación basados en regresiones, con las variables de la ocupación o las estancias diarias, arrojan unos resultados satisfactorios para los pronósticos en establecimientos de características similares. Estos modelos se pueden aplicar en cualquier tipo de suministro, siempre que las instalaciones a estudiar se mantengan con iguales o similares características durante el periodo de tiempo de la investigación. Se puede comprobar en la ***Figura 5.1*** la aplicación para el cálculo de la curva característica de consumo de agua en hoteles de 4 estrellas.

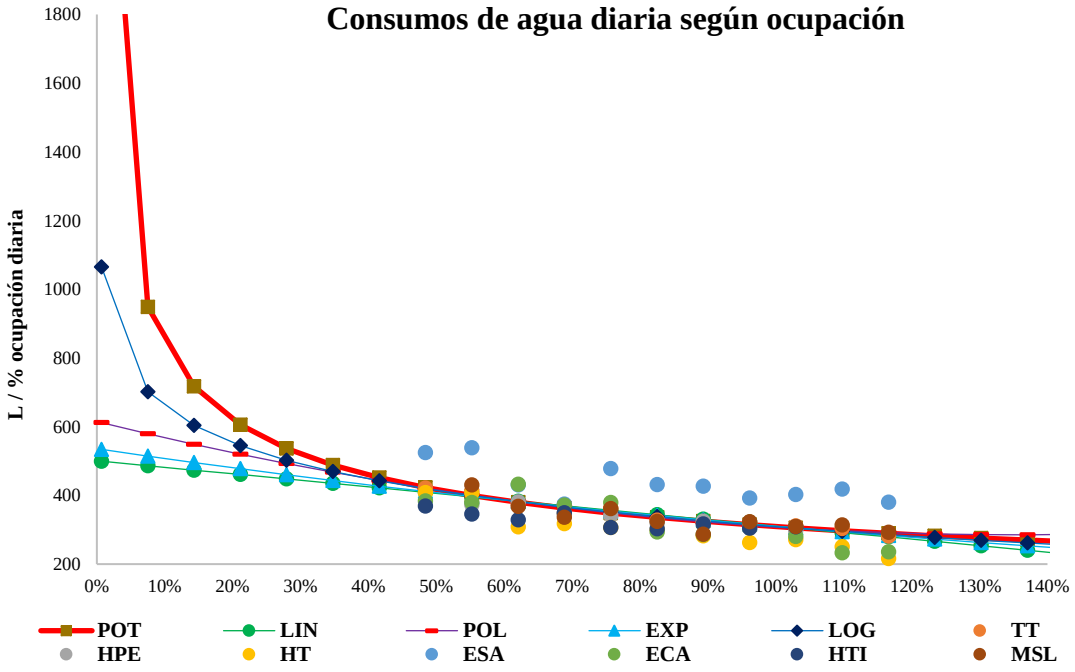


Figura 5.1. *Curvas de consumos de agua para hoteles 4 estrellas según ocupación de clientes.*

En la siguiente ***Figura 5.2*** se muestra el esquema de cálculo simplificado que se ha utilizado para realizar los modelos de consumos de cualquier tipo de suministro y de sus emisiones asociadas.

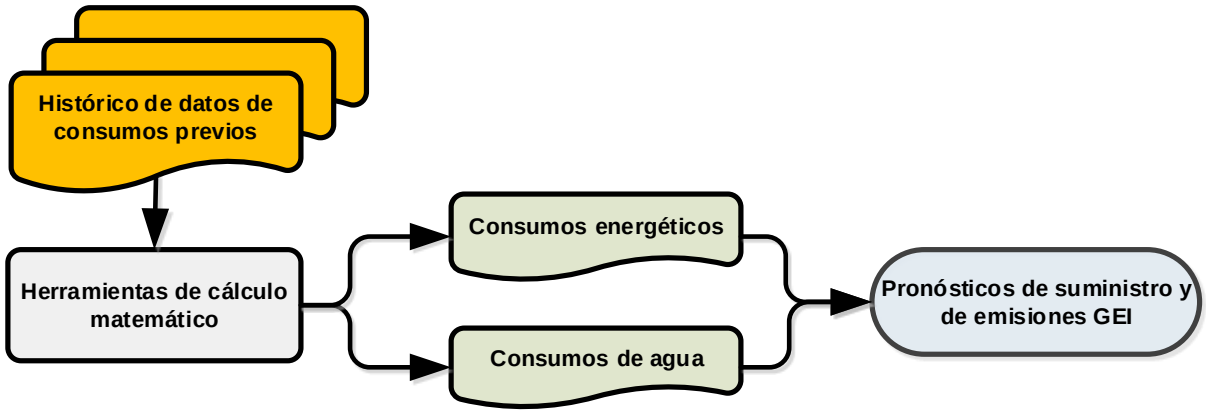


Figura 5.2. *Modelo de cálculo para calcular pronósticos de suministros y emisiones.*

B) Modelo de suministro de energía y electricidad en hoteles.

Mediante el método de cálculo explicado basado en regresiones, también se ha realizado el modelizado de los consumos de electricidad y energía total en hoteles. Quedando demostrada la validez de los modelos de regresión polinómica y potencial utilizados para calcular los valores aproximados de consumo de electricidad y energía total, los cuales pueden ser aplicados en la mayoría de los hoteles con una tasa de ocupación promedio de clientes de entre el 40% y el 120%, que son típicamente las ocupaciones promedio de los hoteles en las Islas Canarias durante los diferentes meses del año.

Con el modelo y algoritmo desarrollado, se pueden realizar simulaciones de consumo para hoteles con las mismas o similares características. Siendo una aplicación muy interesante el modelizado de consumos una vez realizados ajustes de reducción de energía, simulando valores de ocupación para probar cual es el nivel de reducción. En la ***Figura 5.3*** y en la ***Figura 5.4***. se pueden observar las curvas características de consumo total de energía y electricidad en hoteles de 4 estrellas con características similares.

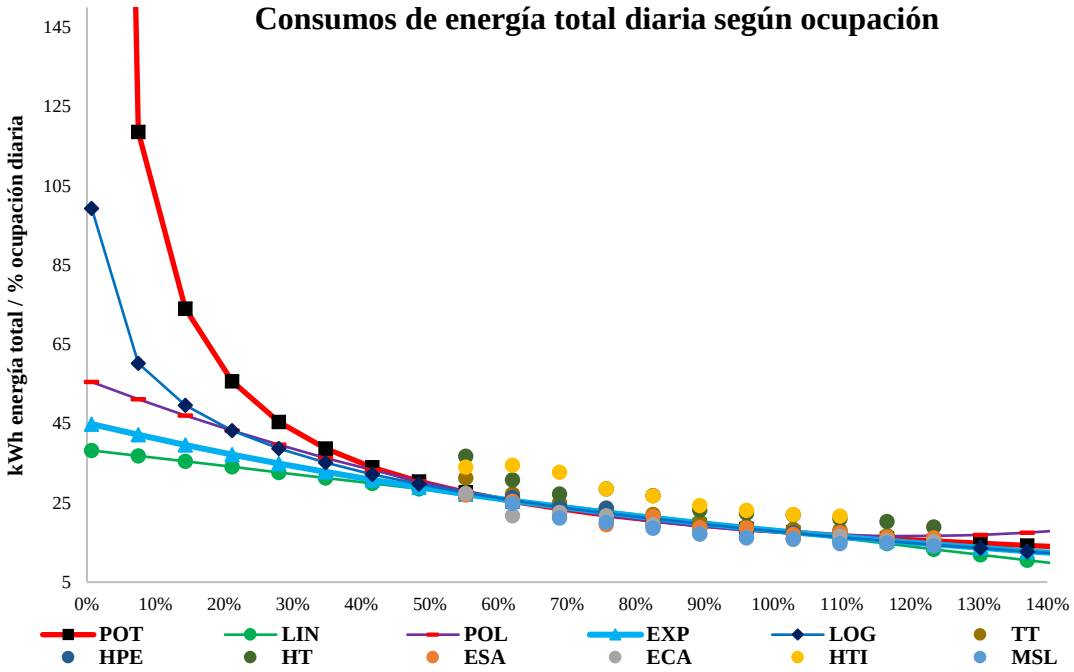


Figura 5.3. *Curvas de consumos de energía para hoteles 4 estrellas según ocupación de clientes.*

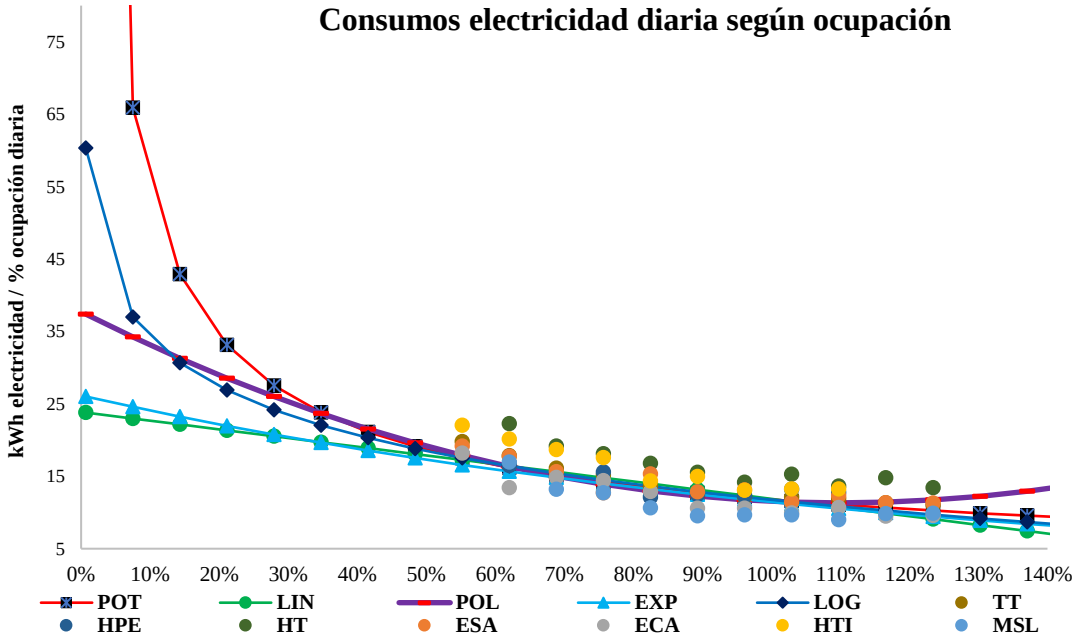


Figura 5.4. *Curvas de consumos de electricidad para hoteles 4 estrellas según ocupación de clientes.*

También se pone de manifiesto que los hoteles con plantas desadoras de agua de mar (EDAM) para el consumo propio, el gasto de energía está directamente relacionado con el consumo de agua producido por los clientes, piscinas y riego, según el tipo de riego utilizado. Poniendo de relieve la necesidad de mejorar la eficiencia de las plantas de desalinización para reducir el consumo de agua y el riego, a fin de lograr una reducción de energía proporcional en los hoteles.

C) Estudio comparativo de la huella de carbono.

En el estudio comparativo de la huella de carbono debido al consumo de agua y energía total se ha demostrado como los establecimientos de categoría superior 5 estrellas, tienen unos consumos y emisiones que triplican a los de categoría inferior y quintuplican los de categorías más baja de 3 estrellas, con unos valores por estancia que pueden ir desde los 41,96 kg CO_2/p en los hoteles de 5* con desaladora centralizada, hasta los valores mínimos de 7,94 kg CO_2/p en los hoteles de 3* con desaladora propia o local, dando unos valores medios de emisiones por estancia de 14,23 kg CO_2/p con desaladora propia o local y de 15,16 kg CO2/p con desaladora centralizada. Las emisiones debidas al consumo eléctrico representan más del 83% de las emisiones del consumo energético, cuando solo representan el 58% de la energía consumida, siendo los coeficientes de emisión de Canarias cerca de 3 veces superior a los peninsulares.

En la siguiente ***Figura 5.5*** se puede observar las grandes diferencias entre las emisiones según las categorías de los hoteles, el tipo de suministro de agua que tienen y se comparan con los suministros en hoteles peninsulares.

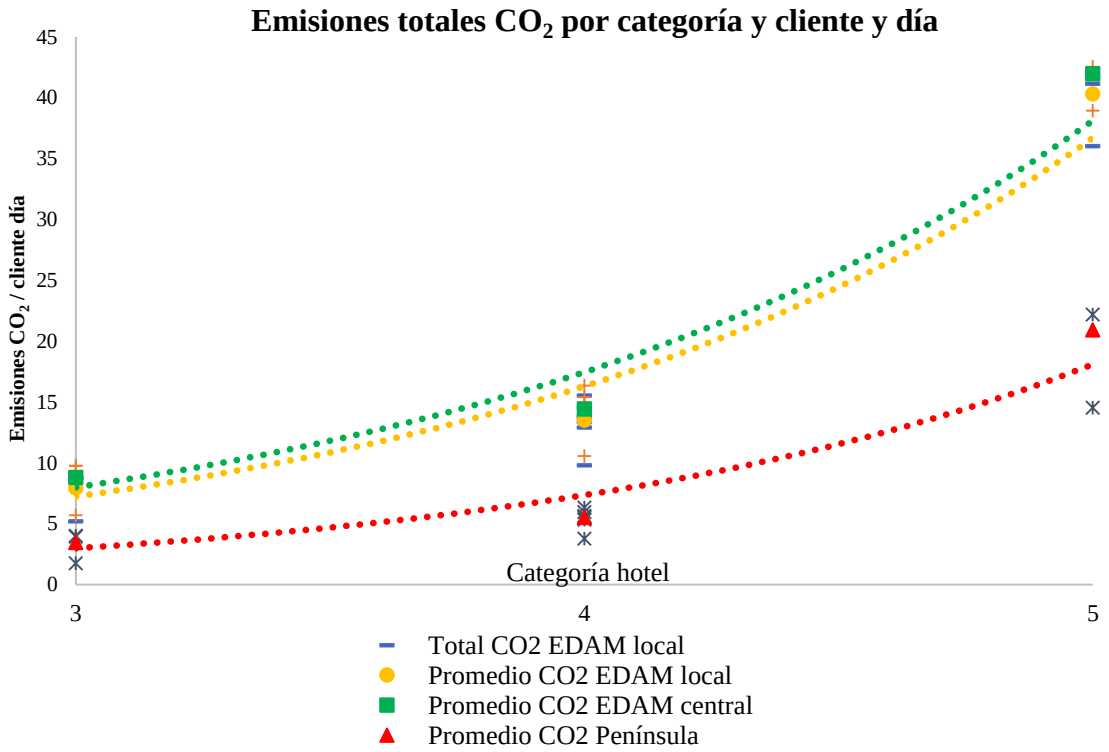


Figura 5.5. *Emisiones CO_2 de los clientes según categoría y tipo de suministro.*

D) Cálculos de consumo de agua, energía y huella de carbono en piscinas turísticas.

Se han encontrado interesantes resultados a partir de una estimación de las necesidades de agua en instalaciones de todas las piscinas turísticas de la región, procesando los datos de diversas fuentes con un algoritmo propiamente definido, basado en los cálculos de consumos total de un amplio grupo de piscinas canarias, considerando a efectos prácticos, que el total de aguas de suministros proviene de EDAM de ósmosis inversa, mediante desaladoras locales o centralizadas. En los resultados se observa que la huella de carbono es un 28,16% más alta a través de la producción centralizada, en comparación con la producción local, debido a las grandes pérdidas en las redes de suministro, comprobándose también la importancia de las emisiones por islas y su gran variación según el tipo de suministro, como se puede observar en la ***Figura 5.6*** donde se muestran las emisiones del total de piscinas de cada isla.

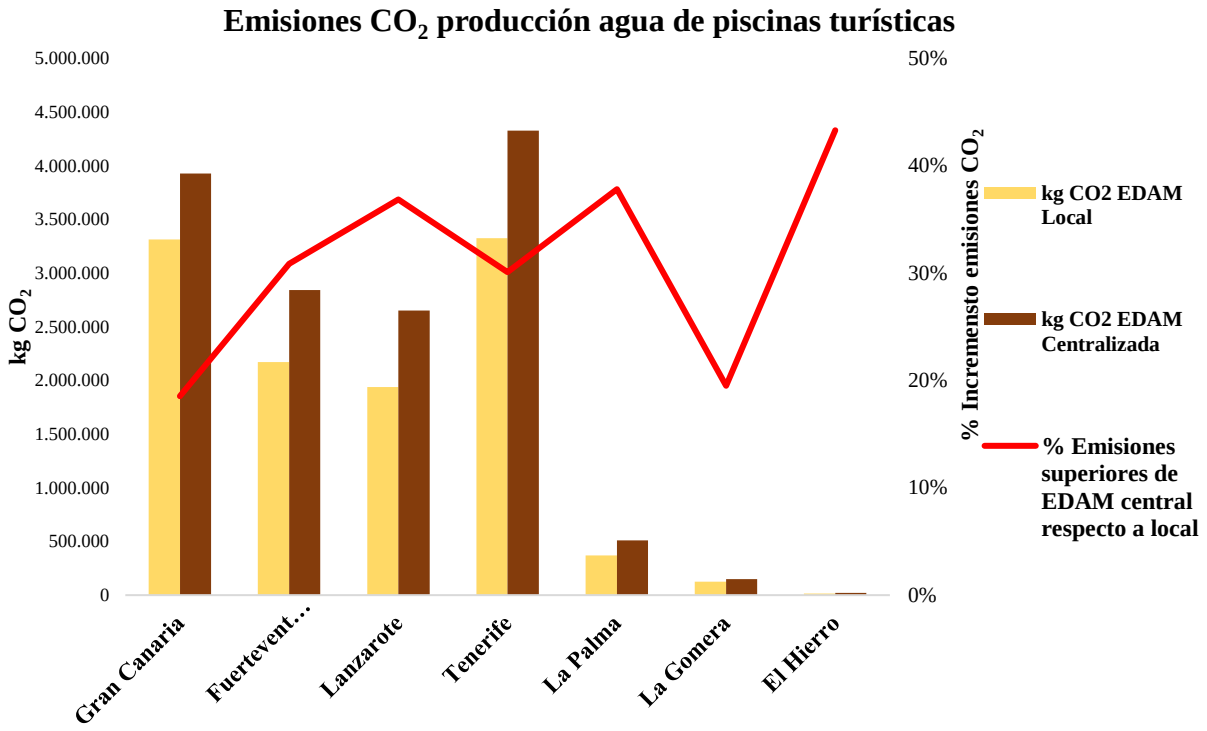


Figura 5.6. *Emisiones de CO_2 debidas a la generación de agua de piscinas turísticas según tipo de suministro.*

Se ha estimado que la generación del agua necesaria para piscinas turísticas a través de EDAM representaría entre 0.089% y 0.114% de todas las emisiones en la región, de acuerdo con el tipo de suministro, local o centralizado, respectivamente. Valores extremadamente significativos y equivalentes al tratamiento biológico de todos los residuos sólidos de las islas.

E) Cálculo de reducción de consumos en el ACS mediante aerotérmia

Se muestra un modelo de reducción de consumos del ACS de sistemas actuales basados en energías fósiles, a otros sistemas más eficientes mediante la instalación de nuevos equipos de calentamiento por bombas de calor de alta temperatura con disipación por aerotermia. Se comprueba la eficiencia de estos equipos, con una reducción de los consumos energéticos superior al 60% y una disminución de los gastos económicos imputables para el calentamiento del ACS superiores al 70%. Con un retorno de la inversión muy rápido, de menos de un año y medio y con una duración prevista de 12 años, lo cual es un sistema muy rentable, reduciendo los gastos económicos del establecimiento y posibilitando la reinversión del dinero ahorrado en los clientes o sumarlo como beneficio neto de la compañía.

F) Cálculos generación solar fotovoltaica.

Se muestra un método para el cálculo de la irradiación y con ella, de la generación eléctrica mediante placas solares fotovoltaicas, basado en la estimación de la irradiación incidente en un área geográfica, a través de la producción de energía eléctrica generada por instalaciones solares fotovoltaicas conocidas. Se comprueba como con dos modelos matemáticos no lineales ampliamente conocidos y utilizados para otras cuestiones, como son el modelo estadístico ARIMA o Box-Jenkins y el modelo de descomposición en series de Fourier, se pueden calcular estimación de irradiación solar válidas para los pronósticos de generación fotovoltaica, obteniendo muy buenas estimaciones y pronósticos de irradiación, con valores de R^2 superiores a 0,81 en todos los casos. Siendo el modelo más recomendable el de la descomposición de Fourier, con la que obtenemos unos mejores indicadores de los pronósticos y un índice de correlación R^2 superior a 0,95 en todos los casos.

5.3. DISCUSIÓN

5.3.1. Suministros energéticos y de agua. Emisiones asociadas

Este modelo de cálculo mostrado se ha aplicado a un destino turístico especifico, como es el archipiélago de las islas Canarias, el cual es un destino sensible y vulnerable medioambientalmente, debido a su dependencia energética externa, su gran valor ecológico y sus necesidades de desalación de agua. Convirtiéndolo en un buen laboratorio para poder comprobar los consumos energéticos y de agua de los edificios actuales, con las variables de ocupación y categorías, así como sus emisiones asociadas.

La dependencia energética externa actual de esta zona, es debida principalmente a la falta de inversiones y de no apostar por las energías verdes o EERR tanto por parte de las administraciones como de los empresarios, lo que ha genera en este destino, una huella del carbono muy superior a los destinos peninsulares. El principal factor implicado en estas emisiones tan importantes, son los coeficientes de emisión de CO_2 de la electricidad, siendo casi el triple en Canarias que en la Península, como se puede observar en la ***Figura 5.7*** donde se muestran los coeficientes mensuales de emisores promedios de la electricidad de los últimos años (2015 a 2017) de Canarias y Península *[REE]*.

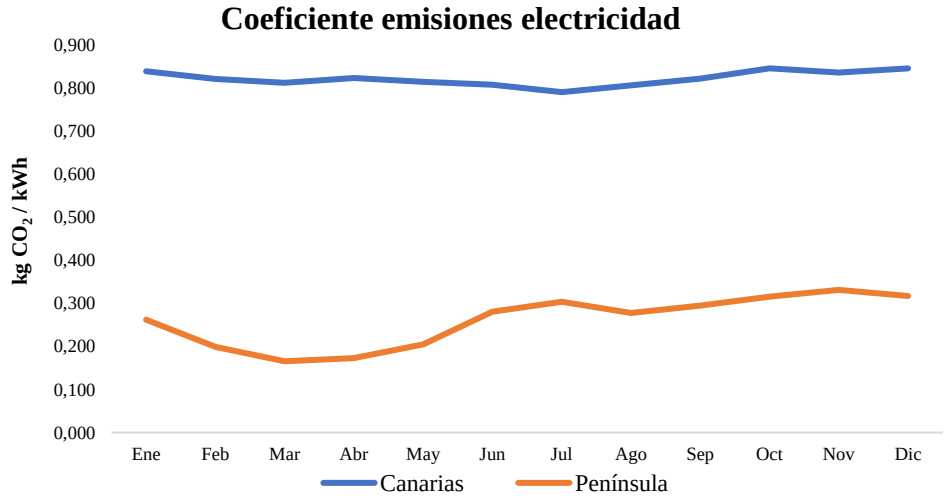


Figura 5.7. *Coeficientes de emisión mensuales promedio de la electricidad en suministro de media tensión de Canarias y Península.*

Con estos datos de coeficientes de emisiones, y teniendo en cuenta que el porcentaje de generación de EERR en Canarias es tal solo del 8% mientras que en Península ha variado entre

el 30% al 40% en los últimos años *[REE, 2018]*, se comprueba la necesidad de disminuir dichos coeficientes de emisiones de esta energía, para que la huella del carbono de los edificios hoteleros también disminuya, ya que como se ha dicho anteriormente el 60% del consumo energético promedio de los hoteles, corresponde a la electricidad, pero sus emisiones representan más del 83% de las emisiones totales de la energía.

En el cálculo de las emisiones totales de los establecimientos debidos a los suministros, también se han tenido en cuenta los correspondientes a la producción del agua, para lo cual hay que considerar que en la actualidad, más del 94% del agua suministrada y consumida en el archipiélago canario proviene de EDAM, y teniendo en cuenta el cambio climático y la disminución de las lluvias esperadas para mediados y finales de siglo, tanto en este destino y como en la Península, éste es el modelo de suministro que se considera sea el más probablemente utilizado para cubrir las demandas hídricas de los establecimientos y de las viviendas. La suma de los datos de energía y agua nos ha dado como resultado, la huella del carbono total de las estancias turísticas, comprobando las grandes diferencias entre las categorías hoteleras. En la siguientes ***Figura 5.8*** se puede observar los cálculos realizados para un grupo de hoteles de categoría 3,4 y 5 estrellas, para los valores de emisiones de energía y de agua mediante suministro centralizado, por las redes de abastecimiento actuales, comparándolo con los mismos hoteles a igualdad de consumos, si estuviesen en la Península.

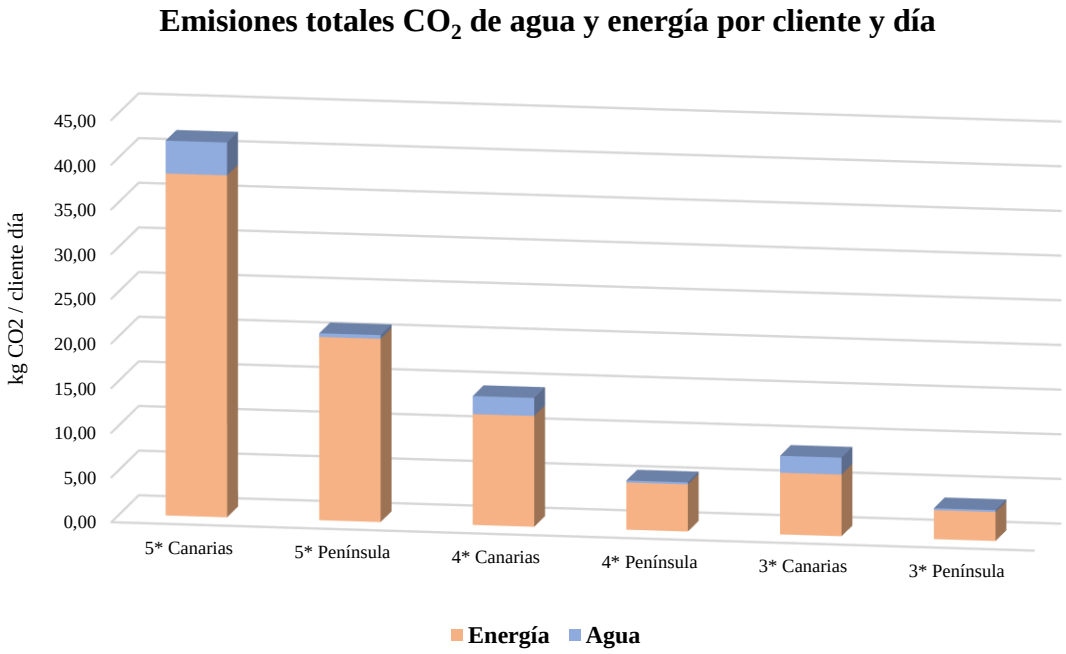


Figura 5.8. *Emisiones de CO_2 debidas a la energía y agua de hoteles de categorías 5,4 3 estrellas en Canarias y Península por cliente y día.*

Teniendo en cuenta las emisiones calculadas por pernoctación en la investigación realizada, se obtiene unas emisiones promedio por estancia de Canarias de 14,54 kg CO_2/estancia, de las emisiones totales de energía y agua. Realizando los cálculos de emisiones estimadas para el año 2017 según las pernoctaciones en el archipiélago *[ISTAC, 2018]*, y con los datos obtenidos del estudio que nos da los valores de emisiones de cada categoría, obtenemos los valores de emisiones totales anuales para cada categoría de hotel que se muestran en la ***Tabla 5.1.***

Categoría	Estancias	kg CO_2
1*	782.893	1.305.073
2*	2.907.491	9.928.048
3*	17.164.454	137.641.686
4*	44.649.618	607.041.031
5*	7.585.809	306.836.460
Total	**73.090.265**	**1.062.752.298**

Tabla 5.1. *Emisiones estimadas anuales por categoría hoteleras en Canarias año 2017.*

Con estos resultados de emisiones comprobamos que los hoteles de categorías superiores, 4 y 5 estrellas, que representan la mayor parte de las estancias en hoteles anuales, con un 71,5% del total, sus emisiones son muy superiores, correspondiéndoles el 86% de todas las emisiones de los establecimientos turísticos de Canarias. Estos datos nos muestran el camino a seguir y por donde se ha de empezar a realizar las reducciones de emisiones, la cual se ha de centrar en los establecimientos turísticos de categorías superiores. En la ***Figura 5.9*** se puede observar gráficamente, la importancia de las emisiones, principalmente de los establecimientos de 4 y 5 estrellas como se ha comentado.

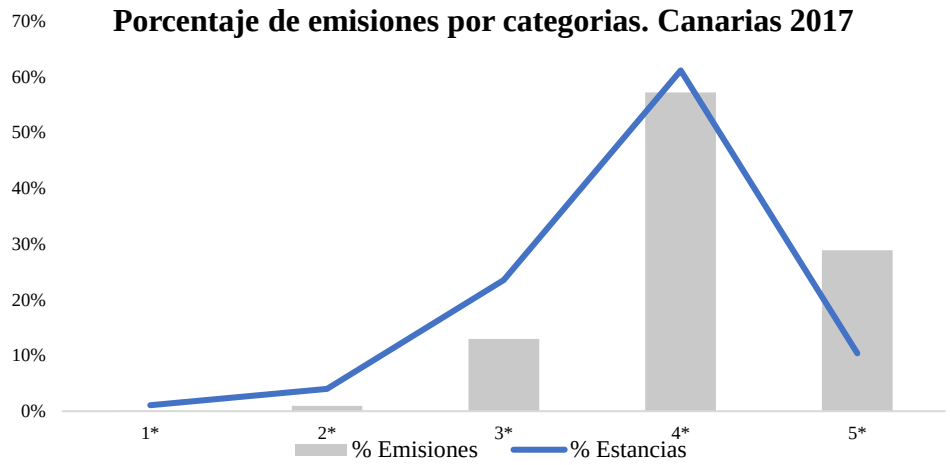


Figura 5.9. *Porcentaje de emisiones y estancias según categorías para Canarias 2017.*

5.3.2. Reducción de consumos y emisiones

Una vez que ya obtenidos los modelos de consumos característicos respecto de la ocupación de los establecimientos hoteleros de estudio, el consumo energético y de agua por categorías y sus emisiones asociadas, es necesario avanzar para comprobar cómo se pueden reducir estos consumos y emisiones de forma eficiente y económicamente viable, para que los edificios actuales puedan seguir con su actividad económica, manteniendo los servicios y sin que se vea afectada la calidad que demandan los clientes de este tipo de establecimientos.

Teniendo en cuenta que un hotel tiene múltiples instalaciones y sistemas consumidores de energía y agua, como pueden ser sistemas de calentamiento de agua caliente sanitaria (ACS), climatización (aire acondicionado (AA) o calefacción, según zonas climáticas), cocinas, instalaciones frigoríficas, alumbrado, piscinas y otros equipos consumidores varios. Respecto de la energía, los principales suministros son la electricidad y el gas, también utilizando en algunos hoteles gasoil y sistemas de EERR para generar energía térmica o eléctrica. Debido a la gran cantidad de sistemas, instalaciones y suministros es importante que cualquier estudio de mejoras o eficiencia energética se vaya realizando individualmente por sistemas o equipos para poder obtener resultados a corto plazo y lo más realistas posibles.

En la ***Figura 5.10*** se muestra un método sencillo que se puede considerar su uso para poder conseguir unos resultados adecuados en los planteamientos de mejoras, donde claramente se observa que hay que centrarse en las diferentes instalaciones de forma individual. En este caso se ha centrado el estudio en las piscinas, el suministro de agua local mediante desaladoras, las EERR basada en energía solar y otras instalaciones, para poder obtener unos resultados que sean más fácilmente evaluables. También se ha de tener en cuenta que con el conjunto de mejoras realizados sobre cada instalación, se debe de volver a realizar un análisis de consumos y emisiones, según los procedimientos de modelización mostrados, hasta conseguir los resultados finales deseados y esperados.

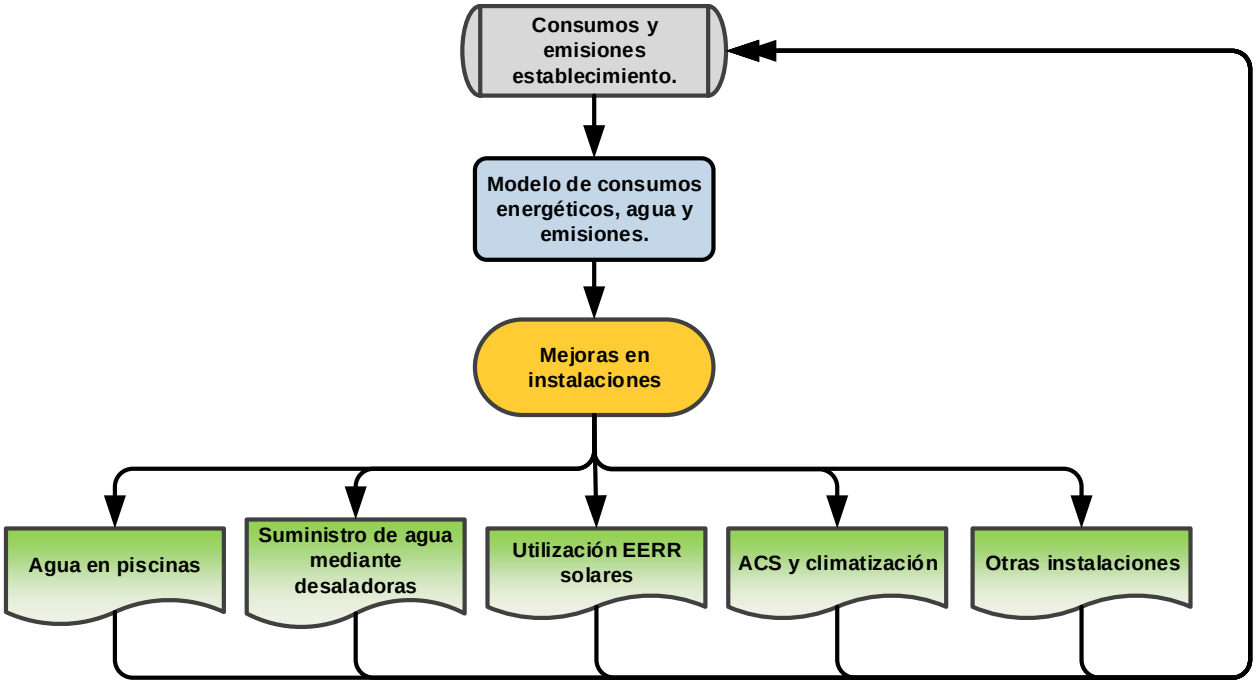


Figura 5.10. *Método de mejora de consumos e instalaciones en los establecimientos hoteleros.*

En la investigación realizada, se han estudiado estas instalaciones mostradas en la anterior figura, y sobre cada una de ellas se pueden realizar mejoras para aumentar su eficiencia, reducir consumos, o utilizar métodos o modelos alternativos para el pronóstico de las medidas a tomar. Dentro de los diferentes sistemas estudiados, se podrían realizar las siguientes mejoras que con los datos obtenidos en la investigación consideramos serían los más adecuados.

- **Agua de piscinas**. El consumo del agua de las piscinas es muy importante en los hoteles vacacionales, ya que se pueden considerar a las piscinas como un servicio casi imprescindible en este tipo de establecimientos y en el destino estudiado del archipiélago de las Islas Canarias, se ha comprobado como la mayoría de los hoteles actuales tienen piscinas. Las mejoras que implementar serían:
  - ✓ Reducción de los volúmenes totales de las piscinas, mediante vasos poco profundos, pero que sean confortables para el cliente, debido a que como se ha demostrado, el consumo de las piscinas es función del volumen de la misma.
  - ✓ Combinar los vasos de las diferentes piscinas, para conseguir el mínimo número de vasos de piscinas posibles, ya que, a igualdad de volumen total, cuantas más piscinas haya, mayores serán las pérdidas totales de las mismas.

- **Suministro de agua mediante EDAM**. Teniendo en cuenta que los modelos de desalación actuales se basan principalmente en las tecnologías de osmosis inversa, con EDAM propias o centralizadas para múltiples establecimientos y con distribución por las redes de suministro actuales, se debería mejorar en:
  - ✓ Todas las desaladoras han de tener sistemas de recuperación de energía mediante el agua de rechazo de las mismas.
  - ✓ En los establecimientos que se pueda utilizar desaladoras propias, se han de instalar para reducir las perdidas asociadas a la distribución centralizada.
  - ✓ Mantener y mejorar las redes de suministro actuales, para reducir las perdidas en los sistemas de distribución, que aumentan las emisiones de forma considerable, según la situación de dichos sistemas en cada isla. Estas diferencias se pueden observar en la ***Tabla 5.2***, donde se muestran los porcentajes de pérdidas de las redes de abastecimiento de los principales suministradores por islas, y el porcentaje de aumento de emisiones de las desaladoras centralizadas respecto de las locales.

ISLA	% Pérdidas en las redes de suministro	% Emisiones superiores de las desaladoras centralizadas respecto de las locales
Gran Canaria	23,0%	18,53%
Fuerteventura	35,8%	30,87%
Lanzarote	42,0%	36,84%
Tenerife	35,0%	30,10%
La Palma	43,0%	37,81%
La Gomera	24,0%	19,50%
El Hierro	48,7%	43,30%

Tabla 5.2. *Porcentaje de pérdidas en redes de suministro y aumento de emisiones del agua de las desaladoras centralizadas respecto de las locales.*

- **Utilización de EERR basadas en la energía solar**. Para conseguir la reducción de la huella del carbono de la producción energética en las zonas con alta dependencia externa, han de intentar reducir los coeficientes de emisiones generales de la energía, en este caso de la electricidad, para lo cual, basándose en las EERR solares, se ha de tener en cuenta:
  - ✓ Se han de utilizar de modelos de cálculo de pronósticos basados en bases de datos fiables para obtener valores realistas de producción energética, apoyado

principalmente en modelos de producción eléctrica mediante placas solares fotovoltaicas. Existen muchas diferencias entre las múltiples bases de datos existentes para una misma zona geográfica, por lo cual se ha de usar el que consiga unos pronósticos más acertados y realistas, comparando los valores pronosticados con los valores reales de instalaciones generadoras en funcionamiento, para poder escoger en cada caso las bases de datos más fiables.

- ✓ En la mayor parte de los edificios hoteleros las superficies libres para instalar sistemas de placas solares son escasas, por lo cual se han de usar los menores ángulos de inclinación posible para que admitan la mayor cantidad de placas solares por unidad de superficie posible. En la siguiente ***Figura 5.11*** se puede observar la importancia del incremento de la superficie de los colectores para una instalación en Canarias, comprobando como la superficie necesaria aumenta de forma considerable mientras que la diferencia ángulos no llega al 8% mientras que la superficie se puede incrementar en más del 80%.

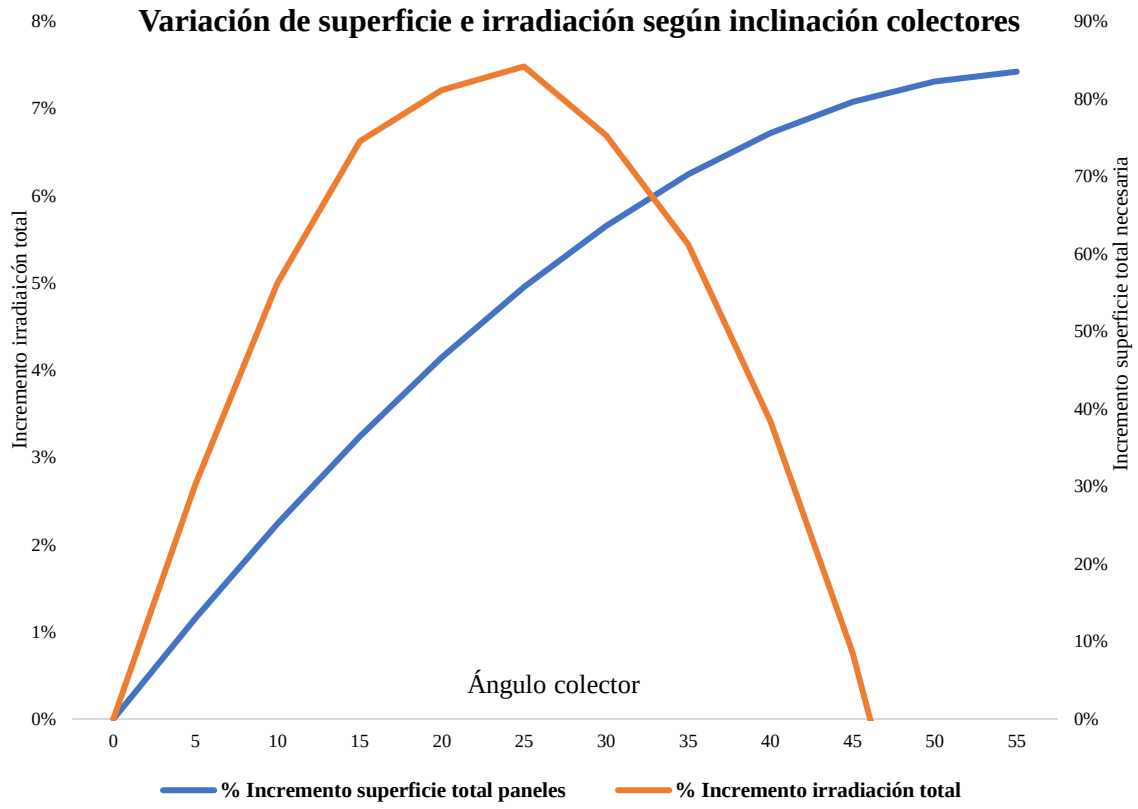


Figura 5.11. *Incremento de irradiación total y superficie necesaria de instalación con la variación de inclinación de los colectores.*

- ✓ En los casos donde no se disponga de datos fiables para los pronósticos de generación e irradiación, se utilizarán las instalaciones actuales en marcha como base para poder realizar los pronósticos mediante los múltiples modelos matemáticos de uso general que se pueden utilizar, como pueden ser el modelo ARIMA como se observa en la ***Figura 5.12,*** donde se muestran las curvas reales de irradiación calculada y los valores pronosticados mediante el método comentado, o por otros métodos como el modelo de descomposición de funciones de Fourier.

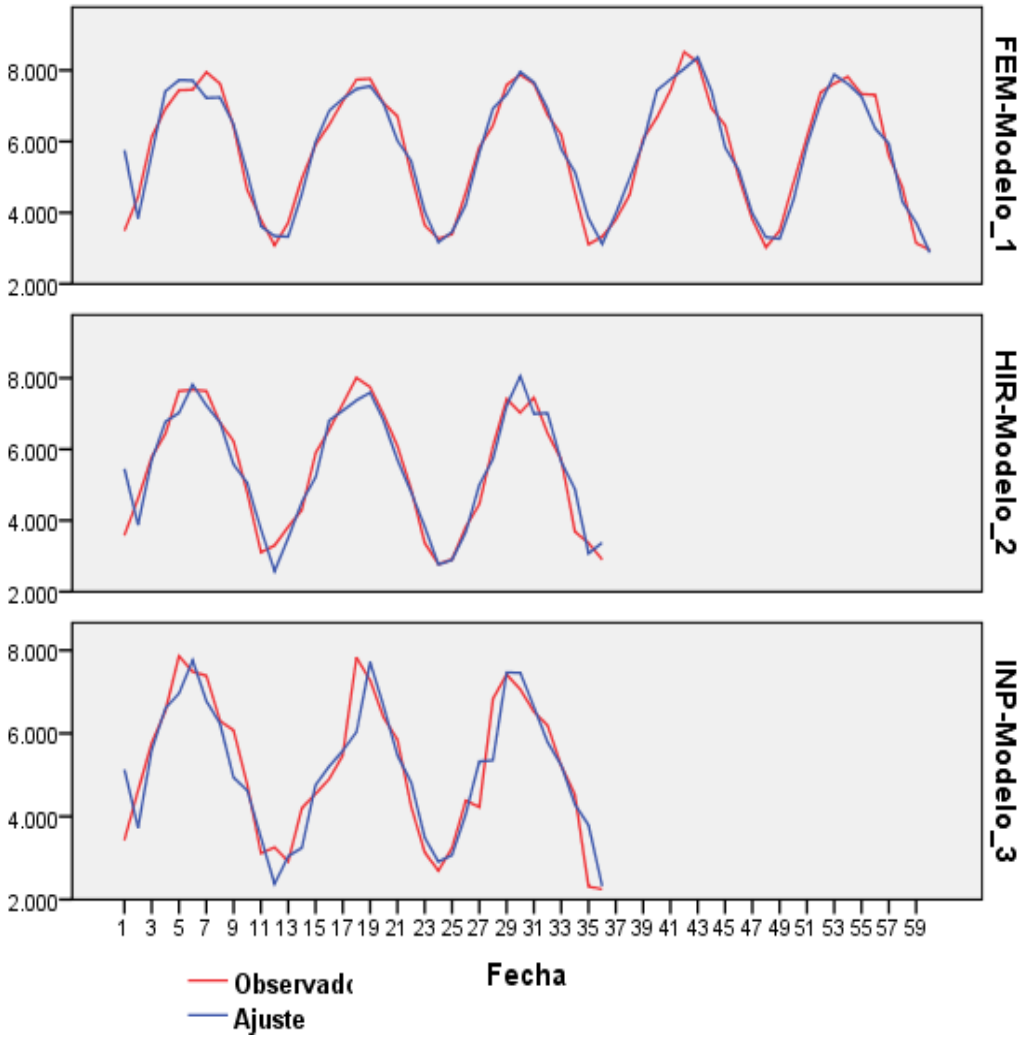


Figura 5.12. *Irradiación real calculada y pronosticada mediante el método ARIMA de tres instalaciones solares fotovoltaicas.*

- **ACS**. Como se ha demostrado, la viabilidad económica y rápido retorno de la inversión hace muy recomendable la instalación de equipos basados en bombas de calor de alta temperatura para poder obtener una reducción de consumos y de gastos económicos en el calentamiento del agua. Teniendo en cuenta la eficiencia de estos equipos se podrían realizar los siguientes sistemas de reducción energética con bombas de calor:
  - ✓ Realizar sistemas mixtos de ACS y aire acondicionado (AA)para recuperar el fluido condensado y poder reutilizarlo para el pre-enfriamiento de sistemas basados en enfriamiento de agua centralizado, o para la reducción de temperatura de locales o instalaciones que necesiten mantener una baja temperatura.
  - ✓ Utilización de sistemas de disipación más eficientes como pueden ser los geotérmicos o hidrotérmicos en zonas geográficas sea factible su utilización.
  - ✓ Utilizar modelos mixtos de bombas de calor y placas solares fotovoltaicas para reducir las emisiones debidas a la producción de ACS.

- **Otras instalaciones**. Como se comentó anteriormente, los edificios actuales están formados por múltiples instalaciones sobre las que se puede actuar (sin considerar su envolvente como posible mejora) siendo algunas de estas posibles mejoras las siguientes:
  - ✓ Buscar la escalabilidad de las instalaciones, que se puedan ajustar a la ocupación de los establecimientos, para no producir consumos innecesarios en las mismas, y que cada zona se pueda considerar como una parte fraccionable del establecimiento para su uso según demanda.
  - ✓ Realizar siempre estudios previos de consumos y emisiones de forma individual de cada sistema, para poder obtener varias alternativas de mejora.
  - ✓ La utilización del agua reutilizada para el riego se ha mostrado imprescindible para zonas con recursos hídricos escasos y teniendo en cuenta el cambio climático que reducirá las recargas hídricas y las reservas del subsuelo por la disminución de las lluvias, se han de buscar métodos de purificación para que estas aguas también se puedan utilizar para otros fines, como la limpieza de instalaciones.

5. DISCUSIÓN Y FUTURAS LÍNEAS DE INVESTIGACIÓN

Todas las mejoras en las instalaciones han de tener en cuenta su durabilidad, eficiencia y rentabilidad económica, para que su implantación sea viable para el futuro de la actividad del establecimiento, y que no disminuya las expectativas de los clientes, ni su bienestar, debido a las soluciones empleadas, si no que ha de seguir contando con los mismos servicios que disfrutaba.

Para los establecimientos hoteleros se ha mostrado los pasos a seguir, pero desde las instituciones, también hay que continuar trabajando para conseguir la sostenibilidad de los destinos, lo cual pasa por el giro de las políticas turísticas actuales para realizar una apuesta firme por las energías "verdes" o renovables, para que los destinos turísticos más medioambientalmente vulnerables logren una independencia energética e hídrica que minimice la huella del carbono generada en los mismos.

Las políticas turísticas de los gobiernos han de converger hacia modelos basados en legislaciones medioambientales y de eficiencia energéticas más restrictivas, con el fin de conseguir unos edificios más autosuficientes, energéticamente hablando, y poner medios para logralo, tanto financieros para las empresas como de inspección y control de los establecimientos actuales y futuros.

5.4. FUTURAS LÍNEAS DE INVESTIGACIÓN

Con los resultados obtenidos se ha comprobado como el modelo presentado es útil para los edificios turísticos actuales que tienen históricos de datos, siendo el principal problema que se puede encontrar con este modelo el cambio de las características de los establecimientos, sus instalaciones o clientes, para lo cual habría que actualizar los datos mediante valores calculados para las nuevas características de los mismos. Teniendo en cuenta esta necesidad de tener datos correctos y suficientes, se pueden considerar que las líneas futuras de investigación se han de centrar en el análisis y disminución de la huella ecológica del turismo, tanto a nivel de consumo de recursos, como de reducción de emisiones y los aspectos económicos de estas mejoras, así como el uso de tecnologías basadas en EERR. En la ***Figura 5.13*** se puede observar las futuras líneas de investigaciones a realizar.

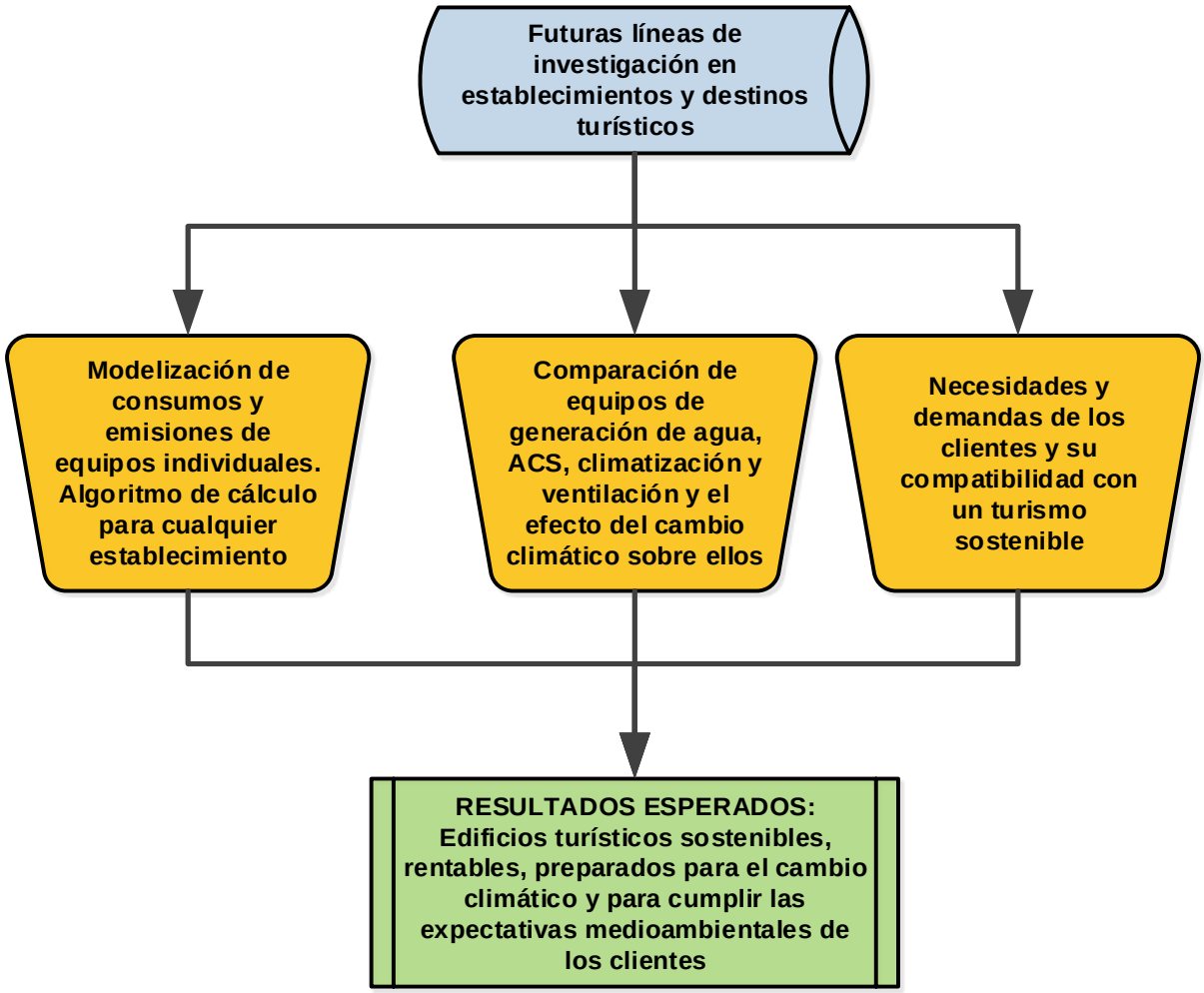


Figura 5.13. *Futuras líneas de investigación*

5. DISCUSIÓN Y FUTURAS LÍNEAS DE INVESTIGACIÓN

Los tres temás principales a desarrollar en futuras líneas de investigaciones serían:

- Modelizar los consumos energéticos, de agua y de emisiones de los equipos individuales de los edificios turísticos, teniendo en cuenta cada sistema e instalación individualmente, comprobando los factores principales que intervienen en dichos consumos, como pueden ser: ocupación, tipo de estancia, datos climáticos, año de instalación / fabricación, externalización de servicios, recursos accesibles, etc. Con estos datos generar los algoritmos de cálculo para poder evaluar de forma rápida y fiable la huella energética y ambiental de cualquier establecimiento, equipo o sistema de un establecimiento turístico, así como el producido por los diferentes tipos clientes.
- Comparación de las distintas tecnologías de equipos para la generación de agua, ACS, climatización y ventilación de las instalaciones, para comprobar cuales se adecuan más a los edificios actuales y la posibilidad de su instalación y amortizaciones futuras, teniendo en cuenta los datos de cambio climáticos previsibles en instalaciones de alta durabilidad, como pueden ser los sistemas solares térmicos o fotovoltaicos, los cuales ya se verán afectados por estos cambios en los parámetros climáticos, los cuales influyen en sus características de funcionamiento y rendimiento, así como su compatibilidad con lograr edificios ZEB.
- Las necesidades y demandas de los clientes y su compatibilidad con los destinos sostenibles. Mediante la comparación de la rentabilidad económica, la necesidad de sostenibilidad de los destinos, tanto a nivel medioambiental como de recursos energéticos y naturales, respecto de lo que el cliente espera obtener en el destino, crear un modelo de equilibrio, que sea provechoso para todos los interesados.

6.

CONCLUSIONES

6.1. CONCLUSIONES

La introspección del trabajo de investigación desarrollado en el ámbito de este estudio, que ha generado la publicación de varios artículos, alguno de ellos en revistas de alto impacto, permite extraer las siguientes conclusiones finales..

- Se ha descrito y verificado un método de cálculo mediante la aplicación de las funciones estadísticas y de correlación, con el cual se han obtenido los modelos y funciones características de los consumos típico de agua, electricidad y energía para un grupo de hoteles homogéneos de un segmento determinado, el cual se puede reproducir para cualquier otro tipo de hotel del sector y con ello, poder comprobar y comparar los consumos de los mismos.
- Queda de demostrado como los establecimientos de categoría superior (5 estrellas) tienen unos consumos y emisiones que triplican a los de categoría directamente inferior (4 estrellas) y quintuplican los de categorías más baja del estudio (3 estrellas).
- Se pone de manifiesto la importancia de la energía eléctrica para las emisiones totales de los establecimientos, que en los hoteles de estudio, representaban más del 83% de las emisiones del consumo energético, cuando solo representan el 58% de la energía consumida, siendo los coeficientes de emisión de Canarias cerca de 3 veces superior a los peninsulares, siendo los culpables de estas altas emisiones el tener tan solo el 8% de este tipo de energía generada por EERR.
- Con el cálculo del aprovechamiento del agua reutilizada para el riego se ha estimado que se podría reducir el 15% del consumo de agua potable total debido al riego, análogamente, con el uso de agua de mar o de pozos para las piscinas, se podría reducir el 16% del agua potable debido al consumo en piscinas. Todo esto totalizaría una media de disminución del 31% el consumo de agua, y consecuentemente, mitigaría las emisiones producidas por la generación de estos recursos hídricos.
- Se han valorado cuantitativamente los consumos y emisiones producidas para la producción del agua necesaria para el mantenimiento de las piscinas turísticas, evidenciando el gran consumo de agua que generan, ya que las renovaciones diarias de agua promedio son de un 2% del volumen de las mismas.

6. CONCLUSIONES

- Queda demostrado que la generación de agua de forma industrial es más rentable, tanto económica como medioambientalmente, mediante la instalación de plantas de desalinización locales en los centros de consumo, que generan un menor gasto energéticos y de emisiones, que las plantas centralizadas lejos de los consumidores, las cuales suministran mediante redes de abastecimiento que generan grandes pérdidas y un sobrecoste energético y medioambiental que sea calculado superior al 28% que las plantas locales.
- Se ha demostrado la viabilidad económica y energética de utilizar bombas de calor de alta temperatura para la reducción de los consumos energéticos y económicos de los establecimientos debidos al calentamiento de agua para el ACS.
- Para la obtención de pronósticos fiables y realistas de la producción de EERR basadas en la radiación solar, como son la generación fotovoltaica y la térmica para climatización y ACS, se han estudiado un método para la creación de pronósticos fiables, basado en el estudio estadístico de equipos generadores actuales, para estimar la irradiación real de zonas específicas, lo cual dio unos valores muy altos de correlación r^2 cercanos al 0,95.

Como síntesis de la investigación realizada, se puede concluir que, para la reducción de los GEI y los consumos energéticos y de agua de los edificios turísticos, y como paso previo para conseguir edificios ZEB o nZEB, se han de centrar los trabajos en cuatro puntos generales:

- Realizar estudios de consumos energéticos y de agua de los edificios actuales, para generar una base para identificar las posibles reducciones a aplicar.
- La producción de agua industrial se ha de realizar mediante EERR en los centros consumidores y reducir las perdidas de las redes de suministro.
- La utilización de sistemas mixtos de instalaciones térmicas para poder reutilizar la energía sobrante de los diferentes sistemas mediante modelos de recuperación energía en ambos sistemas frío / calor.
- La generación energética se ha de basar en EERR, y los pronósticos de generación se han de fundamentar en estudios y bases de datos fiables, adaptados a cada zona e instalación que se vayan a implantar.

6. CONCLUSIONES

Finalmente y ante las proyecciones futuras de cambio climático, apremian actuaciones urgentes para poder reducir las emisiones de CO_2. Los resultados de esta investigación sirven para proponer fundamentos, definir procedimientos y establecer herramientas, que actuarían sobre la eficiencia energética con reducción de consumos de agua y energía en los edificios turísticos y se confirma que el único camino posible para conseguir la sostenibilidad de los destinos turísticos pasa por el giro de las políticas empresariales turísticas para una apuesta firme por las energías "verdes" o renovables, que den una independencia energética e hídrica a los diferentes establecimientos, especialmente en los destinos más vulnerables medioambientalmente y climáticamente debido al impacto del cambio climático.

7.

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ANEXOS

Anexo 1. Autorización y toma de conocimiento.

Anexo 2. Paper: Assement solar database regarding production values in Fuerteventura photovoltaic installations. Indian Journal of Science and Technology, Volume 10, Issue 13, April 2017, Pp:16. DOI: 10.17485/ijst/2017/v10i13/110724.

Anexo 3. Capítulo de libro: Advanced Engineering Research and Applications. Volume - VII, Comparison of Solar Irradiation Data Bases for the Production of Photovoltaic Electric energy. Capitulo 30, Pag 494-529. ISBN: 978-93-87374-27-0.

Anexo 4. Congreso: International Conference on Recent Innovations in Engineering and Technology (ICRIET-16). Modeling of energy and water supplies in hotels in lanzarote and Fuerteventura with and without desalination plant (swrop). 5 y 6 de noviembre de 2016. Gandhi Institute of Engineering & Technology, (G.I.E.T), Gunupur, 765022, Rayagada, Odisha. India. ISBN: 97-9386163-56-1, Track IV, chapter 19, Track IV, chapter 19.

Anexo 5. Congreso: 6Th International conference on advances in civil, architecture and environmental engineering (ICCAEE-2018) Reduction Of Energy Consumption In Hotels With Aerothermal Energy. Case Study: Canary Islands (Spain).

Anexo 1. Autorización y toma de conocimiento

El autor **D. Francisco Javier Díaz Pérez** de los siguientes artículos y libros publicados, autoriza y se da por enterado, de que dichos trabajos se van a utilizar como parte de este trabajo de investigación y confirma que ninguno de ellos se ha utilizado previamente como parte de alguna tesis doctoral.

- Mathematical Model of Supply Water of Consumption Systems in Hotels. International Journal of Applied Engineering Research. Volume 11, Issue 23, (2016). Pp. 11350-11357.
- Modeling of energy and water supplies in hotels in Lanzarote and Fuerteventura with and without desalination plant (SWROP). Indian Journal of Science and Technology. Volume 9, Issue 47, December 2016.Pp: 19
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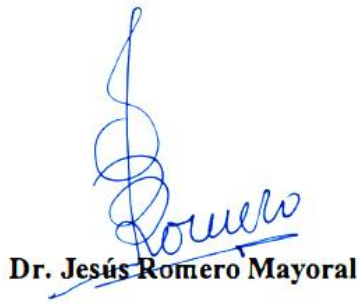
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Dr. Carlos Martínez Domínguez

Anexo 2. Paper: Assement solar database regarding production values in Fuerteventura photovoltaic installations.

Resumen

El conocimiento de la radiación incidente en un área geográfica es muy importante para múltiples facetas del desarrollo de la zona. Los sistemas de cálculo actuales se basan en modelos estadísticos de las mediciones de estaciones locales terrestres o mediante cálculos de la radiación externa por modelos de cálculo de radiación externa medida por satélites. En el siguiente artículo realizamos un estudio de diferentes bases de datos (DB) de irradiación utilizadas para los cálculos de producción de energía solar fotovoltaica, comparando los valores de 8 DB ampliamente reconocidas y utilizadas: PVGIS-Helioclim, Adrase-Ciemat, NASA-SSE, AEMET, Soda-pro, ITC, IDAE-Censolar, y UNE 94003:2007, respecto de los valores de irradiación equivalentes calculados para 11 instalaciones generadoras en funcionamiento conectadas a red, con ángulo de inclinación de 10º, todas ellas ubicadas en la isla de Fuerteventura, en el archipiélago de las Canarias y con potencias máximas instaladas desde los 88 kW a los 552 kW.

Comprobamos con los datos obtenidos y calculados, que las diferencias entre valores pronosticados de las diferentes DB y los reales obtenidos de las instalaciones, pueden llegar a unas diferencias mensuales superiores al 30% y anuales de un 10%, siendo los meses con mayor diferencia los de invierno y otoño. El cálculo de irradiación equivalente para superficies inclinadas se realiza mediante el sistema simplificado por cálculos del ángulo de incidencia mensual, que nos da valores de irradiación global equivalente con valores aproximados de +- 2% entre inclinaciones de 1º a 55º del generador fotovoltaico. Se finaliza calculando los datos de irradiación real de Fuerteventura para superficies planas, y generando la función polinómica que describe la irradiación real mensual en la isla según los datos de generación de las instalaciones de estudio.

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Assement Solar Database Regarding Production Values in Fuerteventura Photovoltaic Installations

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Abstract

Objectives: To investigate the differences between the 8 main databases irradiation, from the values of equivalent irradiation of 11 generating facilities in operation for the Canaries. **Methods/Statistical Analysis**: Itobtains the data of the 8 bases of irradiation (DBs) for 0º and pass for 10º of inclination. It compared the average real of all 11 facilities and compared to those of the study DBs, then calculates the equivalent irradiation on flat surfaces at 0º and compared the values of DBs respect to the calculated for the investigated facilities. Calculate the polynomial function for the irradiation curve from the real valour's of the installations **Findings:** We verified with the data obtained and calculated that the differences between predicted values of the different DBs and the real ones obtained from the facilities can reach monthly differences of more than 30% and annual differences of 10%, the months with the greatest difference being those of winter and autumn. The calculation of equivalent irradiation for inclined surfaces is performed by the simplified system by calculations of the monthly incidence angle, which gives us equivalent global irradiance values with approximate values of +-2% between inclinations of 1 to 55º of the photovoltaic generator. Recommending the use of the data from the UNE 94003: 2007 standard and AEMET data with a difference of less than 1% per year for horizontal surfaces. The PVGIS database is too optimistic in its calculations and its values tend to be with 10% higher yields. The values obtained from differences between databases are comparable with others obtained in their comparisons with data obtained by satellites or in areas such as Poland. **Application/Improvements:** The article concludes that with the data and the function obtained, realistic forecast can be made quickly and easily for further study.

Keywords: PV, Energy in Canary Islands, nZEB, Irradiation, Photovoltaic, Renewable Energy, Solar Energy

1. Introduction

Photovoltaic solar energy is an energy considered as clean and renewable, recognizing its primary fuel as inexhaustible, which are the energy of the photons emitted by our star the Sun. Among its most important and main features of this energy, it can highlight its Free disposition, gratuitousness and its foreseeable duration of millions of years. In addition, photovoltaic solar installations have the possibility of being modular and increasing the power of the generating plants in a simple way, through an increase of generation surfaces, as well as the possibility of architectural integration in current buildings, which makes it highly recommended for installation (ZEB) or near zero (nZEB)[1,2], there being many examples of its application as integration of photovoltaic solar panels in buildings, Building Integrated Photovoltaics (BIPV)[3,4] and in other types of facilities such as airports[5], the main and most important disadvantage is that its production is linked to sunlight, so it can occur during the day, depending on the weather conditions and the incidence of the solar rays of the site where they are installed. It is also verified that the surplus is very small compared to the solar energy received on the surface of the solar plaques, which is increasing annually, passing from its beginnings in 1883 with a yield of 1%[6], up to the current values of the plates Of modern silicon with yields of 25%[7], being the values of generic panels in the market today, between 12% and 16%.

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Taking into account Spain's photovoltaic potential, due to its geographical location, its annual irradiation and the incentives developed by the different Spanish governments to stimulate the installation of photovoltaic plants, together with the rest of renewable energies (RREE)[8-10], achieved that installation of grid-connected generating plants, increased potentially between 2006 and 2011[11]. This continued increase in facilities and the impossibility of sustainability of the incentive system, the different governments were cutting these subsidies to production, beginning in 2010[12] and ending with the definitive suspension of these subsidies and incentives to production in the year 2012[13]. This meant a standstill of the new facilities as of that year, as can be check in Figure1 on the evolution of the photovoltaic power plant at the national level, where it can be observed that as of 2012 the installed power remains constant without increasing it. Due to this suspension of the remunerations to renewable, at present the installations with connection to network no longer have a profitability comparable to the years prior to 2012, although, due to its expected duration of the installations of 25 years, it has not stopped being a bad investment, but with a very low profitability, provided that legal certainty is maintained in its regulation[14].

The self-consumption and BIPV applications have become an interesting model for their installation[15] and integration in existing buildings, which together with other RERs can be made mixed generation models [16-18] to cover the different demands of energy of the buildings, in order to obtain buildings ZEB or nZEB. On the part of the International Energy Agency (IEA), a study on self-consumption through solar photovoltaic energy has been carried out, comparing and informing on the policies of the different countries[19] regarding viability and legislation on self-consumption. Spain is the fourth country of the European Economic Community (EEC), with the highest average annual irradiation[20], which places it in a leading position in order to achieve high yields in photovoltaic solar installations, with any self-consumption facility being much more efficient In Spain than in most countries of the EEC. This generation potential is also applicable to the archipelago of the Canary Islands, an ultra-peripheral region of Europe, located between the co-ordinates 27° 37 'and 29° 25' north latitude and 13° 20 'and 18° 10' west longitude, at about 940 Km to the south of the European continent, but whose average annual irradiation is comparable to the south of mainland Spain, as can be seen by its consideration as zone V, according to the zoning made by the technical code of the building (CTE)[21] in force in Spain.



Source: Spanish Electricity Grid (REE) [11]

Figure 1. Photovoltaic power installed Spain.

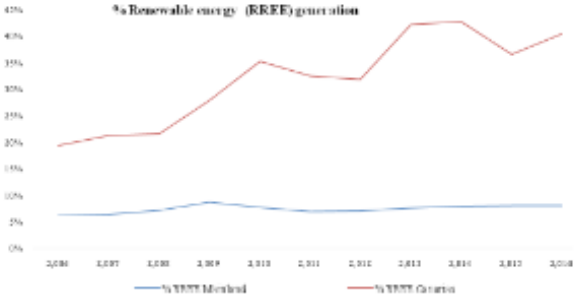


Figure 2. Percentage of RREE generation over the total electricity generation 2006-2016 in the peninsula and the Canaries. Source: REE[11]

Canary Islands, the need for generation through RREE, being an area of special importance, both ecologically and in the capacity to implement development models compatible with its conservation, is very important, proof of this is that 63%[22] of the archipelago's surface is declared a Biosphere Reserve by United Nations Educational, Scientific and Cultural Organisation (UNESCO). The canary current energy model has as one of its main needs to be able to achieve an environmentally sustainable system, the amplification of the systems of generation byRREE, being in values of generation by renewable well below peninsular Spain, where this type of generation has gone from a 19.4% in 2006 to 40.5% in 2016, while in the Canaries its value has remained almost unchanged, from 6.2% in 2006 to 8% in 2016[11], as can be observed In Figure 2, of the structure of electric power generation between 2006 and 2016.

This use of the RREE, has managed to reduce the emission coefficient due to electricity production in mainland Spain 40%, between the period 2006 to2016, being the

reduction for the Canary Islands of only 7%. This causes that the emission factors of the electrical generation are 262% higher in the Canary Islands than in the Peninsula, as can be seen in Figure 3.

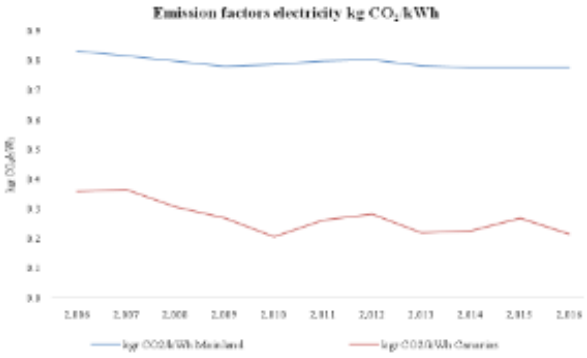


Figure 3. Evolution emission factors Spain peninsular and Canary Islands 2006-2016. Source: REE[11]

Taking into account the importance of continuing with the reduction of CO2 emissions, due to the influence on the climate change that they produce[22], and the possibility of realizing systems of self-generation by photovoltaic solar panels in areas with high irradiation, such as the Canary Islands. It is necessary to verify that the estimated production data calculated by means of the different existing irradiation DBs corresponds to the actual generation of the planned and running plants, since for the estimation of the production of electric energy by means of PV, the main data needed is the irradiation of the installation area, being in this case an area of the archipelago of the Canaries, which together with the characteristics of the generator itself, will give us the estimated production values for each generating plant. The irradiation data is obtained from the different DBs that are publicly accessible, in most cases, and by means of which an approximate production can be estimated. The different values of the DBs can generate very high estimation differences, as can be verified in the study of irradiation data calculated by satellites[24,25] or in the web-based comparison for Poland[26] over estimation of the winters and the summers are underestimated.

The comparisons of data will be made for 8DB of free access through the corresponding websites of each of them or through access to public regulations. The DBs are: PVGIS-Helioclim, ADRASE-Ciemat, NASA, AEMET, Soda-pro, ITC-Canarias, IDAE-Censolar and UNE standard 94003:2007, comparing the irradiance data of flat surfaces with the calculated values of irradiation for 11 installations of peak power or maximum installed between 88kW and 552kW, all of them with angle of inclination of the plates of 10º.

2. Experimental

Earth Planet, due to its movement of translation around the sun and the decline of the axis of rotation, produces a difference in the incidence of solar radiation between + 23.45° to -23.45°, with respect to the reference latitude. This difference makes it necessary to calculate the decline of the earth each day, in order to estimate the optical angle of the photovoltaic solar panels, in order to achieve the highest irradiation. For the calculations of the angle of decline of the earth relative to the Sun, it use the well-known Cooper equation[27], which gives the value of the approximate decline of the reference point at solar noon of the day considered

$$\delta(n) = 23,45 \bullet sen\left[360 \bullet \left(\frac{284 + n}{365}\right)\right]$$

Where "n" is chosen day counting from January 1 to the day in question. In this study we will use the average decline for each day 15 of each month (14 in February), to later calculate the optimum slope of the collectors on that date, where it would receive the solar rays in a perpendicular way and be able to take advantage of 100% of the energy. The angle of each day will be given by the formula:

$$\beta(n) = \theta - \delta(n)$$

Where "θ" is the latitude of the place, "δ (n)" is the declination of the earth on the chosen calculation day. It should be noted that the slope or angle of the collectors calculated will be South in the Northern Hemisphere and North in the Southern Hemisphere.

The other adjustable angle of the solar panels is the azimuth, which is the orientation angle of the panels with respect to the north south axis thereof. In our case the facilities are always oriented to the south to 0º, per local will not be taken into account. Since the azimuth is a not very important reduction factor, with annual values that, according to the CTE[21], the value of approximate losses can be calculated for slope values of panels larger than 15°, by means of the function:

$$L_{\downarrow}az = 1 - (3,5 \cdot [10]^{\intercal}(-5) \bullet \mu^{\intercal}2\ )$$

Where "μ" is the azimuth angle to the South.

To take into account that the global irradiation data of the different DBs that are obtained are for flat surfaces, so

it is necessary to calculate the same for inclined surfaces. In order to obtain this new value as accurate as possible, the values of the three components of direct, diffuse and albedo radiation must be found, with several methods for obtaining and estimating them[28-31]. For our model of approximation, we will use the global irradiance values of the DB for the flat surface and calculate the global irradiance value for the angle of inclination of the panels, according to the latitude of the place, for the 15th day of each month (14 In February), with the calculation function where the multiplying factor of the irradiance value is obtained for flat surfaces, and will give us the approximate result for the inclined surfaces, by means of the following function:

$$K(n) = \frac{\cos(\theta - \alpha - \delta(n)}{\cos(\theta - \delta(n))}$$

$$G(\beta) = K(n) * G(0^{\circ})$$

Where "θ" is the latitude of the place, "n" is the chosen day counting from January 1 to the day in question, "δ (n)" is the declination and of the earth on the chosen calculation day, A "is the fixed inclination angle of the solar panels e" G (0°) "is the irradiance value for flat surfaces at 0°.

The approximation values of this method are sufficient for this study, since as can be verified in Figure 4, the differences between the values calculated by this method described above or by the decomposition of global irradiation in direct, diffuse and albeo that the base performs of European PVGIS-Helioclim data, we obtain a maximum difference for the average annual value of 5% at inclinations of 70º. In our research, with 10º tilt angles, the difference is 1.31% over the annual average, so it will use this approximation method.

2.1. Calculus Production

In order to carry out generation calculations using PVs, it is necessary to take into account the incident radiation at each moment, the maximum or peak power of the generator and the total losses, which are included in a total efficiency index known as "Performance ratio" (PR)[32]. With the following function we calculate the generated energy injected in the network, at each moment:

$$E_{red} = PR * G(\beta, \mu) * P_{pp}$$

Where "PR" is the global loss index that encompasses all losses of the system, "G(β, μ)" is the mean irradiance according to a declination and a given azimuth and "Ppp" is the maximum power of photovoltaic generators

The calculation of the PR is made taking into account all the losses of the generating system, which are given by the function:

$$PR = (1 - (L_T + L_D + L_R + L_p)) * L_E * L_{In} * L_V$$

The meaning and calculation of the different terms of the equation are as follows:

Temperature loss of the "LT" module. Due to the operation at a temperature different from the one calculated in standard conditions, it generates losses that we calculate them by the method of Osterwald[33], that according to the Tº of the cells we will have losses, that comes given by the function

$$L_T = 1 - (\gamma * (T_C - 25))$$

$$T_C = T_a + \left(G_{in} * \frac{NOCT - 25}{800}\right)$$

Where "Gin" is the instantaneous or average daily radiation in W/m², "γ" is the coefficient of variation of the maximum power point with temperature, "Tc" is the plate temperature, "Ta" is the ambient temperature And "NOCT"[34] is the nominal operating temperature of the module for radiation values of 800W/m², 20ºC ambient temperature, with AM 1.5G spectral distribution and 1 m/s air velocity.

Lost by dispersion of parameters "LD". The PVs are not exactly the same and have a power difference between them, so these differences create losses in generation.

Dirt of "LP" plates. Losses due to dust on the modules. In Canary Islands due to the episodes of "**calima**"[35], this parameter becomes very important and its value can become very high if the modules are not cleaned regularly.

Lost by angular and spectral reflectance "LR". Due to the angles of incidence of the solar rays and the selective spectrum of the photocells, whose current generated is different for each wavelength of the solar spectrum of the incident radiation.

Losses due to the efficiency of the "LIn" inverter. The European efficiency value of the inverter[36] given by the manufacturer, which is calculated by the function

$$\eta_E = \sum a_{eu} * \eta_{i_{MPP}}$$

Where "aeu" is the European weighting factor, "ηi_MPP" corresponds to the inverter / follower performance / efficiency value for the maximum power point, "η5" represents the performance at 5% of the power of the follower, "η10 " to 10% and so on, with the different yields expressed for the powers represented by the subscript.

Lost in "LE" electrical wiring. Total losses due to voltage drop from the DC and AC part.

Other "LV" losses. There are several other losses not previously considered.

In order to make a comparison of the efficiency of the systems using a common unit or index, the value of YF[32], which represents equivalent or peak solar hours (HSP), is a unit that measures solar irradiation and is defined as the time in hours of a hypothetical constant solar irradiance of 1000 W/m² calculated in standard conditions (STC), that in case of knowing the generated energy is given by the expression:

$$YF = HSP = \frac{E_{red}}{P_{pp}}$$

Where "Ered" is the generated energy injected into the grid, and "Ppp" is the maximum power of photovoltaic generators.

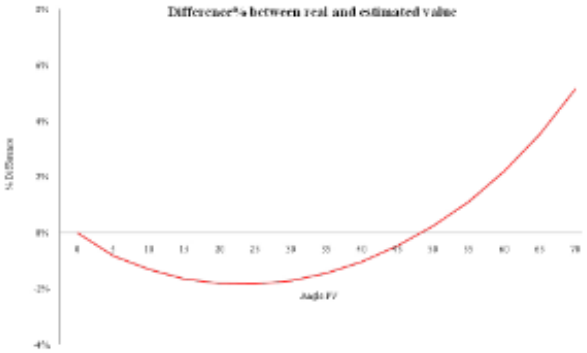


Figure 4. Differences between the value obtained by PVGIS and the approximate used, for the annual average of irradiation.

2.2. Methods

The method used to compare the actual data with those of the study DBs was the following:

1. Initially the data of the irradiation values of the different DBs of their web pages or recognized documents and those of production of the study plants supplied by the managers of the facilities were obtained.
2. We pass the irradiance value from flat surface to inclined surface of all DBs, obtaining the monthly irradiation values at 10º of inclination, as well as their average, maximum and minimum values.
3. We calculate the average "PR" for all the research facilities, for which we took the average radiation values of all the data of the monthly DB, obtaining the value of the PR for each month. As the plates are with similar characteristics we use the standard values for all of them.
4. With the data of monthly irradiation and "PR" we calculate the equivalent HSP of each of the DB. The HSPs of the different facilities are also calculated by monthly production of the same and their maximum power or peak installed, obtaining the monthly data per installation as the averages of the generation of the years per installation.
5. We compare the average real HSP data of all the facilities, compared to those of the study DBs at the 10º angle of the plates. Compare the actual generation data with the different DBs: total annual values and monthly values.
6. We pass the actual HSP generation data to equivalent flat surface values at 0º, using the conversion factor K and compare the values. With this data we calculate the equivalent irradiation on flat surfaces at 0º.
7. We compared the values of annual and monthly irradiance on a flat surface at 0º of DBs with respect to the calculated real equivalent for the investigated facilities.
8. Calculate the polynomial function for the equivalent irradiation curve in Fuerte ventura using the calculated irradiance data from the real installations.

Figure 5 shows the flow diagram of the research carried out to obtain the actual irradiation data of the installations and their comparison with the data of the different general use DBs.

3. Analysis Data

The data of solar irradiation are fundamentally able to realize any calculation of photovoltaic installations, being able to obtain the same ones of several local or global DBs. In this study eight international comparisons are being made, widely used by designers around the world. Have been chosen for the realization of the investigation are the following:

3.1 PVGIS - Helioclim[37]

- The EEC photovoltaic information system, which through the network of meteorological stations, satellites and by means of data interpolation, performs its irradiation calculations with a GIS positioning system and the model "r .sun " [38]. Widely used by all types of institutions and

designers, with data from Europe, Africa and Asia for any inclination.

3.2 ADRASE - Ciemat[39]

- Access to solar radiation data from Spain (ADRASE) of the Spanish government's energy, environmental and technological research centre (CIEMAT), which supplies solar radiation data from Spain with a resolution of 5x5 km, with averages of values from the last 20 years of satellite measurements and 50 ground stations. Calculations are obtained for percentile 25 and 75, as well as maximum and minimum[40] of the different zones. Data are taken from the 75th percentile for the study.

3.3 NASA-SSE[41]

- Meteorological and solar data sponsored by the US National Aeronautics and Space Administration (NASA) in the Surface Meteorology and Solar Energy (SSE) program, which provides data for the whole world, with solar radiation values on a horizontal plane. Covers a resolution of 100x100 km. Average of temporary data of 22 years. It compares the data of the satellites with those of its world stations on land. Widely used globally for comparative irradiation studies [42-44].

3.4 AEMET[45]

- Data provided by Spain's state meteorological agency (AEMET), whose data have been condensed into Spain's solar radiation atlas[46], with data averages from 1983 to 2005, using satellite data and of the national radiometric network. Average values data are used. The resolution of data is of 3x3 km and the values of provincial capitals are given. In this case, data from Las Palmas de Gran Canarias are used.

3.5 Soda-pro[47]

- A service created from the Information Society Technologies (IST) program of the European Commission for the year 2000[48]. This service offers time series of monthly, weekly and daily values of global solar irradiation in a horizontal plane, as well as the monthly irradiation received by a plane normal to the solar rays. The geographical coverage corresponds to the field of vision of the Meteosat satellite, ie, it covers Europe, Africa, the Atlantic Ocean and theMiddle East. The spatial resolution is approximately 20x20 km. The temporal coverage of the data is from 1985 to 2005.

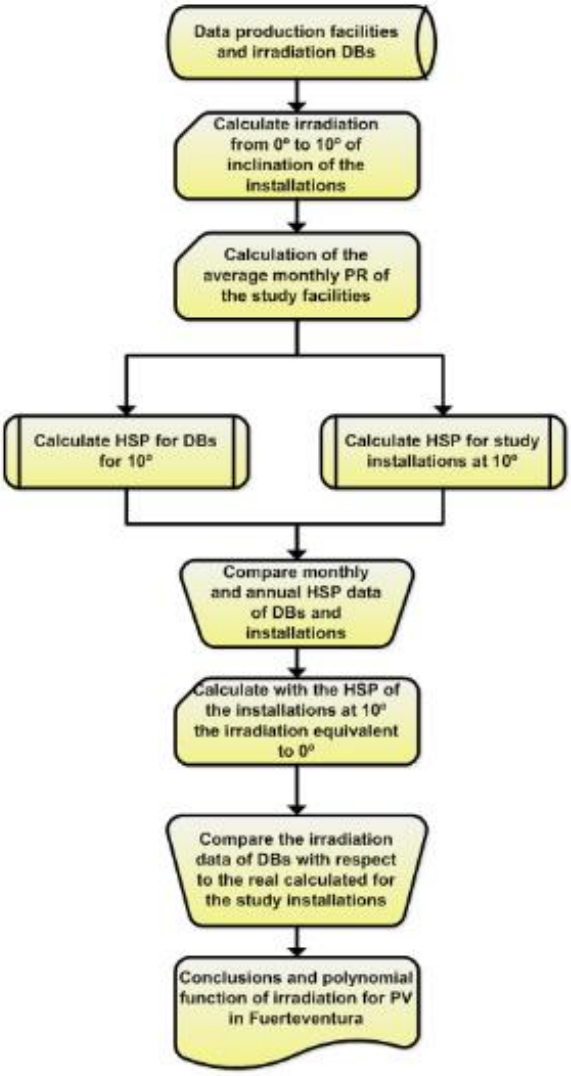


Figure 5. Research Flow Diagram.

3.6 ITC-Canarias[49]

- Data from the Canaries of the Canary Islands Technological Institute (ITC) which have been

obtained from 51 radiometric stations between 1998 and 2009. A geographic information system with approximate resolution of 250x250m per pixel. The data are for horizontal global irradiation and global horizontal irradiation to sky. The data we use are horizontal global irradiation.

3.7 IDAE - Censolar[50]

- The Institute for Diversification and Energy Saving (IDAE) also makes available the solar radiation tables of the company Censolar, for use in the calculation of solar thermal plates[51], checking its utility for photovoltaics' in this study. Average data on the irradiation of provincial capital of various models of calculation of external radiation and by measuring stations, with adjustments of approximately -10% of the actual values that are not useful for useful generation. It refers to provincial capitals, in this case, the data of Las Palmas de Gran Canarias are used.

3.8 UNE 94003: 2007[52]

- Spanish national standard that provides the reference values of global daily irradiance, daily and monthly temperature on horizontal surface, for calculations of low temperature solar thermal plants, but we will check in this study its Useful for calculations of photovoltaic generation. It refers to provincial capitals, in this case, the data of Las Palmas de Gran Canarias are used.

In the following Table 1, all the data of average irradiation for horizontal surfaces of the different DBs for the study area, that is the capital of the island of Fuerteventura, Puerto del Rosario, located in the coordinates 28.50º north and 13 , 86º west. This is the easternmost and closest island to Africa, the archipelago of the Canary Islands (Spain). The data will be compared to verify the maximum, minimum and average values of the different DBs, where it can be seen that the differences between irradiation values are very high, reaching values of about 28% difference. In the annual averages, we find differences of 20%, values which to make estimations are already considerable, for calculations of viability of solar installations and must be taken into account for adjustments of possible projects. The shaded DBs give values of the provincial capital, Las Palmas de Gran Canarias and not Puerto del Rosario, being those that have to be used for the whole province, for which, these values are used for comparison.

The data of temperature and daily in isolation will be used those supplied by AEMET for the station located in the municipality of Puerto del Rosario through several programs of public use of AEMET[53,54] and obtaining the values that appear in Table 2. It can be observed as the average temperatures of 1980-2010 and 2010-2015 have increased an average of 3% in recent years, due to which we will use the average data of the most updated years

Table 1. Solar irradiation data in kWh/m² month of study DB for horizontal surfaces 0º

MONTH	PVGIS Helioclim	ADRASE Ciemat	NASA	AEMET	Soda Pro	ITC Canarias	IDAE Censolar	UNE 94003	Max	Ave-rage	min	% Diff. Max min
JAN.	3.980	3.500	3.700	3.760	3.140	3.475	3.111	3.720	3980	**3548**	3111	**27,9%**
FEB.	4.810	4.700	4.630	4.450	4.910	4.439	3.944	4.435	4910	**4540**	3944	**24,5%**
MAR.	5.910	5.900	5.860	5.380	6.130	5.864	4.944	5.342	6130	**5666**	4944	**24,0%**
APR.	6.850	6.700	6.810	6.240	6.410	6.428	5.444	6.132	6850	**6377**	5444	**25,8%**
MAY	7.390	7.400	7.320	6.670	6.960	7.202	6.027	6.618	7400	**6948**	6027	**22,8%**
JUN.	7.540	7.700	7.320	6.570	6.620	7.407	6.250	6.742	7700	**7019**	6250	**23,2%**
JUL.	7.530	7.600	6.990	6.570	7.530	7.357	6.750	6.747	7600	**7134**	6570	**15,7%**
AUG.	7.220	7.000	6.880	6.380	6.980	6.899	6.083	6.354	7220	**6724**	6083	**18,7%**
SEP.	6.280	6.000	6.110	5.730	5.850	6.024	5.500	5.680	6280	**5897**	5500	**14,2%**
OCT.	5.220	4.700	4.990	5.220	4.870	4.716	4.194	4.766	5220	**4834**	4194	**24,5%**
NOV.	4.200	3.700	3.930	3.840	4.160	3.637	3.416	3.914	4200	**3850**	3416	**23,0%**
DIC.	3.660	3.200	3.400	3.470	3.260	3.182	2.972	3.462	3660	**3326**	2972	**23,1%**
Average	**5.890**	**5.675**	**5.660**	**5.357**	**5.580**	**5.553**	**4.889**	5.326	5890	5491	4889	20,5%

for the calculation of temperature losses calculations solar panels. The average monthly sunshine data will also be used by AEMET as they are based on the observation data of the Puerto del Rosario weather station with average historical data from 1980 to 2010. The solar hours of the month of February are referred to 28 days.

Table 2. Temperature and insolation data of Puerto del Rosario, Fuerteventura. Source: AEMET [33]

Month	Insolation hours/ month	Insolation hours/day	Tº Average 1980-2010	Tº Average 2010-2015	% Differ Averages
JAN.	190,00	6,13	17,6	18,4	4,82%
FEB.	189,90	6,78	17,9	18,2	1,40%
MAR.	233,00	7,52	18,9	19,0	0,33%
APR.	242,30	8,08	19,5	20,1	3,18%
MAY.	280,20	9,04	20,6	22,1	7,31%
JUN.	284,80	9,49	22,5	23,2	3,20%
JUL.	293,90	9,48	24	24,5	2,07%
AUG.	288,80	9,32	24,6	25,5	3,66%
SEP.	246,20	8,21	24,4	24,8	1,53%
OCT.	227,10	7,33	22,9	24,1	5,15%
NOV.	202,60	6,75	20,9	21,5	3,05%
DIC.	185,90	6,00	18,9	19,6	3,68%
Average	2835,50	7,77	21,1	21,7	3,08%

The characteristics of the island of Fuerteventura, where the installations are located, is extremely arid, with 86.6% of the area classified as arid and the remaining 13.4% is semi-arid[35]. Suspension is usually quite high because of the sand and dry land of Fuerteventurageography. To the dust in its own suspension, we must add that of the Saharan air masses that regularly affect the Canary Islands and the island of Fuerteventura mainly due to its proximity to the Sahara[36,37], as well as the insignificant annual rainfall, With a mean of 98 mm annually[34], less than 0.3 L/m² per year, causes that the losses of the plates by dirt due to the dust, are very high in these installations, if it is not made a correct maintenance and control Of cleaning them.

Table 3 shows the main data of the 11 study facilities, where there are installations connected to low voltage and medium voltage, with maximum or peak power values ranging from 88 kW to 552 kW, with nominal power greater than 100 kW connected to power transformers medium voltage. All equipment is located on roofs and flat or sloping roofs of industrial buildings. The models of panels are of siliconpolycrystalline with values of variation of the coefficient of temperature of between -0,43% ºC to -0,48% ºC, with an average value of -0,45% ºC, as well as a nominal operating temperature Between 45°C and 47°C, with an average of all facilities of 47°C. The efficiency of the panels is between minimum values of 13% and above 14%, with an average efficiency of 13.62%. With all these data can be considered that the different panels are of similar characteristics to each other, so the calculations of losses and PR value, we will perform with the average values of the study facilities. Another very characteristic feature of these facilities is The angle of inclination of the panels of 10°, which is with all these data can be considered that the different panels are of similar characteristics to each other, so the calculations of losses and PR value,

Table 3. Fuerteventura Facility's data

Installation	Mark	Model	Tº Coeff.	TONC	m² PV	Efficiency	Wpp PV	Nº PV	Peak Power	Rated power
FEM	SolarWorld	SW220	-0,48%	46	1,68	13,12%	220	400	88.000	80.000
INP	SolarWorld	SW230	-0,48%	46	1,68	13,72%	230	1.920	441.600	400.000
HIE	SolarWorld	SW230	-0,48%	46	1,68	13,72%	230	2.400	552.000	500.000
INS1	SCHOTT	ASE165T- 170	-0,47%	45	1,31	12,96%	170	592	100.640	90.000
INS2	SKY GLOBAL	SCM 72-180	-0,45%	46	1,32	13,61%	180	576	103.680	100.000
INS3	Photowatt	PW1650-175	-0,43%	47	1,29	13,55%	175	495	*86.625*	100.000
		PW1650-170	-0,43%	47	1,29	13,16%	170	175	*29.750*	
INS4	Photowatt	PW1650-175	-0,43%	47	1,29	13,55%	175	495	*86.625*	100.000
		PW1650-170	-0,43%	47	1,29	13,16%	170	175	*29.750*	
INS5	Photowatt	PW2050-200	-0,43%	47	1,47	13,64%	200	518	103.600	90.000
INS6	SolarWorld	SW240-245	-0,45%	46	1,68	14,61%	245	448	109.760	100.000
CAR	Photowatt	PW2050-210	-0,43%	47	1,47	14,32%	210	512	107.520	100.000
OCA	Photowatt	PW2050-205	-0,43%	47	1,47	13,98%	205	1.606	329.230	300.000

we will perform with the average values of the study facilities due to the need of space saving to be able to install more solar modules in the existing surface, that is to say to increase the installed power by unit of surface, but without producing shades that diminish the generation in winter. If we take into account that the minimum distance between rows of panels must ensure that the generated shadow produces 4 hours of sunshine around noon of the winter solstice[28], we can calculate the minimum distance between contiguous panels by the following function:

$$h = \frac{L * sin\ \alpha}{tan(61 - \theta)}$$

Where "L" is the height of the panel, "θ" is the latitude of the location and "α" is the fixed inclination angle of the solar panels.

Taking into account this way of calculating it, will verify that the differences between placing the solar plates at the optimal angle of 28º at this chosen angle of 10º reduces the distance between panels by 65%, which means that the distance is 1.7 times lower with this chosen angle, and instead the energy production of using the optimal angle of inclination 28° would only increase by 4% than if we used the chosen inclination of 10°. This motivates that the cases of reduced surfaces in roofs of existing buildings, it is advisable to use small angles of inclination in order to be able to install as many photovoltaic modules in the smallest possible space, which in this case, is the own one of the roof of the ship where the generators are installed, and in this way, increase the installed power per unit area.

Table 4. Loss or efficiency values for calculations. Source: IDAE and own

Name	Description	Value
L_Y	Temperature losses	Calculate
L_D	Lost by dispersion	2,0%
L_P	Lost dust and dirt	3,0%
L_R	Lost reflectance	3,0%
L_{IN}	European Investor Efficiency	95%
L_E	AC and DC circuit efficiency	97%
L_V	Efficiency due to other losses	96%

4. Calculus

In order to calculate the losses by estimating the PR, the irradiation is taken from all the irradiation values of the DBs, once adjusted for the 10º inclination angle of the study facilities, and with the daily in isolation data, The radiation values are obtained, with which the temperature loss data can be calculated. The rest of the values of losses and average efficiency used will be those of the following Table 4, where they appear the generic coefficients of calculation. Figure 6 shows the graph of the PR value for the different months, checking the validity of the calculation model, since the differences between the maximum and minimum radiation values only influence + - 1% of the PR average value. We take these average values to perform the calculations.

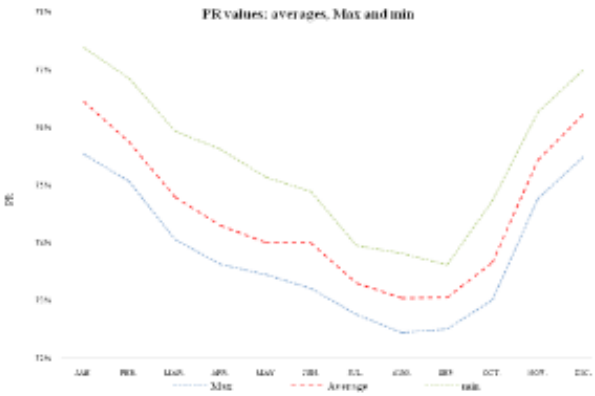


Figure 6. Differences in PR values according to average, maximum and minimum irradiance data of the different study DBs.

In the following Figure 7 the values in columns of the actual generation of the different installations per year in MWh appear. The values of the graphs, being of installations with different maximum peak power, are not comparable to each other, for which we have to pass the data to the same indicator that does not take into account the generated total energy but the HSP equivalents of production, And in this way we can compare all the facilities to referring an equal index and with the same unit.

In order to carry out the calculations of the facilities to obtain their equivalent HSPs, we take the average generation values per month and per year of each installation, with respect to all the annual and monthly data we have obtained from the different installations. The calculation performed is for the daily averages of HSP, which is calculated by dividing the actual produced energy value between the installed peak power and this value is divided between the days of the month to have a daily HSP value, which will be the comparable data for all generating plants. Once this value is calculated, the plants

can already be compared to each other, by a same ratio, independent of the total installed power. Figure 8 shows all the average production curves in HSP calculated for the average of each month, with the data of all the years of study of all the generating stations, as well as the average values, maximum and minimum values.

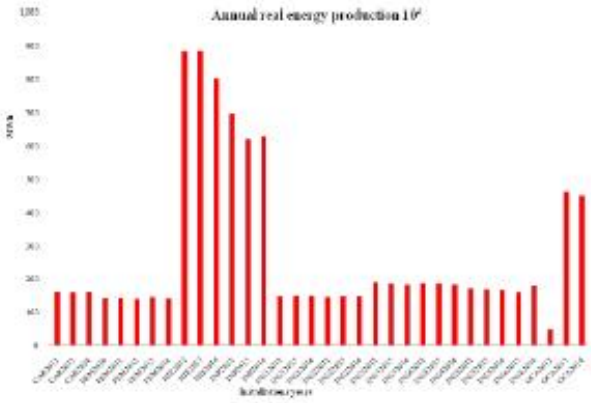


Figure 7. Production values in kWh of the different installations per year.

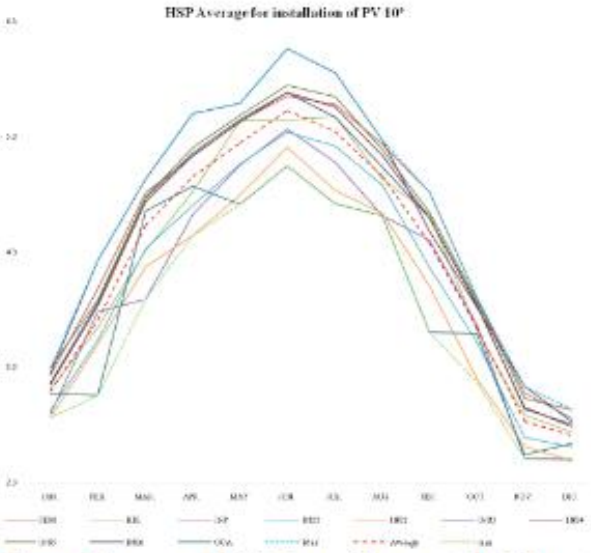


Figure 8. Average real HSP values of the years of the different installations with panels with 10° angle.

Table 5 shows the average monthly HSP data of the data obtained from the different stations of study, calculating the average generation per month of the years that have data, with the monthly and annual maximum and minimum values, as well as the Standard deviation of the same. It can be seen that the months of greatest differences are those of February and September, which has a variation of 27.6% between generations of plants. The average annual difference reaches 14.9% between the maximum and minimum values, so the average value we get, will give us results that will be within the limits of + -7.5% of the estimated real value, with the data between +6% and +14% according to the calculated months, with respect to the average value obtained, with an average standard deviation of the annual data of 0,34HSP.

Table 5. Maximum, minimum and average values of HSP and their deviations for the study facilities 10°

Month	Max	Average	min	Diff. % Max-min	Standard deviation
JAN.	3,29	3,09	2,86	13,2%	0,22
FEB.	4,22	3,70	3,06	27,6%	0,58
MAR.	4,93	4,53	3,89	21,2%	0,53
APR.	5,50	4,95	4,44	19,3%	0,53
MAY	5,59	5,24	4,71	15,8%	0,44
JUN.	6,06	5,53	5,05	16,8%	0,51
JUL.	5,86	5,34	4,72	19,4%	0,57
AUG.	5,27	4,96	4,61	12,5%	0,33
SEP.	4,82	4,37	3,60	25,3%	0,62
OCT.	3,90	3,64	3,17	18,8%	0,37
NOV.	3,13	2,83	2,51	19,9%	0,31
DIC.	2,93	2,71	2,48	15,3%	0,22
TT	4,58	4,24	3,89	14,9%	0,34

The last comparison between the real values of the plants is the YF, which corresponds to the annual production HSP. This value is calculated by dividing the actual output with respect to the installed peak power. This Figure is very important for producers, since this annual value is tabulated by law[12] according to the climatic zone and the type of installation and there are a maximum allowable production values for the payment of production premiums. For study facilities that are untraceable and in climatic zone V[21], it has maximum values of HSP of 1753, not exceeding this value of the plants, as can be observed in Figure 9 where the different values of HSP of all the facilities and all the years of investigation, being verified that the maximum values are above the 1600 hours, as the FEM with 1635 hours, INS3 with 1607 hours, INS4 with 1609 hours, INS5 with 1636 hours and the highest equivalent production, which is the newest

installation INS6 with 1655 hours, but none exceeding the threshold of 1700 equivalent hours.

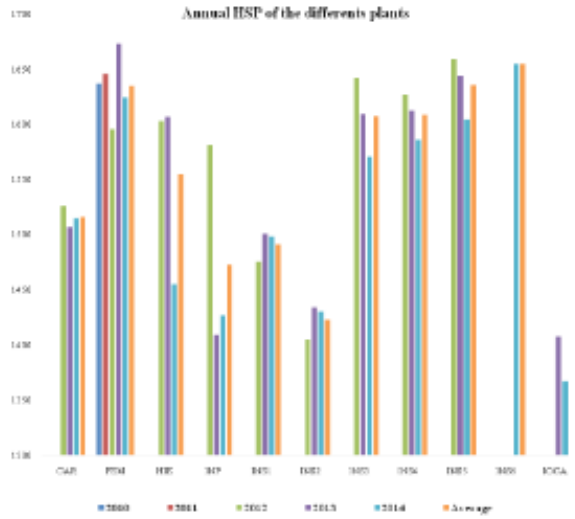


Figure. 9. HSP annuals (YF) Facility's study.

4.1 Comparison of Actual and Projected Values

Once verified and calculated the actual data of the different facilities, for HSP values, then compare these values with those estimated in the different study DBs, for which it pass the irradiation values shown in ***Table 1***, To new values of global irradiance of plates inclined to 10° with the value of the calculated coefficient K, multiply it by irradiation to 0° and give us the value for 10°. With this global irradiation value on the plates at 10°, we perform the total HSP calculations, for which we divide the value between 1000 kWh/m², and finally perform the calculation of the useful HSP by multiplying by the previously calculated monthly PR value. With the data obtained, Table 6 is generated, showing the actual calculated values for the study facilities and the theoretical values of the DBs, where the differences between the HSP values of each DB and the real can already be verified. With these values we perform the calculations of comparison of all the generation data of the different research plants that are converted from kWh to HSP. Figure 10 shows the annual average differential values of the calculated values of the DBs, where it can be seen that the DBs of the UNE 94003 and AEMET are the ones whose projection is closer to reality in all cases, With average differences that do not exceed 5%, the value calculated by PVGIS which gives higher values with an average difference of 12.9%.

It can also be seen how there are generating installations whose calculated value predicted with respect to the real becomes 22.6% higher, in the installation of INS2 with PVGIS data. The differences between the maximum and minimum values are between the different DBs with respect to the annual data between 1% and 10.2%, proving that the differences between the DBs are very linear and follow a very similar irradiation function. Figure 11

Table 6. Summary of daily HES values of the different databases already calculating the total losses by the factor PR with respect to the real value obtained from the study facilities for a 10° angle

Month	PV real value	PVGIS Helioclim	ADRASE Ciemat	NASA	AEMET	Soda-pro	ITC Canarias	IDAE Censolar	UNE 94003	Max	Average	min
JAN.	3,09	3,58	3,19	3,35	3,40	2,89	3,17	2,86	3,37	3,58	3,23	2,86
FEB.	3,70	4,13	4,05	4,00	3,86	4,21	3,85	3,46	3,85	4,21	3,92	3,46
MAR.	4,53	4,80	4,79	4,76	4,41	4,95	4,76	4,09	4,39	4,95	4,62	4,09
APR.	4,95	5,27	5,17	5,24	4,86	4,97	4,99	4,30	4,78	5,27	4,95	4,30
MAY	5,24	5,51	5,51	5,46	5,03	5,22	5,38	4,59	5,00	5,51	5,21	4,59
JUN.	5,53	5,54	5,64	5,39	4,90	4,93	5,45	4,68	5,01	5,64	5,19	4,68
JUL.	5,34	5,52	5,56	5,17	4,89	5,52	5,41	5,01	5,01	5,56	5,26	4,89
AUG.	4,96	5,39	5,24	5,17	4,83	5,23	5,18	4,63	4,81	5,39	5,06	4,63
SEP.	4,37	4,87	4,68	4,76	4,50	4,58	4,70	4,33	4,46	4,87	4,61	4,33
OCT.	3,64	4,27	3,89	4,11	4,27	4,02	3,90	3,51	3,94	4,27	3,99	3,51
NOV.	2,83	3,69	3,29	3,48	3,41	3,66	3,24	3,06	3,46	3,69	3,41	3,06
DIC.	2,71	3,33	2,95	3,12	3,18	3,00	2,94	2,76	3,17	3,33	3,06	2,76
TT	4,24	4,77	4,64	4,62	4,39	4,56	4,55	4,05	4,37	4,77	4,49	4,05

shows the representative graphs of theexisting differences between the actual values as compared to those of the monthly level. This is observed more clearly as the winter and autumn months are the ones that generate greater differences, which become Up to 31% higher than the values observed in the real installations, and are the main cause of the annual differences that forecast much higher values of generation than the real ones. While in the summer months, the values are quite close to reality, being even lower in some cases. Again, the values obtained by the PVGIS database are those that give higher values, while the values of IDAE-Censolar have lower values than the real ones, and the values of the standard UNE 94003 and of the AEMET Which are more similar to reality, even so, all of them being overly optimistic in HSP values for the months of November mainly.

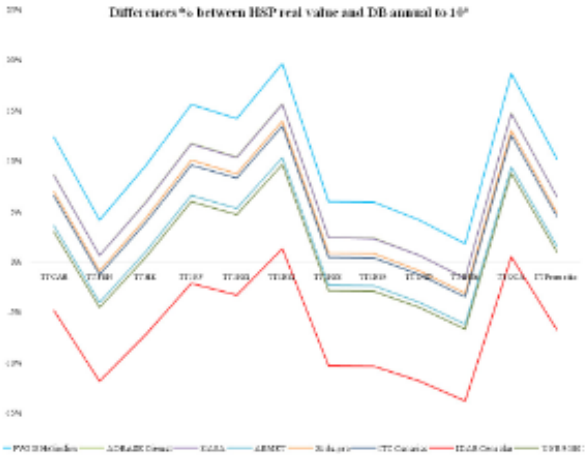


Figure 10. Differences between total annual values HSP calculated from irradiationDB, with respect to the real value with the plates at 10°.

Once verified and demonstrated the differences of values between the DBs respect of the real production data of the studied facilities, we have to calculate what the actual irradiation incident on flat surfaces of the plants of Fuerteventura, to verify the differences of real values of irradiation With the DBs. Having the average HSP value of the installations with the solar plates inclined 10°, we perform the theoretical calculation of HSP equivalents for a flat surface 0°, calculating the divisor factor K for each month, which is the same one that we use for the Adjustment of the irradiation of the DBs to 10°. Calculating the value of HSP with losses due to the PR factor, we have to calculate the real incident value without losses, dividing this value between the efficiency coefficient of the system or PR previously obtained, finally obtaining the actual value of HSP for horizontal PVs of 0 ° angle. With the actual value of HSP which allows to have radiation incident, multiplying that value by 1000 kWh/m². Table 7 shows the data corresponding to HSP with losses and real, at 10° and 0°, as well as the values of PR and K, obtaining the final value of the irradiation without losses and for flat surfaces at 0°.

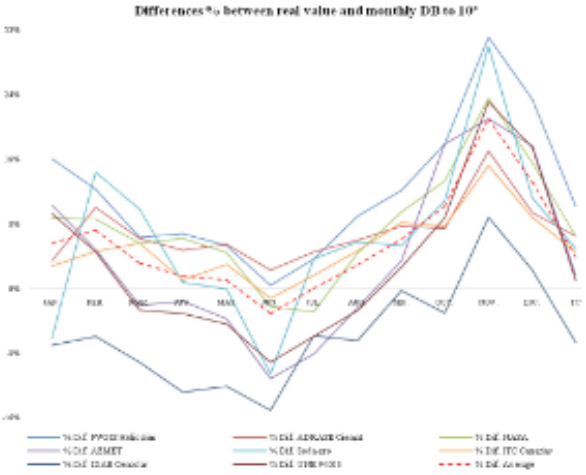


Figure 11. Monthly differences between total HSP values calculated from irradiation and real DB.

Table 7. Average values of HSP, coefficients PR and K, and irradiance value equivalent to 0°

Month	K	HSP PR 10°	HSP PR 0°	PR	HSP 0°	Irradiation kWh/m²
JAN.	1,19	3,09	2,59	76,45%	3,39	3.394
FEB.	1,14	3,70	3,24	75,75%	4,28	4.282
MAR.	1,09	4,53	4,15	74,79%	5,55	5.554
APR.	1,04	4,95	4,74	74,30%	6,38	6.380
MAY	1,01	5,24	5,17	74,00%	6,98	6.983
JUN.	1,00	5,53	5,53	74,00%	7,47	7.467
JUL.	1,01	5,34	5,31	73,30%	7,25	7.245
AUG.	1,03	4,96	4,81	73,05%	6,59	6.587
SEP.	1,07	4,37	4,09	73,06%	5,59	5.593
OCT.	1,12	3,64	3,25	73,66%	4,41	4.410
NOV.	1,18	2,83	2,41	75,43%	3,19	3.191
DIC.	1,21	2,71	2,24	76,22%	2,94	2.944
TT		4,24	3,96	74,50%	5,34	5.336

Comparing the annual average annual irradiance values for flat horizontal surfaces of the DBs with respect to the calculated real value, we obtained Figure 12, where we can graphically check how the values of AEMET DB and UNE 94003:2007 only differ from + -0.3% in relation to the real value. The biggest differences are PVGIS with a value higher than + 10.2% and with the data from IDAE -Censolar that values are much lower than -8.5%. It is very important to keep in mind that these data refer to irradiation on flat surfaces, ie at 0º of inclination. The calculated values of irradiation show that for annual values the differences are not very excessive, considering that the values of + -5% per year are acceptable, among which we can consider AEMET, Solar-pro, ITC-Canarias and UNE 94003 DBs acceptable.

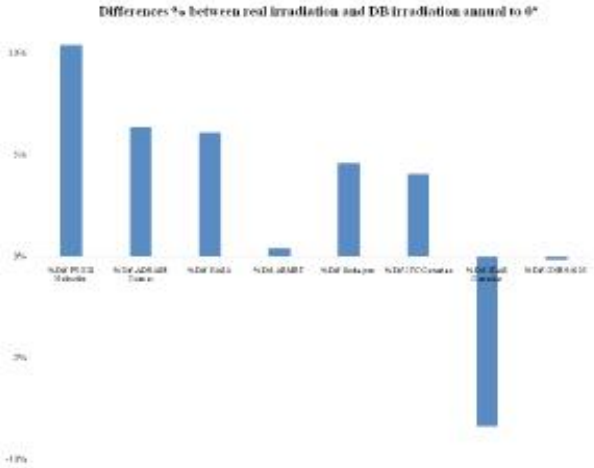


Figure12. Percent annual differences between the real value and the DB for horizontal surface irradiation.

It also compare the monthly irradiation data of all the DBs with respect to the calculated real, showing in Figure 13 the graphs of the different irradiations, where it can be observed how the real irradiation is found, in most of the months, between the Values of the different DBs, being in the months of November and December when its value is inferior to all DBs. The data of IDAE-Censolar always are well below the rest of values of irradiation, as well as those of PVGIS also usually have the superior value of the rest in most of the months, reason why it gives calculated values of tan generation Generous in most of the months. In order to perform rapid calculations of irradiation of Fuerteventura, we have calculated the characteristic polynomial function, which is also shown along with the previous graphs, performing the regression of the real irradiation data, giving us the value of the characteristic function, which can be used to make the necessary monthly approximations for calculations of photovoltaic production.

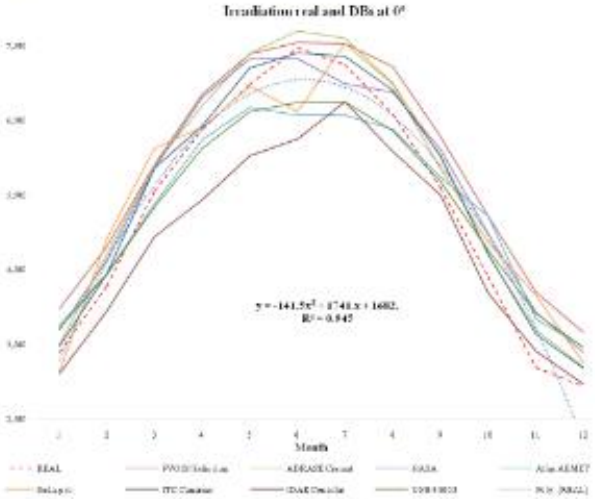


Figure 13. Curves of real irradiation and of the DB for Fuerteventura.

$$y = -141{,}51x^2 + 1741{,}3x + 1682{,}5$$

Table 8 summarizes the percentage differences between the actual irradiance value calculated for the installations and the data that the different DBs offer us, where the contrasts between real values and those obtained by the DBs are appreciated.

Having real values of irradiation is very important for its use in monthly and not only annual electricity generation forecasts, since at the moment the current facilities that are made of self-consumption is necessary to have real monthly values, in order to calculate the effective savings according to the electric rate of each billing period, which changes according to the hours and months of the year according to 2, 3 or 6 tariff periods and thus make the amortizations in the shortest possible time. Along with the monetary savings achieved, savings in CO_2 emissions must be taken into account in order to achieve low emission buildings as well as a real alternative to near-zero energy (nZEB) projects.

5. Discussions and Conclusions

Through this research study of irradiation comparison of general DBs with respect to real data, it has been verified that all DBs have different data, not agreeing their values

Table 8. Percentage differences between the real value and the values of the DBs for irradiation in horizontal surfaces at 0º

Month	PV real value	PVGIS Helio-clim	ADRASE Ciemat	NASA	AEMET	Soda-pro	ITC Can-arias	IDAE Censolar	UNE 94003	Max	Average	Min
JAN.	3.394	17,3%	3,1%	9,0%	10,8%	-7,5%	2,4%	-8,3%	9,6%	17,3%	4,5%	-8,3%
FEB.	4.282	12,3%	9,8%	8,1%	3,9%	14,7%	3,7%	-7,9%	3,6%	14,7%	6,0%	-7,9%
MAR.	5.554	6,4%	6,2%	5,5%	-3,1%	10,4%	5,6%	-11,0%	-3,8%	10,4%	2,0%	-11,0%
APR.	6.380	7,4%	5,0%	6,7%	-2,2%	0,5%	0,8%	-14,7%	-3,9%	7,4%	0,0%	-14,7%
MAY	6.983	5,8%	6,0%	4,8%	-4,5%	-0,3%	3,1%	-13,7%	-5,2%	6,0%	-0,5%	-13,7%
JUN.	7.467	1,0%	3,1%	-2,0%	-12,0%	-11,3%	-0,8%	-16,3%	-9,7%	3,1%	-6,0%	-16,3%
JUL.	7.245	3,9%	4,9%	-3,5%	-9,3%	3,9%	1,5%	-6,8%	-6,9%	4,9%	-1,5%	-9,3%
AUG.	6.587	9,6%	6,3%	4,4%	-3,1%	6,0%	4,7%	-7,7%	-3,5%	9,6%	2,1%	-7,7%
SEP.	5.593	12,3%	7,3%	9,2%	2,4%	4,6%	7,7%	-1,7%	1,5%	12,3%	5,4%	-1,7%
OCT.	4.410	18,4%	6,6%	13,1%	18,4%	10,4%	6,9%	-4,9%	8,1%	18,4%	9,6%	-4,9%
NOV.	3.191	31,6%	15,9%	23,2%	20,3%	30,4%	14,0%	7,0%	22,7%	31,6%	20,6%	7,0%
DIC.	2.944	24,3%	8,7%	15,5%	17,9%	10,7%	8,1%	0,9%	17,6%	24,3%	13,0%	0,9%
TT	5.336	10,4%	6,4%	6,1%	0,4%	4,6%	4,1%	-8,4%	-0,2%	10,4%	2,9%	-8,4%

in any case and with very large differences according to the calculation months. It is verified that the actual data differ from those projected in absolute and monthly annual values, with very large variations depending on the DB used. It has been possible to verify and conclude that:

- The calculation of irradiation for inclined surfaces can be made by the simplified method to values close to 55º of inclination, with differences of + -2% that can be assumed in most projects.
- When installing PV in areas where the surface of use is very important and high values of installed power per unit area are required, smaller angles of inclination should be chosen, lower than the optimum value, in order to reduce the distance between Modules and thus increase the installed power per unit area.
- The different DBs do not agree in their values or in their production estimates, so their use must be careful and whenever annual and non-monthly estimates can be made, whose values are more closely adjusted to actual productions.
- When it is necessary to make monthly production estimates, you must perform calculations with several DBs and take the average values to obtain more realistic adjustments.
- The DBs that have more real values, to be able to make correct estimates, are those that have been calculated by observation and crossing of data of stations, being for the zones of calculation, those generated by national estates, recommending the use of the data from the UNE 94003:2007 standard and AEMET data with a difference of less than 1% per year for horizontal surfaces. The PVGIS database is too optimistic in its calculations and its values tend to be with 10% higher yields.
- In order to carry out more accurate calculations and forecasts, account must be taken of meteorological and land-type data, since in this case it is verified that being an arid zone the losses are probably higher due to dirt on the plates and losses by Dust in suspension in the months of winter and autumn, due mainly to the calima, for which a future investigation on the influence of this phenomenon in the production would have to be made.
- The most up-to-date and modern facilities have a higher efficiency with equivalent HSPs per plant which can be up to 7% higher than the average.

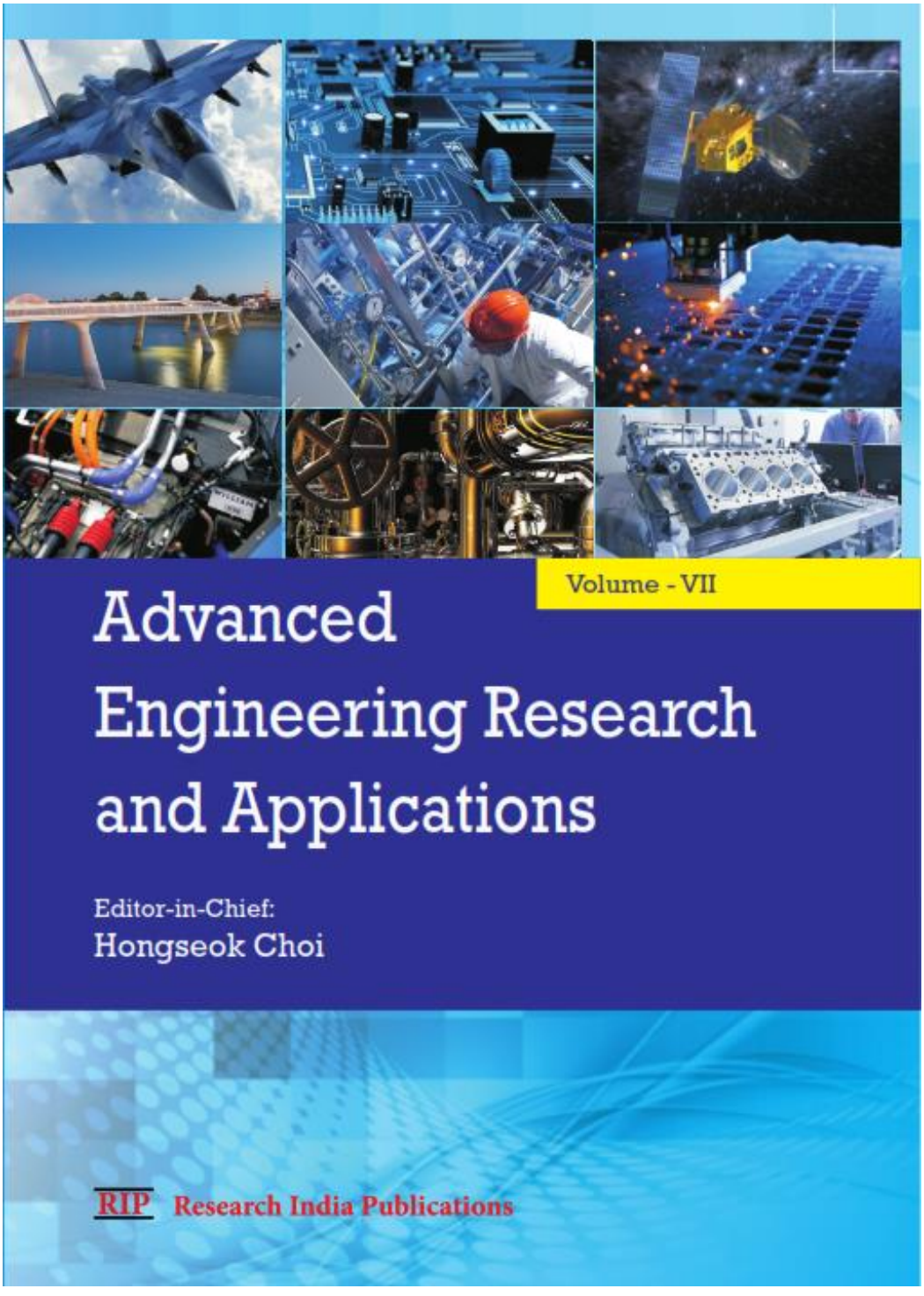
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CHAPTER - 30

Comparison of Solar Irradiation Data Bases for the Production of Photovoltaic Electric Energy

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Abstract

In recent years solar photovoltaic energy has gained much prominence as producer of electric energy for sale and self-consumption, as well as for its environmental side, as a greenhouse gas reducer. This makes it necessary to make production forecasts as close as possible to reality and, in this way, to be able to evaluate its economic viability and the environmental improvements by reducing emissions achieved as realistically as possible. In the following article, we performed a study of the different irradiation databases (DB) used for calculations of photovoltaic solar energy production, comparing the widely recognized and used 8 DB values, PVGIS, Adrase-Ciemat, NASA, AEMET, Soda-pro, ITC, IDAE-Censolar, and UNE 94003, with respect to the equivalent irradiance values of 11 generating installations in operation, connected to a network with a 10 ° inclination angle, all located on the island of Fuerteventura, in the archipelago of The Canary Islands (Spain) and with maximum powers installed from 88 kW to 552 kW.

We verified with the data obtained and calculated that the differences between predicted values of the different DBs and the real ones obtained from the facilities can reach monthly differences of more than 30% and annual differences of 10%, the months with the greatest difference being those of winter and

autumn. The calculation of equivalent irradiation for inclined surfaces is performed by the simplified system by calculations of the monthly incidence angle, which gives us equivalent global irradiance values with approximate values of +-2% between inclinations of 1 to 55º of the photovoltaic generator. It is concluded by calculating the real irradiance data of Fuerteventura for flat surfaces, and generating the polynomial function that describes the monthly real irradiance in the island according to the generation data of the study facilities.

Keywords: solar energy, photovoltaic, nZEB, irradiation, PV, renewable energy, energy in Canary Islands.

1. INTRODUCTION

Photovoltaic solar energy is an energy considered as clean and renewable, recognizing its primary fuel as inexhaustible, which are the energy of the photons emitted by our star the Sun. Among its most important and main features of this energy, we can highlight its Free disposition, gratuitousness and its foreseeable duration of millions of years. In addition, photovoltaic solar installations have the possibility of being modular and increasing the power of the generating plants in a simple way, through an increase of generation surfaces, as well as the possibility of architectural integration in current buildings, which makes it highly recommended for installation (ZEB) or near zero (nZEB) (Attia, S., Mlecniki, E., Loon, S.,2011), (Crawley, D., Pless, S., Torcellini, P. 2009) there being many examples of its application as integration of photovoltaic solar panels in buildings (Building Integrated Photovoltaics' BIPV) (ww.batchgeo.com, 2017), (Yoon, J.H., Song, J. and Lee, S.J., 2011) and in other types of facilities such as airports (Rüther, R and Braun, P.,2009) The main and most important disadvantage is that its production is linked to sunlight, so it only occurs during the day, depending on the weather conditions and the incidence of the solar rays of the site where they are installed. It is also verified that the surplus is very small compared to the solar energy received on the surface of the solar plaques, which is increasing annually, passing from its beginnings in 1883 with a yield of 1%, (Kenneth, Z. and Paul, H., 1984). up to the current values of the plates of modern silicon with yields of 25% (Green, M.A., Emery, K., Hishikawa, Y. et al, 2016), being the values of generic panels in the market today, between 12% and 16%.

Considering Spain's photovoltaic potential, due to its geographical location, its annual irradiation and the incentives developed by the different Spanish governments to stimulate the installation of photovoltaic plants, together with the

rest of renewable energies (RREE) (Government of Spain, 2007), (Government of Spain, 2010), (REE, 2017), achieved that installation of grid-connected generating plants, increased potentially between 2006 and 2011 (REE, 2017). This continued increase in facilities and the impossibility of sustainability of the incentive system, the different governments were cutting these subsidies to production, beginning in 2010 (Government of Spain, 2010) and ending with the definitive suspension of these subsidies and incentives to production in the year 2012 (Government of Spain, 2012). This meant a standstill of the new facilities as of that year, as can be check in **Fig. 1** on the evolution of the photovoltaic power plant at the national level, where it can be observed that as of 2012 the installed power remains constant without increasing it. Due to this suspension of the remunerations to renewable, at present the installations with connection to network no longer have a profitability comparable to the years prior to 2012, although, due to its expected duration of the installations of 25 years, it has not stopped being a bad investment, but with a profitability Very low, provided that legal certainty is maintained in its regulation (Guaita-Pradas, I. and Marí Soucase, B., 2014).

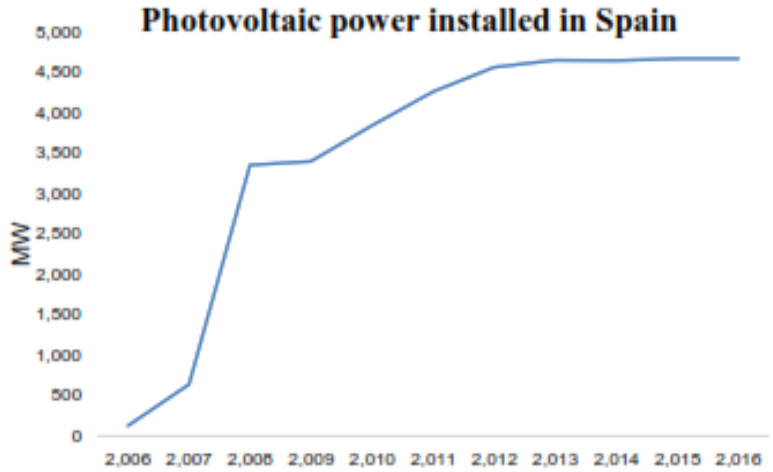


Fig. 1. Photovoltaic power installed Spain.
Source: Spanish Electricity Grid (REE)

The self-consumption and BIPV applications have become an interesting model for their installation (Matallanas, E., Castillo-Cagigal, M., Caamaño-Martín, E. et al, 2011) and integration in existing buildings, which together with other RERs can be made mixed generation models (Gallo, A., Téllez Molina, B., Prodanovic,

M., et al, 2014), (Badwawi, R.A., Abusara, M. and Mallick, T., 2015), (Kim, J.H., Kim, H.R. and Kim, J.T., 2015) to cover the different demands of energy of the buildings, in order to obtain buildings ZEB or nZEB. On the part of the International Energy Agency (IEA), a study on self-consumption through solar photovoltaic energy has been carried out, comparing and informing on the policies of the different countries (Masson, G., Ignacio Briano, J. and Jesus Baez, M., 2016) regarding viability and legislation on self-consumption. Spain is the fourth country of the European Economic Community (EEC), with the highest average annual irradiation (Suri, M., Huld, T.A., Dunlop, E.D. and Ossenbrin, H.A., 2007), which places it in a leading position to achieve high yields in photovoltaic solar installations, with any self-consumption facility being much more efficient In Spain than in most countries of the EEC. This generation potential is also applicable to the archipelago of the Canary Islands, an ultra-peripheral region of Europe, located between the co-ordinates 27º 37 'and 29º 25' north latitude and 13º 20 'and 18º 10' west longitude, at about 940 Km to the south of the European continent, but whose average annual irradiation is comparable to the south of mainland Spain, as can be seen by its consideration as zone V, according to the zoning made by the technical code of the building (CTE) (Government of Spain, 2006) in force in Spain.

Canary Islands, the need for generation through RREE, being an area of special importance, both ecologically and in the capacity to implement development models compatible with its conservation, is very important, proof of this is that 63% (Government of the Canary Islands, 2016) of the archipelago's surface is declared a Biosphere Reserve by UNESCO. The canary current energy model has as one of its main needs to be able to achieve an environmentally sustainable system, the amplification of the systems of generation by RREE, being in values of generation by renewable well below peninsular Spain, where this type of generation has gone from a 19.4% in 2006 to 40.5% in 2016, while in the Canaries its value has remained almost unchanged, from 6.2% in 2006 to 8% in 2016, as can be observed in **Fig. 2,** of the structure of electric power generation between 2006 and 2016.

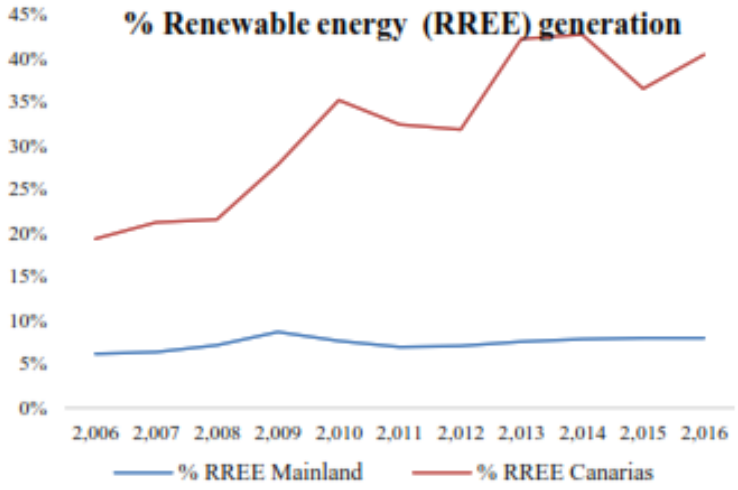


Fig. 2. Percentage of RREE generation over the total electricity generation 2006-2016 in the peninsula and the Canaries.
Source: REE

This use of the RREE, has managed to reduce the emission coefficient due to electricity production in mainland Spain 40%, between the period 2006 to 2016, being the reduction for the Canary Islands of only 7%. This causes that the emission factors of the electrical generation are 262% higher in the Canary Islands than in the Peninsula, as can be seen in **Fig. 3.**

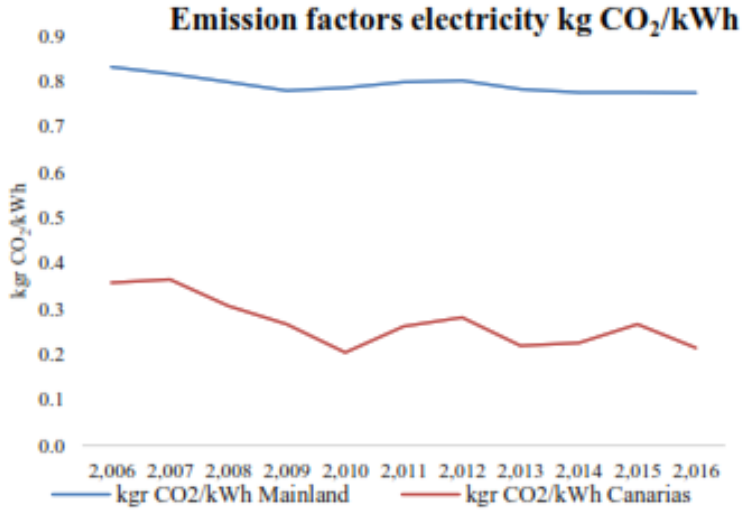


Fig. 3. Evolution emission factors Spain peninsular and Canary Islands 2006-2016.
Source: REE

Taking into account the importance of continuing with the reduction of CO2 emissions, due to the influence on the climate change that they produce (IPCC, 2015), and the possibility of realizing systems of self-generation by photovoltaic solar panels in areas with high irradiation, such as the Canary Islands, it is necessary to verify that the estimated production data calculated by means of the different existing irradiation DBs corresponds to the actual generation of the planned and running plants, since for the estimation of the production of electric energy by means of PV, the main data needed is the irradiation of the installation area, being in this case an area of the archipelago of the Canaries, which together with the characteristics of the generator itself, will give us the estimated production values for each generating plant. The irradiation data are obtained from the different DBs that are publicly accessible, in most cases, and by means of which an approximate production can be estimated. The different values of the DBs can generate very high estimation differences, as can be verified in the study of irradiation data calculated by satellites (Vernaya, C., Pitavala, S. and Blancb, P., 2014), (Suri, M., Remund, J., Cebecauer, T. et al, 2008) or in the web-based comparison for Poland (Mazurek, G., 2014) overestimation of the winters and the summers are underestimated.

The comparisons of data will be made for 8 DB of free access through the corresponding websites of each of them or through access to public regulations. The DBs are: PVGIS-Helioclim, ADRASE-Ciemat, NASA, AEMET, Soda-pro, ITC-Canarias, IDAE-Censolar and UNE standard 94003:2007, comparing the irradiance data of flat surfaces with the calculated values of irradiation for 11 installations of peak power or maximum installed between 88 kW and 552 kW, all of them with angle of inclination of the plates of 10º.

2. EXPERIMENTAL

Earth Planet, due to its movement of translation around the sun and the decline of the axis of rotation, produces a difference in the incidence of solar radiation between + 23.45° to -23.45°, with respect to the reference latitude. This difference makes it necessary to calculate the decline of the earth each day, to estimate the optical angle of the photovoltaic solar panels, to achieve the highest irradiation. For the calculations of the angle of decline of the earth relative to the Sun, we use the well-known Cooper equation (Cooper, P.I., 1969), which gives the value of the approximate decline of the reference point at solar noon of the day considered

$$\delta(n) = 23,45 * sen\left[360 * \left(\frac{284 + n}{365}\right)\right]$$

Where "n" is the chosen day counting from January 1 to the day in question. In this study we will use the average decline for each day 15 of each month (14 in February), to later calculate the optimum slope of the collectors on that date, where it would receive the solar rays in a perpendicular way and be able to take advantage of 100% of the energy. The angle of each day will be given by the formula:

$$\beta(n) = \theta - \delta(n)$$

Where "θ" is the latitude of the place, "δ (n)" is the declination of the earth on the chosen calculation day. It should be noted that the slope or angle of the collectors calculated will be South in the Northern Hemisphere and North in the Southern Hemisphere.

The other adjustable angle of the solar panels is the azimuth, which is the orientation angle of the panels with respect to the north south axis thereof. In our case the facilities are always oriented to the south to 0º, per local will not be considered. Since the azimuth is a not very important reduction factor, with annual values that, according to the CTE, the value of approximate losses can be calculated for slope values of panels larger than 15°, by means of the function:

$$L_{az} = 1 - (3,5 * 10^{-5} * \mu^2)$$

Where "μ" is the azimuth angle to the South.

We must consider that the global irradiation data of the different DBs that are obtained are for flat surfaces, so it is necessary to calculate the same for inclined surfaces. To obtain this new value as accurate as possible, the values of the three components of direct, diffuse and albedo radiation must be found, with several methods for obtaining and estimating them (Muzathik, A.M., Ibrahim, M.Z., Samo, K.B. and Wan Nik, W.B., 2011), (Aggarwal, R.K., 2013), (Nooriana, A.M., Moradib, I. and Kamalia, G.A., 2008), (Klein, S.A. and Theilacker, J.C., 1981). For our model of approximation, we will use the global irradiance values of the DB for the flat surface and calculate the global irradiance value for the angle of inclination of the panels, according to the latitude of the place, for the 15th day of each month (14 In February), with the calculation function where the multiplying factor of the irradiance value is obtained for flat surfaces, and will give us the approximate result for the inclined surfaces, by means of the following function:

$$K(n) = \frac{\cos(\theta - \alpha - \delta(n)}{\cos(\theta - \delta(n))}$$

$$G(\beta) = K(n) * G(0º)$$

Where "θ" is the latitude of the place, "n" is the chosen day counting from January 1 to the day in question, "δ (n)" is the declination and of the earth on the chosen calculation day, A "is the fixed inclination angle of the solar panels e" G (0°) "is the irradiance value for flat surfaces at 0°.

The approximation values of this method are sufficient for this study, since as can be verified in **Fig. 4**, the differences between the values calculated by this method described above or by the decomposition of global irradiation in direct, diffuse and albeo that the base performs of European PVGIS-Helioclim data, we obtain a maximum difference for the average annual value of 5% at inclinations of 70º. In our research, with 10º tilt angles, the difference is 1.31% over the annual average, so we will use this approximation method.

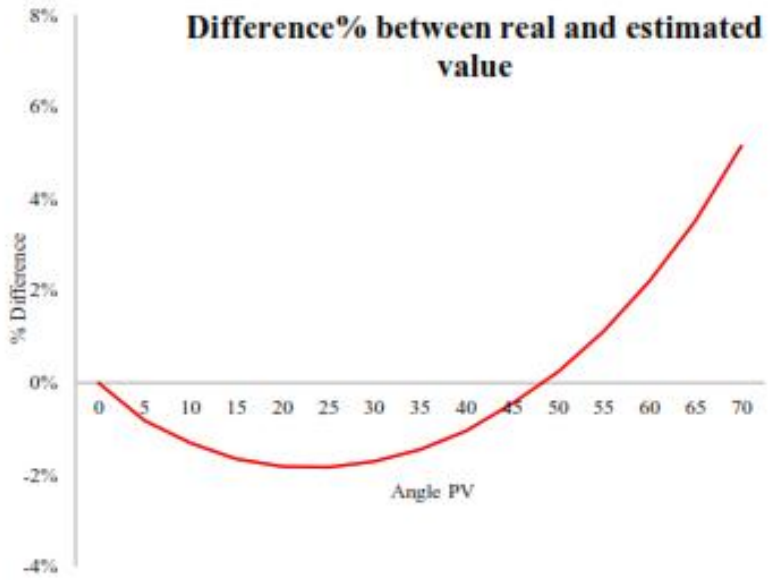


Fig. 4. Differences between the value obtained by PVGIS and the approximate used, for the annual average of irradiation.

2.1. Calculus production

To carry out generation calculations using PVs, it is necessary to consider the incident radiation at each moment, the maximum or peak power of the generator

and the total losses, which are included in a total efficiency index known as "Performance ratio" (PR) (UNE-EN, 2000). With the following function we calculate the generated energy injected in the network, at each moment:

$$\mathbf{E_{red} = PR * G(\beta, \mu) * P_{pp}}$$

Where "PR" is the global loss index that encompasses all losses of the system, "G (β, μ)" is the mean irradiance according to a declination and a given azimuth and "Ppp" is the maximum power of photovoltaic generators

The calculation of the PR is made considering all the losses of the generating system, which are given by the function:

$$\mathbf{PR = (1 - (L_T + L_D + L_R + L_p)) * L_E * L_{In} * L_V}$$

The meaning and calculation of the different terms of the equation are as follows:

- Temperature loss of the "LT" module. Due to the operation at a temperature different from the one calculated in standard conditions, it generates losses that we calculate them by the method of Osterwarld (Osterwald, C.R., 1986), that according to the Tº of the cells we will have losses, that comes given by the function

$$\mathbf{L_T = 1 - (\gamma * (T_C - 25))}$$

$$\mathbf{T_C = T_a + (G_{in} * \frac{NOCT - 25}{800})}$$

  Where "Gin" is the instantaneous or average daily radiation in W/m², "γ" is the coefficient of variation of the maximum power point with temperature, "Tc" is the plate temperature, "Ta" is the ambient temperature and "NOCT" (IEC, 2016) is the nominal operating temperature of the module for radiation values of 800 W/m², 20ºC ambient temperature, with AM 1.5G spectral distribution and 1 m/s air velocity.

- Lost by dispersion of parameters "LD". The PVs are not the same and have a power difference between them, so these differences create losses in generation.

- Dirt of "LP" plates. Losses due to dust on the modules. In Canary Islands due to the episodes of **"calima"** (Viana, M., Querol, X., Alastuey, A. et al, 2002), this parameter becomes very important and its value can become very high if the modules are not cleaned regularly.

- Lost by angular and spectral reflectance "LR". Due to the angles of

incidence of the solar rays and the selective spectrum of the photocells, whose current generated is different for each wavelength of the solar spectrum of the incident radiation.

- Losses due to the efficiency of the "LIn" inverter. The European efficiency value of the inverter (UNE-EN, 2013) given by the manufacturer, which is calculated by the function

$$\eta_E = \sum a_{eu} * \eta_{i\_MPP}$$

Where "aeu" is the European weighting factor, "ηi_MPP" corresponds to the inverter / follower performance / efficiency value for the maximum power point, "η5" represents the performance at 5% of the power of the follower, "η10 " to 10% and so on, with the different yields expressed for the powers represented by the subscript.

- Lost in "LE" electrical wiring. Total losses due to voltage drop from the DC and AC part.
- Other "LV" losses. There are several other losses not previously considered.

To make a comparison of the efficiency of the systems using a common unit or index, the value of YF (UNE-EN, 2000), which represents equivalent or peak solar hours (HSP), is a unit that measures solar irradiation and is defined as the time in hours of a hypothetical constant solar irradiance of 1000 W/m^2 calculated in standard conditions (STC), that in case of knowing the generated energy is given by the expression:

$$YF = HSP = \frac{E_{red}}{P_{pp}}$$

Where "Ered" is the generated energy injected into the grid, and "Ppp" is the maximum power of photovoltaic generators.

2.2. Methods

The method used to compare the actual data with those of the study DBs was the following:

1. Initially the data of the irradiation values of the different DBs of their web pages or recognized documents and those of production of the study plants supplied by the managers of the facilities were obtained.

2. We pass the irradiance value from flat surface to inclined surface of all DBs, obtaining the monthly irradiation values at 10º of inclination, as well as their average, maximum and minimum values.
3. We calculate the average "PR" for all the research facilities, for which we took the average radiation values of all the data of the monthly DB, obtaining the value of the PR for each month. As the plates are with similar characteristics we use the standard values for all of them.
4. With the data of monthly irradiation and "PR" we calculate the equivalent HSP of each of the DB. The HSPs of the different facilities are also calculated by monthly production of the same and their maximum power or peak installed, obtaining the monthly data per installation as the averages of the generation of the years per installation.
5. We compare the average real HSP data of all the facilities, compared to those of the study DBs at the 10º angle of the plates. Compare the actual generation data with the different DBs: total annual values and monthly values.
6. We pass the actual HSP generation data to equivalent flat surface values at 0°, using the conversion factor K and compare the values. With this data we calculate the equivalent irradiation on flat surfaces at 0º.
7. We compared the values of annual and monthly irradiance on a flat surface at 0º of DBs with respect to the calculated real equivalent for the investigated facilities.
8. Calculate the polynomial function for the equivalent irradiation curve in Fuerteventura using the calculated irradiance data from the real installations.

Fig. 5 shows the flow diagram of the research carried out to obtain the actual irradiation data of the installations and their comparison with the data of the different general use DBs

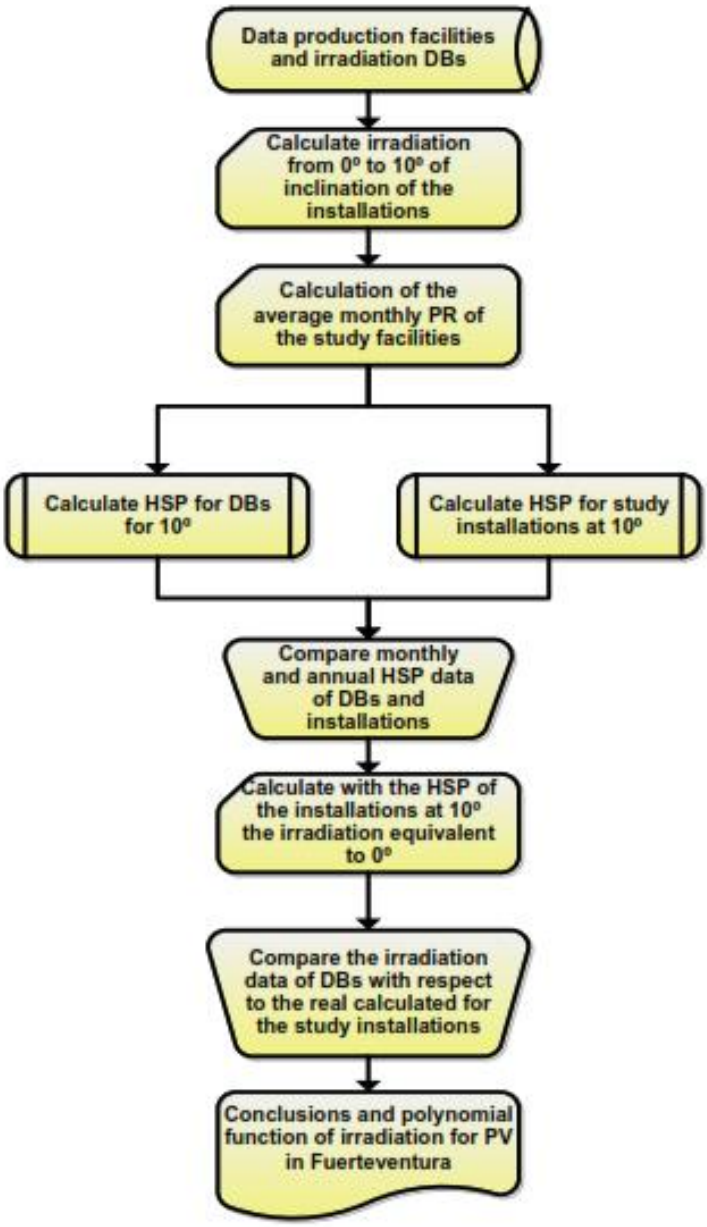


Fig. 5. Research Flow Diagram.

3. ANALYSIS DATA

The data of solar irradiation are fundamental to be able to realize any calculation of photovoltaic installations, being able to obtain the same ones of several local or global DBs. In this study eight international comparisons are being made, widely used by designers around the world. Have been chosen for the realization of the investigation are the following:

- **PVGIS – Helioclim** (PVGIS, 2017): the EEC photovoltaic information system, which through the network of meteorological stations, satellites and by means of data interpolation, performs its irradiation calculations with a GIS positioning system and the model "r.sun" (Šúri, M., Huld, T.A. and Dunlop, E.D., 2005). Widely used by all types of institutions and designers, with data from Europe, Africa and Asia for any inclination.

- **ADRASE – Ciemat** (ADRASE-CIEMAT, 2017): Access to solar radiation data from Spain (ADRASE) of the Spanish government's energy, environmental and technological research center (CIEMAT), which supplies solar radiation data from Spain with a resolution of 5x5 km, with averages of values from the last 20 years of satellite measurements and 50 ground stations. Calculations are obtained for percentile 25 and 75, as well as maximum and minimum (Polo, J., 2012) of the different zones. Data are taken from the 75th percentile for the study.

- **NASA-SSE** (NASA-SSE, 2017)**:** meteorological and solar data sponsored by the US National Aeronautics and Space Administration (NASA) in the Surface Meteorology and Solar Energy (SSE) program, which provides data for the whole world, with solar radiation values on a horizontal plane. Covers a resolution of 100x100 km. Average of temporary data of 22 years. It compares the data of the satellites with those of its world stations on land. Widely used globally for comparative irradiation studies (Gairaa, K., Benkaciali, S., 2011), (Mitrushi, D., Berberi, P., Irma Bërdufi, I. et al, 2015), (Piragnolo, M, Masiero, A., Fissore, F. and Pirotti, F., 2015)**.**

- **AEMET** (AEMET, 2017-1): data provided by Spain's state meteorological agency (AEMET), whose data have been condensed into Spain's solar radiation atlas (Sancho, J.M., Riesco, J., Jiménez, C. et al, 2012)**,** with data averages from 1983 to 2005, using satellite data and of the national radiometric network. Average values data are used. The resolution of data is of 3x3 km and the values of provincial capitals are given. In this case, data from Las Palmas de Gran Canarias are used.

- **Soda-pro** (Soda-pro, 2017): A service created from the Information Society Technologies (IST) program of the European Commission for the year 2000 (Gschwind, B., Menard, L., Albuisson, M. and Wald, L., 2006)**.** This service offers time series of monthly, weekly and daily values of global solar irradiation in a horizontal plane, as well as the monthly irradiation received by a plane normal to the solar rays. The geographical coverage corresponds to the field of vision of the Meteosat satellite, ie, it covers Europe, Africa, the

Atlantic Ocean and the Middle East. The spatial resolution is approximately 20x20 km. The temporal coverage of the data is from 1985 to 2005.

- **ITC-Canarias** (ITC-Canarias, 2017): data from the Canaries of the Canary Islands Technological Institute (ITC) which have been obtained from 51 radiometric stations between 1998 and 2009. A geographic information system with approximate resolution of 250x250m per pixel. The data are for horizontal global irradiation and global horizontal irradiation to sky. The data we use are horizontal global irradiation.
- **IDAE–Censolar** (IDAE, 2017)**:** the Institute for Diversification and Energy Saving (IDAE) also makes available the solar radiation tables of the company Censolar, for use in the calculation of solar thermal plates (IDAE, 2009)**,** checking its utility for photovoltaics' in this study. Average data on the irradiation of provincial capital of various models of calculation of external radiation and by measuring stations, with adjustments of approximately -10% of the actual values that are not useful for useful generation. It refers to provincial capitals, in this case, the data of Las Palmas de Gran Canarias are used.
- **UNE 94003:2007** (UNE-EN, 2007)**:** Spanish national standard that provides the reference values of global daily irradiance, daily and monthly temperature on horizontal surface, for calculations of low temperature solar thermal plants, but we will check in this study its Useful for calculations of photovoltaic generation. It refers to provincial capitals, in this case, the data of Las Palmas de Gran Canarias are used.

In the following **Table 1**, all the data of average irradiation for horizontal surfaces of the different DBs for the study area, that is the capital of the island of Fuerteventura, Puerto del Rosario, located in the coordinates 28.50º north and 13,86º west. This is the eastern most and closest island to Africa, the archipelago of the Canary Islands (Spain). The data will be compared to verify the maximum, minimum and average values of the different DBs, where the differences between irradiation values are very high, reaching values of about 28% difference. In the annual averages, we find differences of 20%, values which to make estimations are already considerable, for calculations of viability of solar installations and must be considered for adjustments of possible projects. The shaded DBs give values of the provincial capital, Las Palmas de Gran Canarias and not Puerto del Rosario, being those that must be used for the whole province, for which, these values are used for comparison.

Table 1. Solar irradiation data in kWh/m² month of study DB for horizontal surfaces 0º

MONTH	PVGIS Helioclim	ADRASE Ciemat	NASA	AEMET	Soda Pro	ITC Canarias	IDAE Censolar	UNE 94003	Max	Average	min	% Diff. Max min
JAN.	3.980	3.500	3.700	3.760	3.140	3.475	3.111	3.720	3980	**3548**	3111	**27,9%**
FEB.	4.810	4.700	4.630	4.450	4.910	4.439	3.944	4.435	4910	**4540**	3944	**24,5%**
MAR.	5.910	5.900	5.860	5.380	6.130	5.864	4.944	5.342	6130	**5666**	4944	**24,0%**
APR.	6.850	6.700	6.810	6.240	6.410	6.428	5.444	6.132	6850	**6377**	5444	**25,8%**
MAY	7.390	7.400	7.320	6.670	6.960	7.202	6.027	6.618	7400	**6948**	6027	**22,8%**
JUN.	7.540	7.700	7.320	6.570	6.620	7.407	6.250	6.742	7700	**7019**	6250	**23,2%**
JUL.	7.530	7.600	6.990	6.570	7.530	7.357	6.750	6.747	7600	**7134**	6570	**15,7%**
AUG.	7.220	7.000	6.880	6.380	6.980	6.899	6.083	6.354	7220	**6724**	6083	**18,7%**
SEP.	6.280	6.000	6.110	5.730	5.850	6.024	5.500	5.680	6280	**5897**	5500	**14,2%**
OCT.	5.220	4.700	4.990	5.220	4.870	4.716	4.194	4.766	5220	**4834**	4194	**24,5%**
NOV.	4.200	3.700	3.930	3.840	4.160	3.637	3.416	3.914	4200	**3850**	3416	**23,0%**
DIC.	3.660	3.200	3.400	3.470	3.260	3.182	2.972	3.462	3660	**3326**	2972	**23,1%**
Average	**5.890**	**5.675**	**5.660**	**5.357**	**5.580**	**5.553**	**4.889**	**5.326**	**5890**	**5491**	**4889**	**20,5%**

The data of temperature and daily insolation will be used those supplied by AEMET for the station located in the municipality of Puerto del Rosario through several programs of public use of AEMET (AEMET, 2017-2), (AEMET, 2012) and obtaining the values that appear in **Table 2**.

Table 2. Temperature and insolation data of Puerto del Rosario, Fuerteventura. Source: AEMET

Month	Insolation hours/month	Insolation hours/day	Tº Average 1980-2010	Tº Average 2010-2015	% Differ Averages
JAN.	190,00	6,13	17,6	18,4	4,82%
FEB.	189,90	6,78	17,9	18,2	1,40%
MAR.	233,00	7,52	18,9	19,0	0,33%
APR.	242,30	8,08	19,5	20,1	3,18%
MAY.	280,20	9,04	20,6	22,1	7,31%
JUN.	284,80	9,49	22,5	23,2	3,20%
JUL.	293,90	9,48	24	24,5	2,07%
AUG.	288,80	9,32	24,6	25,5	3,66%
SEP.	246,20	8,21	24,4	24,8	1,53%
OCT.	227,10	7,33	22,9	24,1	5,15%
NOV.	202,60	6,75	20,9	21,5	3,05%
DIC.	185,90	6,00	18,9	19,6	3,68%
Average	**2835,50**	**7,77**	**21,1**	**21,7**	**3,08%**

It can be observed as the average temperatures of 1980-2010 and 2010-2015 have increased an average of 3% in recent years, due to which we will use the average data of the most updated years for the calculation of temperature losses calculations solar panels. The average monthly sunshine data will also be used by AEMET as they are based on the observation data of the Puerto del Rosario weather station with average historical data from 1980 to 2010. The solar hours of the month of February are referred to 28 days.

The characteristics of the island of Fuerteventura, where the installations are located, is extremely arid, with 86.6% of the area classified as arid and the remaining 13.4% is semi-arid (Tejedor, M., Jiménez Mendoza, C.C., Díaz Peña, F. et al, 2013). Suspension is usually quite high because of the sand and dry land of Fuerteventura geography. To the dust in its own suspension, we must add that of the Saharan air masses that regularly affect the Canary Islands and the island of Fuerteventura mainly due to its proximity to the Sahara (Dorta, P., Gelado, M.D., Hernández, J.J. et al, 2005), (Dorta, P., 1999), as well as the insignificant annual rainfall, With a mean of 98 mm annually, less than 0.3 L/m^2 per year, causes that the losses of the plates by dirt due to the dust, are very high in these installations, if it is not made a correct maintenance and control Of cleaning them.

Table 3. Fuerteventura Facility's data.

Installation	Mark	Model	T° Coeff.	TONC	m^2 PV	Efficiency	Wpp PV	N° PV	Peak Power	Rated power
FEM	SolarWorld	SW220	-0,48%	46	1,68	13,12%	220	400	88.000	80.000
INP	SolarWorld	SW230	-0,48%	46	1,68	13,72%	230	1.920	441.600	400.000
HIE	SolarWorld	SW230	-0,48%	46	1,68	13,72%	230	2.400	552.000	500.000
INS1	SCHOTT	ASE165T- 170	-0,47%	45	1,31	12,96%	170	592	100.640	90.000
INS2	SKY GLOBAL	SCM 72-180	-0,45%	46	1,32	13,61%	180	576	103.680	100.000
INS3	Photowatt	PW1650-175	-0,43%	47	1,29	13,55%	175	495	86.625	100.000
		PW1650-170	-0,43%	47	1,29	13,16%	170	175	29.750	
INS4	Photowatt	PW1650-175	-0,43%	47	1,29	13,55%	175	495	86.625	100.000
		PW1650-170	-0,43%	47	1,29	13,16%	170	175	29.750	
INS5	Photowatt	PW2050-200	-0,43%	47	1,47	13,64%	200	518	103.600	90.000
INS6	SolarWorld	SW240-245	-0,45%	46	1,68	14,61%	245	448	109.760	100.000
CAR	Photowatt	PW2050-210	-0,43%	47	1,47	14,32%	210	512	107.520	100.000
OCA	Photowatt	PW2050-205	-0,43%	47	1,47	13,98%	205	1.606	329.230	300.000

Table 3 shows the main data of the 11 study facilities, where there are installations connected to low voltage and medium voltage, with maximum or peak power values ranging from 88 kW to 552 kW, with nominal power greater than 100 kW connected to power transformers medium voltage. All equipment is located on roofs and flat or sloping roofs of industrial buildings. The models of panels are of silicon polycrystalline with values of variation of the coefficient of temperature of between -0,43% ºC to -0,48% ºC, with an average value of -0,45% ºC, as well as a nominal operating temperature Between 45°C and 47°C, with an average of all facilities of 47°C. The efficiency of the panels is between minimum values of 13% and above 14%, with an average efficiency of 13.62%. With all these data can be considered that the different panels are of similar characteristics to each other, so the calculations of losses and PR value, we will perform with the average values of the study facilities. Another very characteristic feature of these facilities is The angle of inclination of the panels of 10°, which is with all these data can be considered that the different panels are of similar characteristics to each other, so the calculations of losses and PR value, we will perform with the average values of the study facilities due to the need of space saving to be able to install more solar modules in the existing surface, that is to say to increase the installed power by unit of surface, but without producing shades that diminish the generation in winter. If we consider that the minimum distance between rows of panels must ensure that the generated shadow produces 4 hours of sunshine around noon of the winter solstice (IDAE, 2011), we can calculate the minimum distance between contiguous panels by the following function:

$$\mathbf{h = \frac{L * \sin \alpha}{\tan(61 - \theta)}}$$

Where "L" is the height of the panel, "θ" is the latitude of the location and "α" is the fixed inclination angle of the solar panels.

Considering this way of calculating it, we verify that the differences between placing the solar plates at the optimal angle of 28º at this chosen angle of 10º reduces the distance between panels by 65%, which means that the distance is 1.7 times lower with this chosen angle, and instead the energy production of using the optimal angle of inclination 28° would only increase by 4% than if we used the chosen inclination of 10°. This motivates that the cases of reduced surfaces in roofs of existing buildings, it is advisable to use small angles of inclination to be able to install as many photovoltaic modules in the smallest

possible space, which in this case, is the own one of the roof of the ship where the generators are installed, and in this way, increase the installed power per unit area.

4. CALCULUS

To calculate the losses by estimating the PR, the irradiation is taken from all the irradiation values of the DBs, once adjusted for the 10º inclination angle of the study facilities, and with the daily insolation data, the radiation values are obtained, with which the temperature loss data can be calculated. The rest of the values of losses and average efficiency used, will be those of the following **Table 4**, where they appear the generic coefficients of calculation.

Table 4. Loss or efficiency values for calculations. Source: IDAE and own.

Name	Description	Value
L_T	Temperature losses	Calculate
L_D	Lost by dispersion	2,0%
L_P	Lost dust and dirt	3,0%
L_R	Lost reflectance	3,0%
L_{in}	European Investor Efficiency	95%
L_E	AC and DC circuit efficiency	97%
L_V	Efficiency due to other losses	96%

Fig. 6 shows the graph of the PR value for the different months, checking the validity of the calculation model, since the differences between the maximum and minimum radiation values only influence + - 1% of the PR average value. We take these average values to perform the calculations.

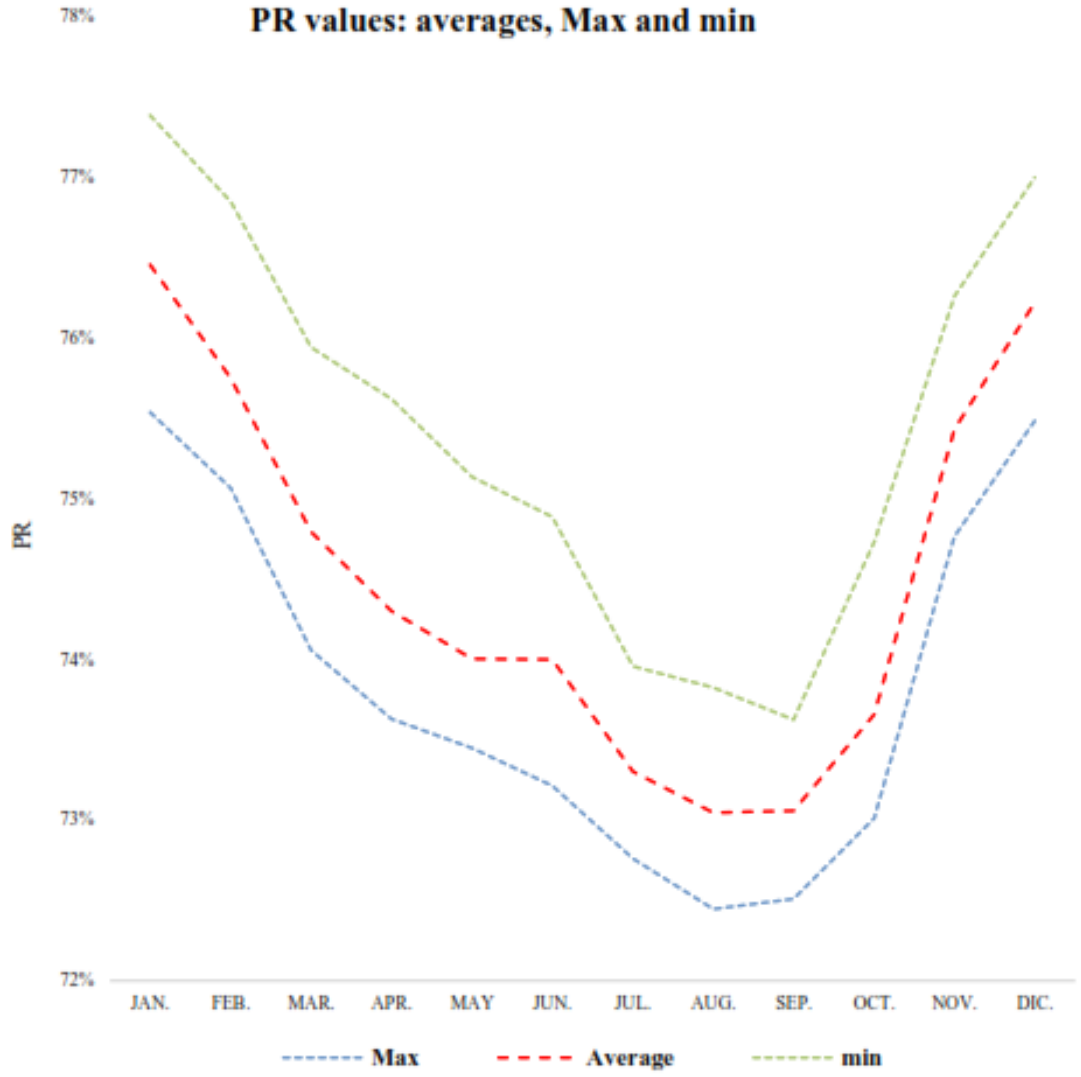


Fig. 6. Differences in PR values according to average, maximum and minimum irradiance data of the different study DBs.

In the following **Fig. 7** the values in columns of the actual generation of the different installations per year in MWh appear. The values of the graphs, being of installations with different maximum peak power, are not comparable to each other, for which we must pass the data to the same indicator that does not consider the generated total energy but the HSP equivalents of production, and in this way, we can compare all the facilities to referring an equal index and with the same unit.

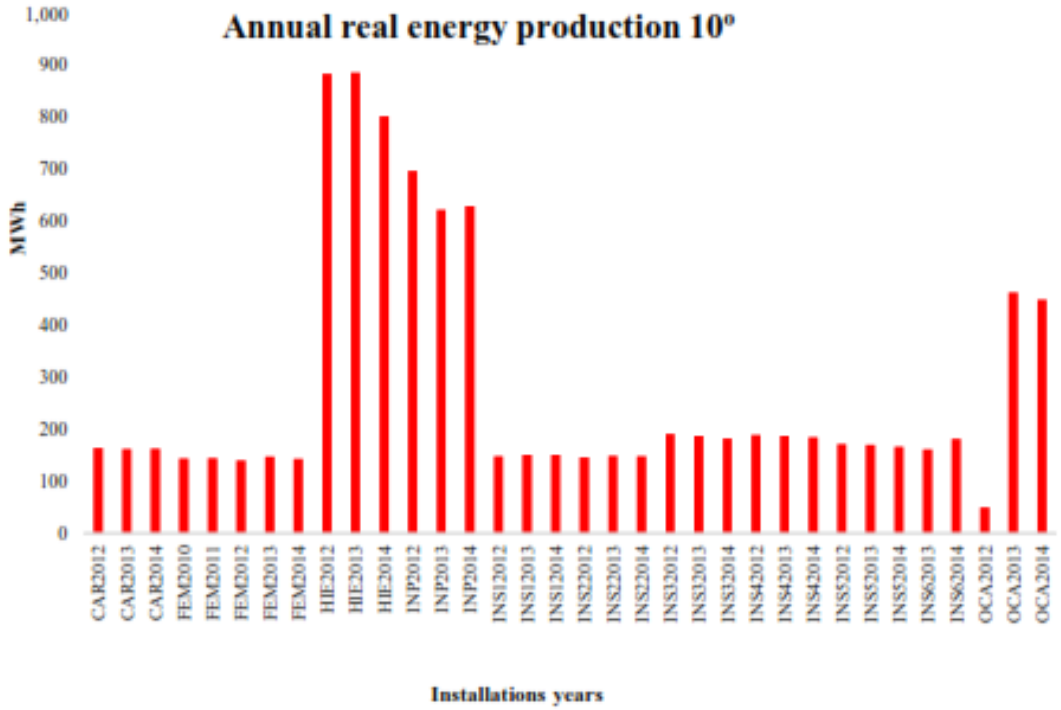


Fig. 7. Production values in kWh of the different installations per year.

To carry out the calculations of the facilities to obtain their equivalent HSPs, we take the average generation values per month and per year of each installation, with respect to all the annual and monthly data we have obtained from the different installations. The calculation performed is for the daily averages of HSP, which is calculated by dividing the actual produced energy value between the installed peak power and this value is divided between the days of the month to have a daily HSP value, which will be the comparable data for all generating plants. Once this value is calculated, the plants can already be compared to each other, by a same ratio, independent of the total installed power. **Fig. 8** shows all the average production curves in HSP calculated for the average of each month, with the data of all the years of study of all the generating stations, as well as the average values, maximum and minimum of the same ones of the Total of the same

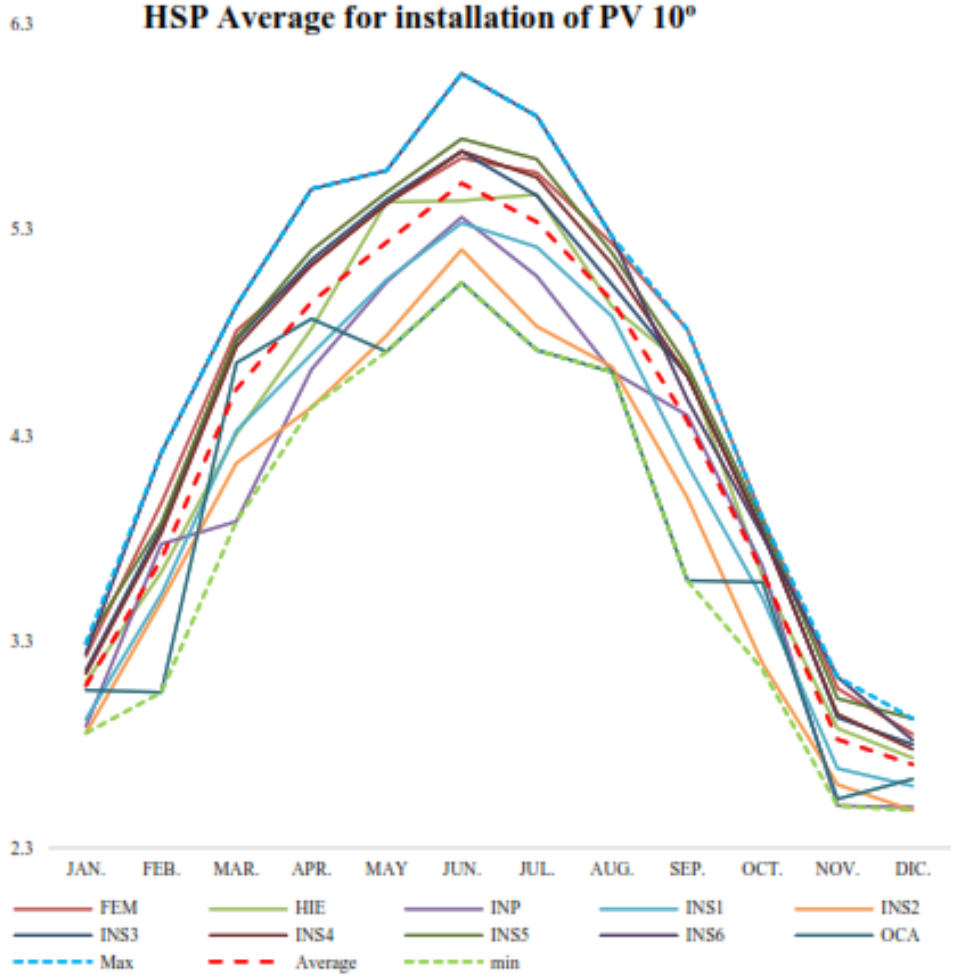


Fig. 8. Average real HSP values of the years of the different installations with panels with 10º angle

Table 5 shows the average monthly HSP data of the data obtained from the different stations of study, calculating the average generation per month of the years that have data, with the monthly and annual maximum and minimum values, as well as the Standard deviation of the same. The months of greatest differences are those of February and September, which has a variation of 27.6% between generations of plants. The average annual difference reaches 14.9% between the maximum and minimum values, so the average value we get, will give us results that will be within the limits of + -7.5% of the estimated real value, with the data between +6% and +14% according to the calculated months, with respect to the average value obtained, with an average standard deviation of the annual data of 0,34 HSP.

Table 5. Maximum, minimum and average values of HSP and their deviations for the study facilities 10º.

Month	Max	Average	min	Diff. % Max-min	Standard deviation
JAN.	3,29	**3,09**	2,86	13,2%	0,22
FEB.	4,22	**3,70**	3,06	27,6%	0,58
MAR.	4,93	**4,53**	3,89	21,2%	0,53
APR.	5,50	**4,95**	4,44	19,3%	0,53
MAY	5,59	**5,24**	4,71	15,8%	0,44
JUN.	6,06	**5,53**	5,05	16,8%	0,51
JUL.	5,86	**5,34**	4,72	19,4%	0,57
AUG.	5,27	**4,96**	4,61	12,5%	0,33
SEP.	4,82	**4,37**	3,60	25,3%	0,62
OCT.	3,90	**3,64**	3,17	18,8%	0,37
NOV.	3,13	**2,83**	2,51	19,9%	0,31
DIC.	2,93	**2,71**	2,48	15,3%	0,22
TT	4,58	**4,24**	3,89	14,9%	0,34

The last comparison we make between the real values of the plants is the YF, which corresponds to the annual production HSP. This value is calculated by dividing the actual output with respect to the installed peak power. This figure is very important for producers, since this annual value is tabulated by law in the CTE, according to the climatic zone and the type of installation and there are a maximum allowable production values for the payment of production premiums. For study facilities that are untraceable and in climatic zone "V", it has maximum values of HSP of 1753, not exceeding this value of the plants, as can be observed in **Fig. 9** where the different values of HSP of all the facilities and all the years of investigation, being verified that the maximum values are above the 1600 hours, as the FEM with 1635 hours, INS3 with 1607 hours, INS4 with 1609 hours, INS5 with 1636 hours and the highest equivalent production, which is the newest installation INS6 with 1655 hours, but none exceeding the threshold of 1700 equivalent hours

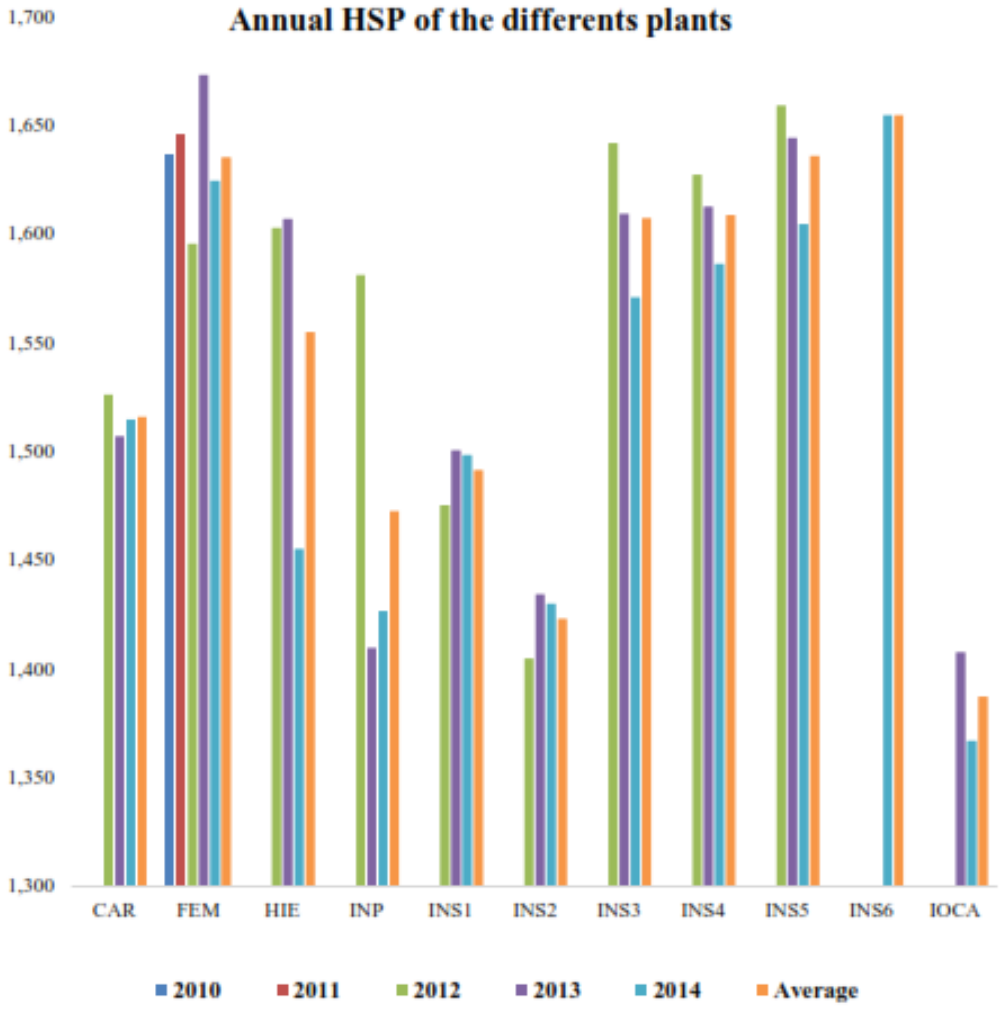


Fig. 9. HSP annuals (YF) Facility's study.

4.1 Comparison of Actual and Projected Values

Once we have verified and calculated the actual data of the different facilities, for HSP values, we will compare these values with those estimated in the different study DBs, for which we pass the irradiation values shown in **Table 1**, To new values of global irradiance of plates inclined to 10° with the value of the calculated coefficient K, we multiply it by irradiation to 0° and give us the value for 10°. With this global irradiation value on the plates at 10º, we perform the total HSP calculations, for which we divide the value between 1000 kWh/m², and finally perform the calculation of the useful HSP by multiplying by the previously calculated monthly PR value. With the data obtained,

Table 6. Summary of daily HES values of the different databases already calculating the total losses by the factor PR with respect to the real value obtained from the study facilities for a 10º angle

Installation	Mark	Model	T° Coeff.	TONC	m² PV	Efficiency	Wpp PV	N° PV	Peak Power	Rated power
FEM	SolarWorld	SW220	-0,48%	46	1,68	13,12%	220	400	88.000	80.000
INP	SolarWorld	SW230	-0,48%	46	1,68	13,72%	230	1.920	441.600	400.000
HIE	SolarWorld	SW230	-0,48%	46	1,68	13,72%	230	2.400	552.000	500.000
INS1	SCHOTT	ASE165T- 170	-0,47%	45	1,31	12,96%	170	592	100.640	90.000
INS2	SKY GLOBAL	SCM 72-180	-0,45%	46	1,32	13,61%	180	576	103.680	100.000
INS3	Photowatt	PW1650-175	-0,43%	47	1,29	13,55%	175	495	86.625	100.000
		PW1650-170	-0,43%	47	1,29	13,16%	170	175	29.750	
INS4	Photowatt	PW1650-175	-0,43%	47	1,29	13,55%	175	495	86.625	100.000
		PW1650-170	-0,43%	47	1,29	13,16%	170	175	29.750	
INS5	Photowatt	PW2050-200	-0,43%	47	1,47	13,64%	200	518	103.600	90.000
INS6	SolarWorld	SW240-245	-0,45%	46	1,68	14,61%	245	448	109.760	100.000
CAR	Photowatt	PW2050-210	-0,43%	47	1,47	14,32%	210	512	107.520	100.000
OCA	Photowatt	PW2050-205	-0,43%	47	1,47	13,98%	205	1.606	329.230	300.000

Table 6 is generated, showing the actual calculated values for the study facilities and the theoretical values of the DBs, where the differences between the HSP values of each DB and the real can already be verified. With these values we perform the calculations of comparison of all the generation data of the different research plants that are converted from kWh to HSP. **Fig. 10** shows the annual average differential values of the calculated values of the DBs, where the DBs of the UNE 94003 and AEMET are the ones whose projection is closer to reality in all cases, with average differences that do not exceed 5%, the value calculated by PVGIS which gives higher values with an average difference of 12.9%.

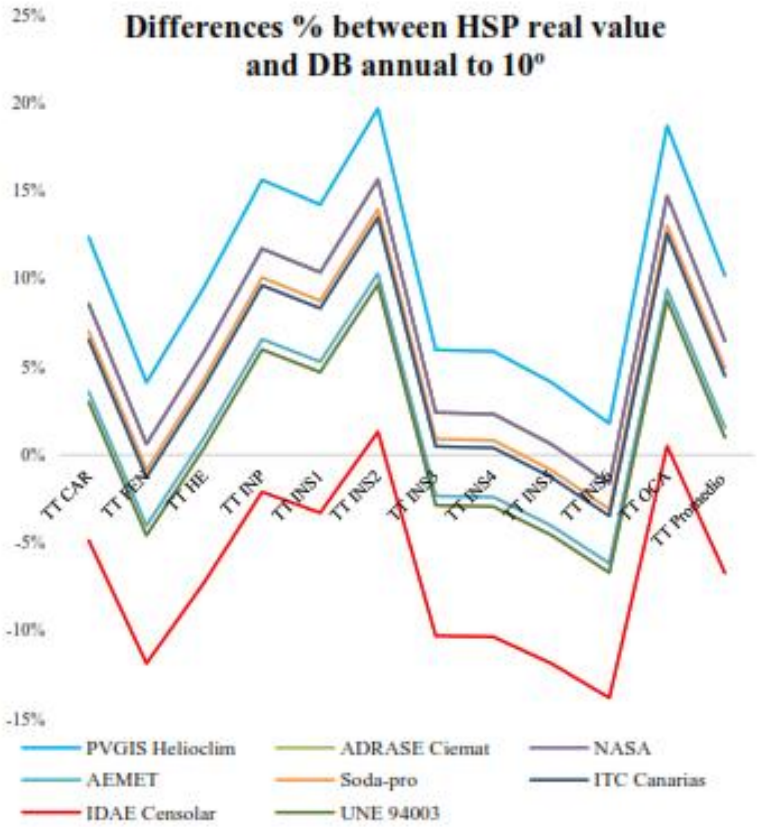


Fig. 10. Differences between total annual values HSP calculated from irradiation DB, with respect to the real value with the plates at 10º.

It can also be seen how there are generating installations whose calculated value predicted with respect to the real becomes 22.6% higher, in the installation of INS2 with PVGIS data. The differences between the maximum and minimum values are between the different DBs with respect to the annual data between 1% and 10.2%, proving that the differences between the DBs are very linear and follow a very similar irradiation function. **Fig. 11** shows the representative graphs of the existing differences between the actual values as compared to those of the monthly level. This is observed more clearly as the winter and autumn months are the ones that generate greater differences, which become Up to 31% higher than the values observed in the real installations, and are the main cause of the annual differences that forecast much higher values of generation than the real ones. While in the summer months, the values are quite close to reality, being even lower in some cases. Again, the values obtained by the PVGIS database are those that give higher values, while the values of IDAE-Censolar have lower values than the real ones, and the values of the standard UNE 94003

and of the AEMET Which are more like reality, even so, all of them being overly optimistic in HSP values for the months of November mainly.

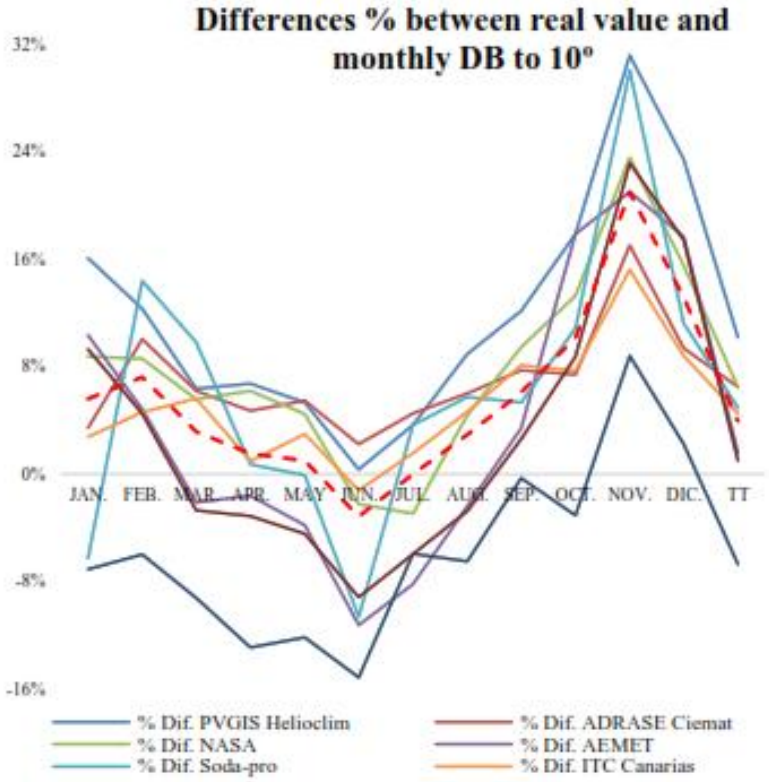


Fig. 11. Monthly differences between total HSP values calculated from irradiation and real DB.

Once verified and demonstrated the differences of values between the DBs respect of the real production data of the studied facilities, we must calculate what the actual irradiation incident on flat surfaces of the plants of Fuerteventura, to verify the differences of real values of irradiation With the DBs. Having the average HSP value of the installations with the solar plates inclined 10º, we perform the theoretical calculation of HSP equivalents for a flat surface 0º, calculating the divisor factor K for each month, which is the same one that we use for the Adjustment of the irradiation of the DBs to 10º. Calculating the value of HSP with losses due to the PR factor, we have to calculate the real incident value without losses, dividing this value between the efficiency coefficient of the system or PR previously obtained, finally obtaining the actual value of HSP for horizontal PVs of 0 ° angle. With the actual value of HSP which allows to have

radiation incident, multiplying that value by 1000 kWh/m². **Table 7** shows the data corresponding to HSP with losses and real, at 10º and 0º, as well as the values of PR and K, obtaining the final value of the irradiation without losses and for flat surfaces at 0º.

Table 7. Average values of HSP, coefficients PR and K, and irradiance value equivalent to 0º.

Month	K	HSP PR 10º	HSP PR 0º	PR	HSP 0º	Irradiation kWh/m²
JAN.	1,19	3,09	2,59	76,45%	3,39	**3.394**
FEB.	1,14	3,70	3,24	75,75%	4,28	**4.282**
MAR.	1,09	4,53	4,15	74,79%	5,55	**5.554**
APR.	1,04	4,95	4,74	74,30%	6,38	**6.380**
MAY	1,01	5,24	5,17	74,00%	6,98	**6.983**
JUN.	1,00	5,53	5,53	74,00%	7,47	**7.467**
JUL.	1,01	5,34	5,31	73,30%	7,25	**7.245**
AUG.	1,03	4,96	4,81	73,05%	6,59	**6.587**
SEP.	1,07	4,37	4,09	73,06%	5,59	**5.593**
OCT.	1,12	3,64	3,25	73,66%	4,41	**4.410**
NOV.	1,18	2,83	2,41	75,43%	3,19	**3.191**
DIC.	1,21	2,71	2,24	76,22%	2,94	**2.944**
TT		4,24	3,96	74,50%	5,34	**5.336**

Comparing the annual average annual irradiance values for flat horizontal surfaces of the DBs with respect to the calculated real value, we obtained **Fig. 12**, where we can graphically check how the values of AEMET DB and UNE 94003:2007 only differ from + - 0.3% in relation to the real value. The biggest differences are PVGIS with a value higher than + 10.2% and with the data from IDAE -Censolar that values are much lower than -8.5%. It is very important to keep in mind that these data refer to irradiation on flat surfaces, ie at 0º of inclination. The calculated values of irradiation show that for annual values the differences are not very excessive, considering that the values of + - 5% per year are acceptable, among which we can consider AEMET, Solar-pro, ITC-Canarias and UNE 94003 DBs acceptable.

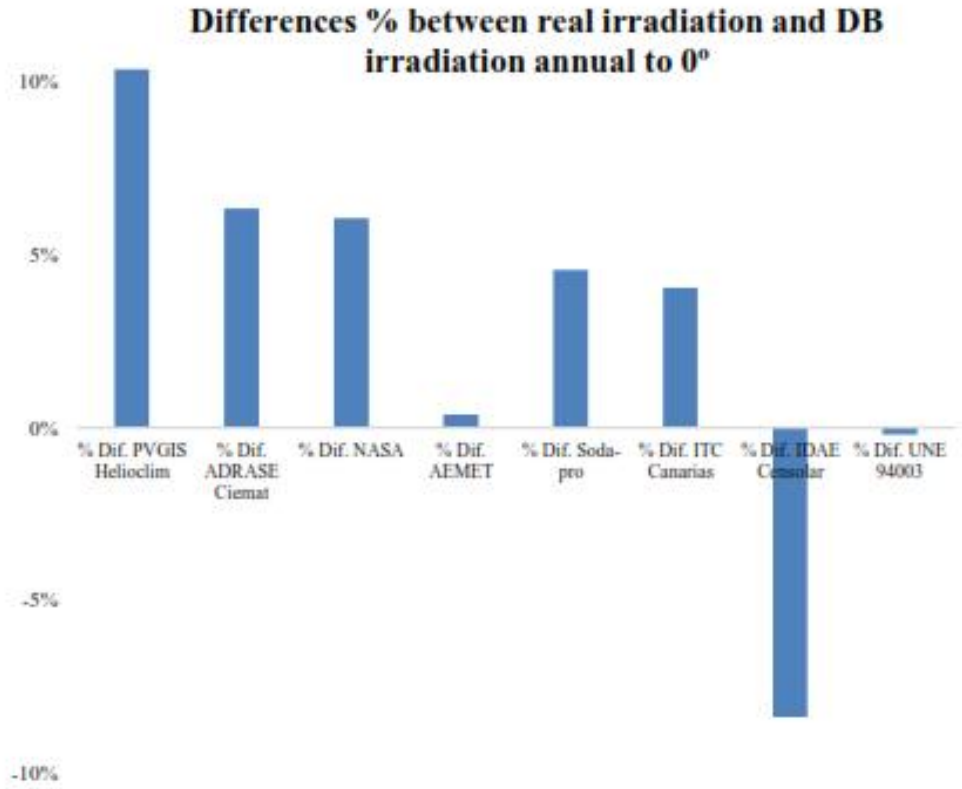


Fig. 12. Percent annual differences between the real value and the DB for horizontal surface irradiation.

We also compare the monthly irradiation data of all the DBs with respect to the calculated real, showing in **Fig. 13** the graphs of the different irradiations, where it can be observed how the real irradiation is found, in most of the months, between the Values of the different DBs, being in the months of November and December when its value is inferior to all DBs. The data of IDAE-Censolar always are well below the rest of values of irradiation, as well as those of PVGIS also usually have the superior value of the rest in most of the months, reason why it gives calculated values of tan generation Generous in most of the months. To perform rapid calculations of irradiation of Fuerteventura, we have calculated the characteristic polynomial function, which is also shown along with the previous graphs, performing the regression of the real irradiation data, giving us the value of the characteristic function, which can be used to make the necessary monthly approximations for calculations of photovoltaic production.

$$y = -141{,}51x^2 + 1741{,}3x + 1682{,}5$$

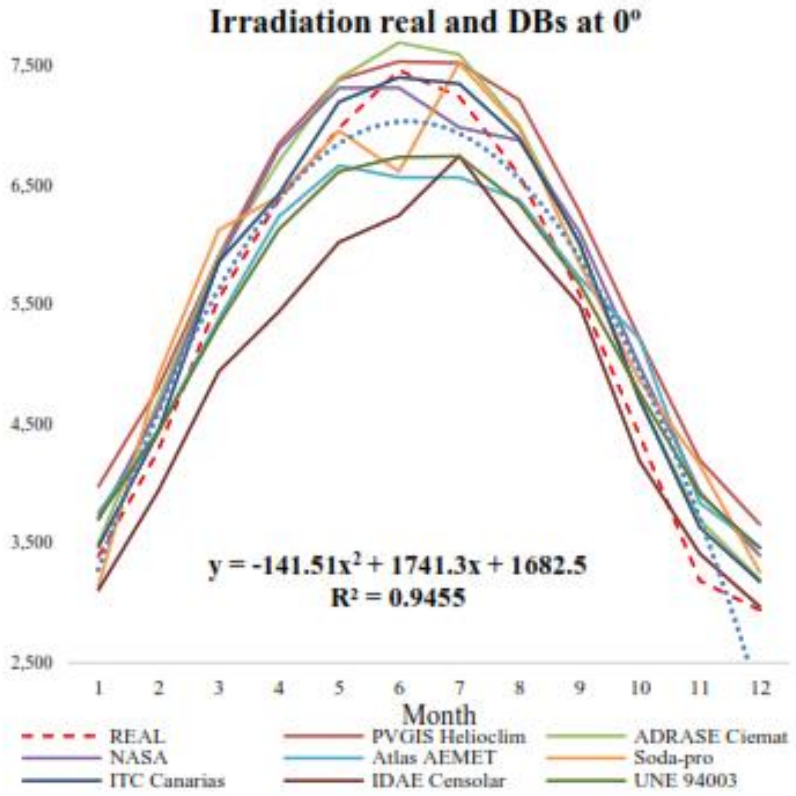


Fig. 13. Curves of real irradiation and of the DB for Fuerteventura.

Table 8 summarizes the percentage differences between the actual irradiance value calculated for the installations and the data that the different DBs offer us, where the contrasts between real values and those obtained by the DBs are appreciated. To highlight the great differences of the month of November in all cases.

Having real values of irradiation is very important for its use in monthly and not only annual electricity generation forecasts, since at the moment the current facilities that are made of self-consumption is necessary to have real monthly values, in order to calculate the effective savings according to the electric rate of each billing period, which changes according to the hours and months of the year according to 2, 3 or 6 tariff periods (Government of Spain, 2008) and thus make the amortizations in the shortest possible time. Along with the monetary savings achieved, savings in CO_2 emissions must be considered to achieve low emission buildings as well as a real alternative to near-zero energy (nZEB) projects.

Table 8. Percentage differences between the real value and the values of the DBs for irradiation in horizontal surfaces at 0º

Month	PV real value	PVGIS Helioclim	ADRASE Ciemat	NASA	AEMET	Soda-pro	ITC Canarias	IDAE Censolar	UNE 94003	Max	Average	min
JAN.	3.394	17,3%	3,1%	9,0%	10,8%	-7,5%	2,4%	-8,3%	9,6%	17,3%	4,5%	-8,3%
FEB.	4.282	12,3%	9,8%	8,1%	3,9%	14,7%	3,7%	-7,9%	3,6%	14,7%	6,0%	-7,9%
MAR.	5.554	6,4%	6,2%	5,5%	-3,1%	10,4%	5,6%	-11,0%	-3,8%	10,4%	2,0%	-11,0%
APR.	6.380	7,4%	5,0%	6,7%	-2,2%	0,5%	0,8%	-14,7%	-3,9%	7,4%	0,0%	-14,7%
MAY	6.983	5,8%	6,0%	4,8%	-4,5%	-0,3%	3,1%	-13,7%	-5,2%	6,0%	-0,5%	-13,7%
JUN.	7.467	1,0%	3,1%	-2,0%	-12,0%	-11,3%	-0,8%	-16,3%	-9,7%	3,1%	-6,0%	-16,3%
JUL.	7.245	3,9%	4,9%	-3,5%	-9,3%	3,9%	1,5%	-6,8%	-6,9%	4,9%	-1,5%	-9,3%
AUG.	6.587	9,6%	6,3%	4,4%	-3,1%	6,0%	4,7%	-7,7%	-3,5%	9,6%	2,1%	-7,7%
SEP.	5.593	12,3%	7,3%	9,2%	2,4%	4,6%	7,7%	-1,7%	1,5%	12,3%	5,4%	-1,7%
OCT.	4.410	18,4%	6,6%	13,1%	18,4%	10,4%	6,9%	-4,9%	8,1%	18,4%	9,6%	-4,9%
NOV.	3.191	**31,6%**	**15,9%**	**23,2%**	**20,3%**	**30,4%**	**14,0%**	**7,0%**	**22,7%**	**31,6%**	**20,6%**	**7,0%**
DIC.	2.944	24,3%	8,7%	15,5%	17,9%	10,7%	8,1%	0,9%	17,6%	24,3%	13,0%	0,9%
TT	5.336	**10,4%**	**6,4%**	**6,1%**	**0,4%**	**4,6%**	**4,1%**	**-8,4%**	**-0,2%**	10,4%	2,9%	-8,4%

5. DISCUSSIONS AND CONCLUSIONS

Through this research study of irradiation comparison of general DBs with respect to real data, it has been verified that all DBs have different data, not agreeing their values in any case and with very large differences according to the calculation months. It is verified that the actual data differ from those projected in absolute and monthly annual values, with very large variations depending on the DB used. It has been possible to verify and conclude that:

- The calculation of irradiation for inclined surfaces can be made by the simplified method to values close to 55º of inclination, with differences of + -2% that can be assumed in most projects.
- When installing PV in areas where the surface of use is very important and high values of installed power per unit area are required, smaller angles of inclination should be chosen, lower than the optimum value, to reduce the distance between Modules and thus increase the installed power per unit area.
- The different DBs do not agree in their values or in their production estimates, so their use must be careful and whenever annual and non-monthly estimates can be made, whose values are more closely adjusted to

actual productions.

- When it is necessary to make monthly production estimates, you must perform calculations with several DBs and take the average values to obtain more realistic adjustments.
- The DBs that have more real values, to be able to make correct estimates, are those that have been calculated by observation and crossing of data of stations, being for the zones of calculation, those generated by national estates, recommending the use of the data from the UNE 94003:2007 standard and AEMET data with a difference of less than 1% per year for horizontal surfaces. The PVGIS database is too optimistic in its calculations and its values tend to be with 10% higher yields.
- To carry out more accurate calculations and forecasts, account must be taken of meteorological and land-type data, since in this case it is verified that being an arid zone the losses are probably higher due to dirt on the plates and losses by Dust in suspension in the months of winter and autumn, due mainly to the calima, for which a future investigation on the influence of this phenomenon in the production would have to be made.
- The most up-to-date and modern facilities have a higher efficiency with equivalent HSPs per plant which can be up to 7% higher than the average.

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ANEXO 4. Congreso: International Conference on Recent Innovations in Engineering and Technology (ICRIET-16). Modeling of energy and water supplies in hotels in lanzarote and Fuerteventura with and without desalination plant (swrop). 5 y 6 de noviembre de 2016. Gandhi Institute of Engineering & Technology, (G.I.E.T), Gunupur, 765022, Rayagada, Odisha. India Track IV, chapter 19.



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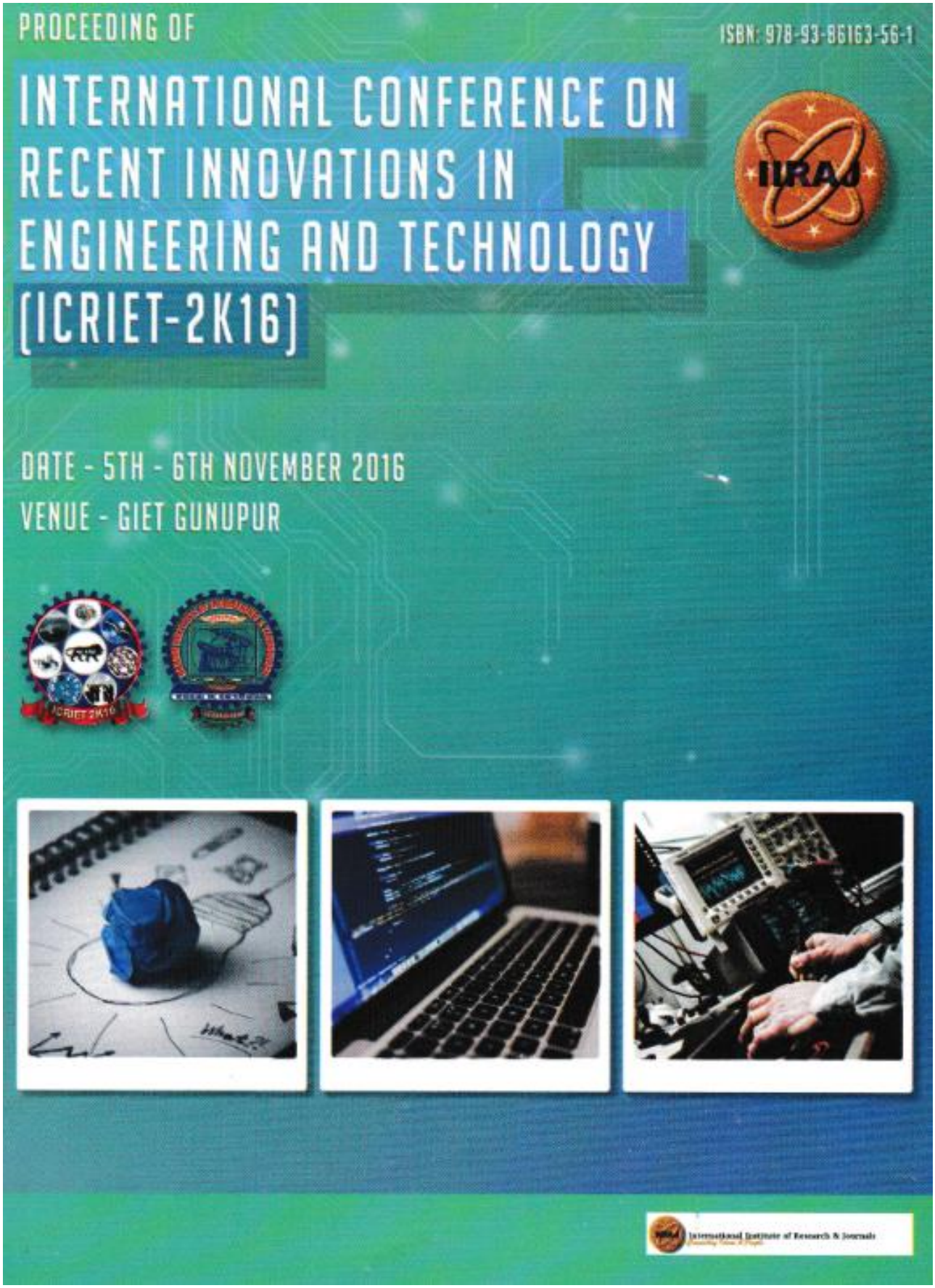
CERTIFICATE OF PRESENTATION

This is to certify that Francisco Javier Díaz Perez, Universidad de San Jorge, Spain has presented the paper entitled Modeling of energy and water supplies in hotels in lanzarote and fuerteventura with and without desalination plant (SWROP) at the International Conference on Recent Innovations in Engineering and Technology held at Gandhi Institute of Engineering and Technology, Gunupur on 5th & 6th November, 2016.

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MODELING OF ENERGY AND WATER SUPPLIES IN HOTELS IN LANZAROTE AND FUERTEVENTURA WITH AND WITHOUT DESALINATION PLANT (SWROP)

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Abstract

This article presents a comparative study of energy and water consumption in four-star hotels in the Canary Islands (Spain), specifically on the islands of Fuerteventura and Lanzarote, with and without desalinationseawater reverse osmosis plants (SWROP), in order to define a pattern of consumption based on the average occupancy rates ofdifferent establishments. They are compared through different types of regression to test the model ofbest fitand generate the calculation algorithm of said consumption. We demonstrate the validity of the potential and polynomial models of regression used to calculate the approximate values for consumption of water, electricity and energy, valid for most of the hotels with an average occupancy rate of between 40% and 120%, which are typically the average occupancy rates for hotels in the Canary Islands during various months of the year. Through a calculated and demonstrated system of analysis, approximate simulations of consumption can be performed for hotels with the same or similar characteristics and modeling of reduced energy consumption can be performed by simulating occupancy values to test the level of reduction. The article concludes with the functions for the approximate calculations of energy consumption, electricity and water per guest, per day for hotels with similar characteristics to those in the study.

Keywords: Canary hotels,energy consumption, energy efficiency, hotel energy performance, modelling.

1. Introduction

At a global level, two-thirds of emissions come from energy consumption, the tourism sector - being a major consumer of energy -contributing 5% due to the inefficiency of energy consumption that occurs in that sector. The tourist accommodation sector represents more than 20% of emissions from tourism and energy consumption from tourism overall[1] is equivalent to 1% of global emissions. For this reason, hotel buildings, which operate in geographical areas with a high concentration of tourism and intensive seasonal use, pose a major challenge to the sustainability of tourist destinations.

The European Union has set a goal of reducing energy consumption, as well as CO2emissions, by 20% by 2020 in comparison to 1990 levels, stipulating that 20% of total energy consumption must come from renewable sources and giving much importance has been placed on energy efficiency through the publication of several directives on the matter, such as directive 2010/31/EU on energy efficiency in buildingsque have generated studies on its implementation in the European Union by A. García Hooghuis y F.J. Neilade [2] y and investigated their application in buildings by M. Kraus , and D. Kubečková [3], and directive 2012/27/EU on energy efficiency, which also highlights the importance of promoting energy efficiency in buildings, setting a time to achieve zero energy buildings (ZEB) or near to zero (nZEB), this being an obligation in new constructions for the year 2018 general government and by 2020 the other buildings, studied its obligation to application by Orsolya Bányai, László Fodor [4]which has been studied their application in Lithuania by A. Zīgurs and U.Sarma [5].

The archipelago of the Canary Islands, belonging to Spain and located in the Atlantic Ocean near the coast of southern Morocco and the Sahara, north Africa, between coordinates 27º37' and 29º25' north latitude and 13º20' and 18º10' west longitude, with a total area of 7447 km^2 and an oceanic subtropical climate, has stable year-round temperatures mitigated by the sea in winter and in summer by trade winds. Currently the tourism sector in the Canary Islands represents 31% of the archipelago's GDP and generates 36% of employment on the islands, it being the main engine of the economy It is the main engine of the economy and its labour mobility as demonstrated in the study of J.S. Leon Santana and Dirk Godenau (2015) [6] on the labour market in the Canary Islands. At this location, there are 626 hotels that offer more than 244,000 hotel beds. Annually, around 13,000,000 tourists visit and produce more than 100 million overnight stays in hotels on the islands. Taking into account the importance of tourism for the Canary Islands, the search for models of energy consumption and water sustainability is essential and valid for implementing energy efficiency strategies in hotels, which has become an essential aspect of European strategy for sustainable growth in 2020, and one of the most profitable ways to strengthen the security of energy supplies, as well as reduce emissions of greenhouse gases and other pollutants. It is very important to know the distribution of energy consumption in hotels so that it can be shown where improvements can and should be made in order to make reductions. Distribution varies according to geographical area and category of hotel, hotels in the Caribbean where 48% of electricity consumed in air conditioning [7], in Hong Kong the air conditioning accounts for 45% of electricity consumption [8], hotels in the Balearic Islands is between 22% for DHW , cooling 14% heating and 21% [9The overall mean of hotels in the US total energy consumption is 31% to the air conditioning, the air conditioning 15% and 17% to ACS [10]

Tourist associations, along with several universities, have conducted various studies on the consumption of hotels. The International Tourism Partnership (ITP), in conjunction with Cornell University, has published the results of the study "Cornell Hotel Sustainability Benchmarking" (CHSB) by Howard Chong and Eric E. Ricaurte [11] to provide points of reference to hotels regarding energy and water consumption, and worldwide carbon footprint references for different types of establishments in various countries.

Other research has been carried out by the scientific community, as the simulation of energy consumption in hotels in Britain by S. Taylor, A. Peacock, P. Ban fi ll, L. Shao [12] with results of average energy intensity of 368 kWh / m2 / year, the study realizadoen one Abdelhak hotel Khemiria Tunisia and Mohamed Hassairib [13] with a result of energy consumption of 171 kWh/m^2/yearsuch as that performed by Rajagopalan Priyadarsini, Wu Xuchao and Lee Siew Eang in 2009 [14] whereby a study of 29 energy intense hotels was conducted in Singapore, checking their linear correlation with various parameters of different hotels, such as the average monthly occupancy rate and average temperature. The average consumption of the hotels stood at 427 kWh/m^2/year. Heterogeneous samples of hotels concluded with the need to group the data into more homogeneous hotels for utility models in simulating energy consumption. In 2012, Jen Chun Wang [15] performed a comprehensive study on the basis of 200 hotels in four categories, checking the levels of energy consumption based on the category of hotels, among other factors. Energy consumption was between 280 and 143 kWh/m^2/year and average consumption per occupied room was between 26.7 and 9.4 kWh/room/year, with 84% of the energy consumed being electricity. In 2012, Ifigenia Farrou, Maria Kolotroni, Mat Santamorius [16] conducted a study on the classification of hotels in Greece for their energy consumption, according to the climatic zone and type of hotel, in which they took into account the size of the hotels but not their occupancy rates. The study of Paulina Bohdanowicz and Ivo Martinac in 2007 [17] - roughly 184 hotels from the Hilton and Scandic chain in Europe - created a model of energy and water consumption in these hotels, taking into account multiple variables and modeling them by linearization of annual consumption. When basing a study on heterogeneous hotels, values are very generic and hardly usable for modeling all hotels, since there are large variations between them. In the study of Miguel Cruz, 2011 [18], to model water consumption in Acapulco, he found that the logarithmic model was the most appropriate for consumption of this type. In 2014, Gregorio Escalera, Amelia Perez and Luis Vizcaino [19] investigated the modeling of water consumption in hotels through regression models in order to obtain a hyperbolic model of water consumption in hotels of the type investigated here. In investigations of Stefan Grossling [20] on the impact of tourism by type of accommodation, it means data for different countries and a global estimate is obtained per bed per night use 36 kWh/bed/night, with consumption water through very uneven, with values between 100 to 2000 l/bed/night so can not generate reliable means of water consumption per customer per day. On the island of Mallorca a study on water consumption was held in hotel and residential populations Hof Angela and Thomas Schmittb in 2011 [21] which concluded that consumption is highly variable between 188-1181 l / person / day and the pool water represents 20 L / person / day.

Data published by the major chains should also be taken into account, since they provide general data on energy and water consumption in their hotels, motivated by environmental certifications and their corporate environmental responsibility policies, which can be useful for checking the average consumption of different establishments comparatively, albeit without any model of consumption or grouping of hotels with similar characteristics.

For this research, we focused on hotels in the Canary Islands, specifically on 4-star hotels, both with and without desalination plants to provide their own water, on the islands of Fuerteventura and Lanzarote. These two destinations have an average of 2.3 and 2 million tourists a year and 18.7 and 16.5 million overnight stays respectively, with an increase in the number of tourists 374% from 1990 to 2010 [22].

The reason that the study focuses on 4-star hotels, is that they represent more than 55% of the hotels in the Canary Islands and more than 70% of the rooms, with which it is possible to realize an approximation of the consumption of most of the hotels on the islands.

2. Experimental

The data obtained from the corporate departments of the hotels from this study of total energy, water and electricity consumption, and number of guests staying a night (= overnight stays), was reviewed alongside the technicians responsible for each establishment, filtering out erroneous data - due mainly to failure to collect it or other chance events outside of normal operations (e.g., water leaks, renovations of facilities, breakage, etc.). With this list of definitive data, already filtered and reviewed, the calculation was performed for the histogram of the resulting data, generating the characteristic points grouped by frequency ranges. To calculate optimal ranges, the Sturges' formula [23] was used, which gives us the number of intervals depending on the amount of data obtained.

The next step was to perform the grouped distributions by intervals calculated, and once thevalues were grouped, the arithmetic mean of the data was performed in order to obtain the different characteristic points of consumption and perform the correlation calculations. The values are ordered by daily guest occupancy rates, which gives us a more accurate correlation than classic systems of monthly or annual consumption, because in this way, errors due to the different number of days in a month - which would provide an error of 6% in February and 3% in the months containing 31 days – are annulled, obtaining a distribution of values more tightly adjusted to their real values. With the data obtained from hotels, the calculations for total energy, electricity and water costs per guest per night were performed.

To test what kind of correlation resembled the models of consumption the most, correlation calculations were performed for linear, exponential, logarithmic, and polynomial of the second degree and potential models, testing their coefficient of determination and calculating their modeling function.

- Linear Regression whose shape fits: $y = ax + b$
- Exponential Regression whose shape fits: $y = ae^{bX}$
- Logarithmicregressionwhoseshapefits: $y = a \ln x + b$
- Secondorderpolynomialregressionwhoseshapefits: $y = a + bx + cx^2$
- Power Regression whose shape fits: $y = ax^b$

The calculation of the values to find the function of the line of different value matrices was performed by the method of least squares. With the lines generated, calculation of the correlation between the values can be performed, which indicates the degree of dependence between two variables, so we used the correlation coefficient of Karl Pearson [24]. To interpret the correlation coefficient of Karl Pearson, it must be taken into account that its value ranges between 1 and -1. Values closer to 1 imply a perfect positive linear relationship

and -1 a perfect negative relationship. Values closer to 0 indicate a lower linear relationship [25].

To test the correlation between the data, the coefficient of determination R^2 was used to interpret the proportion or percentage of variation in the dependent variable, which is explained by the variation in the independent variable, i.e., the percentage of values that fit with the shape of the graph [26]. The functions calculated generate the various energy and water consumption graphs to test their shape and to generate a valid energy model.

This same methodology was used to calculate the correlations of all hotels for different total water, electricity and energy consumption levels. With data from all the establishments, and due to the different maximum capacities of each hotel, guests had to be averaged as a percentage of occupancy, which was necessary to make the relative comparison of the average daily occupancy rate and work with the data from all hotels as if they were a single establishment in order to generate the corresponding function for hotels of similar characteristics.

In the following graph, we show schematically the workflow that was followed to perform the correlation calculations, where a summary of the steps taken can be seen as follows: 1) data collection and filtration, 2) perform the mean arithmetic of the data according to the intervals calculated, 3) perform calculations and generate the correlation graphs of the different models, 4) change the occupancy rates to a percentage and use all the values for the total calculation as if it were a single hotel, 5) calculate the final model of energy and water consumption for establishments, and 6) conclusions.

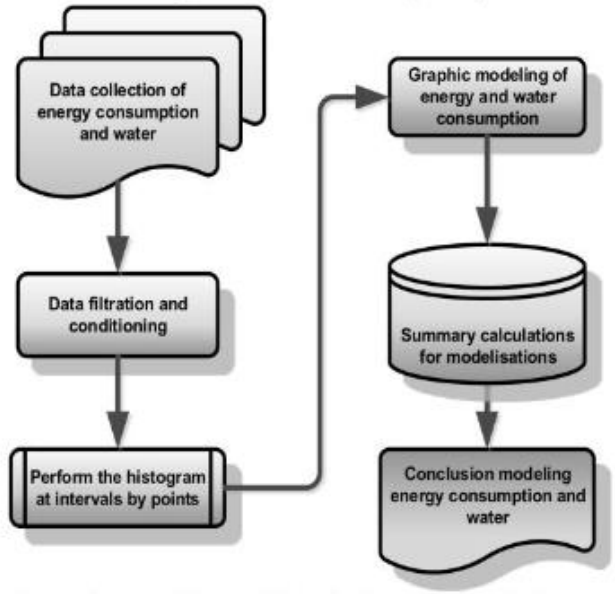


Fig. 1.Diagram of the workflow for the researchwork. Source: Original.

To carry out the study of consumption in hotels, we chose several characteristic hotels in the Canary Islands, located on the eastern islands of Fuerteventura and Lanzarote, which have a peculiarity that distinguishes them from other hotels on other islands: their 100% reliance on desalinated water, due to the absence of hydrological resources for water distribution for general consumption on these islands. The hotels studied differ according to the way they supply water for human consumption, which is by producing water through a desalination seawater reverse osmosis plants (SWROP) either located on the premises and belonging to the hotel or through a public water supply from a municipal plant located externally.

In the search for hotels with homogeneous characteristics, facilities were chosen that were less than 30 years old, had a 4-star rating, and fitted into the category 'holiday establishment', which implies a type of tourism where more of the hotel is enjoyed, such as the continual use of restaurants and swimming pools for the duration of the stay. All establishments have swimming pools and air conditioning, not counting heating. The gardens of the hotels are irrigated with desalinated or reclaimed water, which is motivated by the possibility of having their own treatment plant or external supply of reclaimed or desalinated water, since not all establishments have the possibility of irrigating with reclaimed water. The modeling calculations were performed regardless of the irrigation methods used in each hotel.

The hotels studied do not have the facilities to generate their own electricity, either for their own consumption or for sale, except for replacement generators in case of power failure from the grid, nor do they have their own cogeneration equipment. All electricity comes through an external supply network, being, in all cases, medium voltage with transformers located within the hotel facilities. Other fuels and power generation systems used by hotels, for which data are available are: LPG propane, diesel, biomass pellets and thermal solar panels.

Consumption data for the hotels was obtained between 2007 and 2015, depending on the facilities, with minimum values per hotel of 4 years and maximum of 6 years. During the years of study, diesel boilers have been replaced with biomass boilers, producing similar yields and allowing equivalent calculations to be performed by transferring all combustibles to the same unit of energy, i.e., kWh.

2.1 Dataanalysis

Table 1 shows the general data of the establishments studied, with their main characteristics and facilities being presented. The low use of renewable energy can be observed, present only in a few establishments for the heating of water for human consumption (DHW), as well as the lack of heating facilities. Due to the data protection of the hotels, we refer to each hotel with a code.

In considering a study of hotels with similar capacities and facilities, all feature gardens, swimming pools and have air conditioning in all rooms and public areas (restaurants, bars and lounges). The need be able to generate their own supply of water through desalinationSWROP is also verified where there is an absence in the public supply, as is the case in some areas of the islands in this study, so it is necessary that hotels have their own desalination plants SWROP. With the main data from the hotels, a comparison was performed to check the average values of the facilities listed in Table 2. In this comparison of different facilities, the homogeneity of establishments canbe checked.

Table 1. Details of facilities and characteristics of hotels studied. Source: Original.

DATES		HPE	HT	ESA	ECA	HTI	MSL
GENERAL	Location	Fuerteventura	Fuerteventura	Fuerteventura	Fuerteventura	Lanzarote	Lanzarote
	Construction date	2.000	2.004	2.003	2.007	1.997	1.988
	Land area	30.000	34.879	27.163	34.670	38.622	26.163
	Constructed area	25.912	31.132	22.710	28.307	34.112	24.507
	Rooms	333	354	266	346	329	343
	Beds	678	710	532	692	658	718
	Garden area	8.000	11.000	6.000	14.000	8.000	5.000
	Water source	SWROP	SWROP	Public supply	Public supply	SWROP	SWROP
	Irrigation source	SWROP	SWROP	Recycled	Recycled	SWROP	SWROP
POOLS	Nº Freshwater	2	1	2	1	8	1
	Area m^2	572	240	702	589	1.160	1.084
	Volume m^3	765	266	891	706	1.135	1.727
	Nº Climatized pool	1	3	1	2	2	2
	Heating system	Electricity	AC Recovery	Electricity	Electricity	Electricity	Solar panels
	kW heating	38	378	100	135	25	95
	Area m^2	86	232	331	439	85	120
	Volume m^3	130	240	298	487	95	110
Hot WaterDHW	Combustible	LPG Propane	LPG Propane	Diesel oil	Diesel oil	LPG Propane + Diesel oil	Diesel oil
	kW heating	537	650	800	1.000	272+200	450
Renewable energy	Biomass heating kW					270	
	Nº Solar panels					168	92
	Solar panels m^2					340	795
Air Conditioner	HVAC System	1	2	2	2	1	1
	kW Total HVAC chillers	344	828	792	804	485	450
DesalinationS WROP	kW Power (feed + plant)	65	65			52	120
	Production m3/hour	12	12			11	18
Years of date		2010-2013	2010-2015	2007-2012	2007-2012	2010-2015	2010-2015

Table 2. Main indicators of the hotels studied. Source: Original.

INDICATORS	HPE	HT	ESA	ECA	HTI	MSL	Average	Typical deviation
m^2Construction / rooms	78	88	85	82	104	71	**85**	11
m^2Gardens / rooms	24	31	23	40	24	15	**26**	9
% Gardens / land area	27%	32%	22%	40%	21%	19%	**27%**	8%
m^2 Pools / rooms	2,0	1,5	3,9	3,0	3,8	3,5	**2,9**	1,0
m^3 Pools / rooms	2,7	1,6	4,5	3,4	3,7	5,4	**3,5**	1,3
kW Heating water / rooms	1,6	1,8	3,0	2,9	1,4	1,3	**2,0**	0,7
kW AC / rooms	1,0	2,3	3,0	2,3	1,5	1,3	**1,9**	0,7

Hotels in the Canary Islands, mainly those in the eastern islands of Fuerteventura and Lanzarote, have the peculiarity that they do not need heating in winter. The average winter temperatures do not require the use or installation of heating systems, which reduces the average consumption during the winter months, air conditioning not being required in most establishments either. The average temperature of the coldest months of December, January and February is close to 18°C, with a minimum average of 16°C and a maximum of 20°C, making heating and air conditioning unnecessary.

2.2 Consumptionwater performance

To perform the calculations of water consumption, the peculiarity of these establishments must be taken into account, counting two extra types of consumption that are independent of hotel occupancy and operations. These consumptions are the replacement of swimming pool water and the irrigation of gardens, which have been studied independently.

Consumption from irrigation has not been taken into account in the calculations of the total water consumption of the hotels, since irrigation water can be of two types: purified water which has specific rules Royal Decree 1620/2007 for its implementation, which was studied and compared with other European countries N.V. Paranychianakis, M. Salgot and A.N. Anelakis in 2015 [27], and water for human consumption which has specific rules Royal Decree 140/2003, both of which are incompatible with each other. Irrigation costs in respect to total water consumption can be seen in table 3, reaching an average expenditure at 12% of total water

Table 3. Total consumption, percentages and garden surface area for irrigation water. Source: Original.

TYPE	HPE	HT	ESA	ECA	HTI	MSL	Total / Average
Total water consumption	453.535	468.617	423.494	397.289	424.167	467.479	2.634.581
Irrigation water consumption	46.286	79.232	25.480	77.285	38.263	37.388	303.934
% Consumption irrigation	10%	17%	6%	19%	9%	8%	12%
m^2garden	8.000	11.000	6.000	14.000	8.000	5.000	52.000
Average daily consumption	21	36	10	42	17	11	139
l/m^2daily	2,64	3,29	1,70	3,03	2,18	2,26	2,67

Table 4. Average air temperature and percentage of monthly irrigation water consumption. Source: Original.

UNIT	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dic*	*Average*
T°	17,9	17,9	18,9	20,2	21,7	23,2	24,8	25,5	24,9	23,8	21,3	19,1	17,9
% irrigation	63%	69%	72%	83%	78%	92%	94%	100%	93%	80%	78%	70%	**80%**

consumption. Given the total surface area of the gardens, irrigation consumption is calculated as $m^2$of garden, with an average of 2.67 l/m^2 and a standard deviation of 0.6 l/m^2.

To perform a simplified approximation of the consumption of irrigation, taking into account only the air temperature and not considering go their factors, such as the type of flora, the similarity of the gardens, or the rainfall of the islands, annual accumulated average being the lowest in both the Canary Islands and Spain of between 60 mm on the coast and tourist and 200mm areas uninhabited mountainous areas [28] will not consider this factor. With the average data of the percentage of consumption for irrigation in respect to the maximum value of the monthly irrigation values of the hotels shown in Table 4, a linear regression to test their dependence on the temperature was performed, proving that its coefficient of determination is very high and hence their dependence very strong, as shown in figure 2.

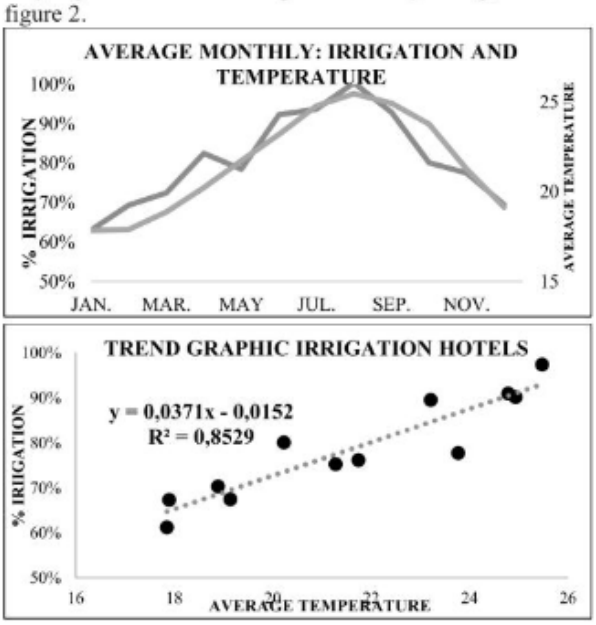


Fig. 2. Average consumption of irrigation water and representation of the linear regression function.

Given that the annual average for daily consumption is 2.67 l/m^2, corresponding to 80% of the value of irrigation, the maximum value, 100%, corresponds to 3.34 l/m^2, which is the maximum value of daily irrigation. With the function calculated by linear regression, the function for calculating monthly consumption in litresfor irrigation according to the surface area of the garden can be generated.

$$W_{irr} = (3,34(0,0371t - 0,0152)A_g)d$$

Where "A_g" is the area of garden in m^2, "d" is the number of days of the month of calculation and "t" the average monthly temperature in °C in the area where the hotel is situated on the islands.

With the consumption of water in swimming pools, which is another determinant factor in the cost of water, there are several variables involved in the daily renewal necessary to maintain the level of the swimming pools, which can be enumerated with the following factors: evaporation, leakage in the pool itself and the circuit, washing of filters, etc. Table 5 shows consumption data for hotel swimming pools, differentiating between the cold and heated pools. The importance of pool maintenance, which amounts to 13% of the water consumption of a hotel, can be checked, without taking into account maintenance of hot tubs, which are affected by the rules of legionella RD 865/2003 and which mark the minimum amount of water maintenance of this type It has been studied for this type of thermal pools by Maciej Walczak , Aleksandra Burkowska -But , Maria Swiontek Brzezinska , and Arkadiusz Krawiec [29] .Daily consumption of water for swimming pool maintenance, generically speaking, takes a daily value of 2.42%, with a standard deviation of 0.5%, which is considered sufficient to perform an approximate calculation for the water consumption of swimming pools, according to volume.

As hotel swimming pools use fresh water, this expense for modeling calculations of total water consumption has to be taken into account. In order to calculate approximations of monthlyswimming pool water consumption in m^3, taking into account the volume, the following function can be used to simulate an approximation of consumption:

$$Wp_m = (0,0242V_{Tp})d$$

Where "V_{TP}" is the total volume of coldwater swimmingpools,

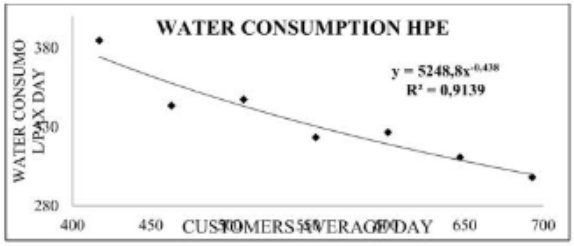
Table 5.Water consumption in recreational and climatized pools. Source: Original.

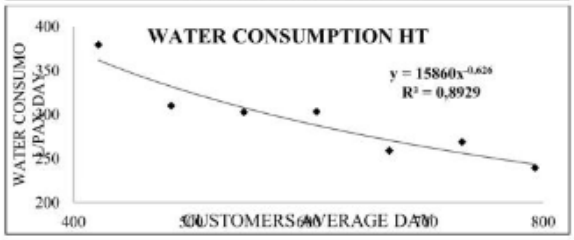
	TYPE	*HPE*	*HT*	*ESA*	*ECA*	*HTI*	*MSL*	*TOTAL*
Total Year	*Total water consumption*	453.535	468.617	423.494	397.289	424.167	467.479	2.634.581
	Consumption water pools	53.929	26.342	49.930	66.824	40.976	113.899	351.900
	% consumption pool	12%	6%	12%	17%	10%	24%	**13%**
Cold pool	*Volume water pool m^3*	765	266	891	706	1.135	1.727	5.490
	Averagedaily consumption	21	4	17	16	18	48	123
	% averagedaily consumption	2,76%	1,51%	1,91%	2,22%	1,55%	2,78%	2,25%
Climatized pool	*Volume water pool m^3*	130	298	298	487	79	110	1.402
	Averagedaily consumption	3	7	7	19	2	6	43
	% averagedaily consumption	1,96%	2,47%	2,35%	3,85%	2,18%	5,44%	3,09%
Total	*Volume water pool m^3*	895	564	1.189	1.193	1.214	1.837	6.892
	Averagedaily consumption	24	11	24	34	19	54	167
	% averagedaily consumption	2,64%	2,01%	2,02%	2,89%	1,59%	2,94%	**2,42%**

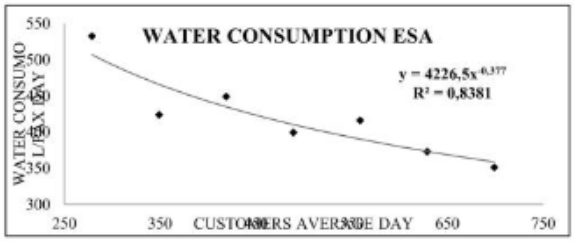
heated pools and Spas in m^3, "d" is the number of days of the month of the calculation.

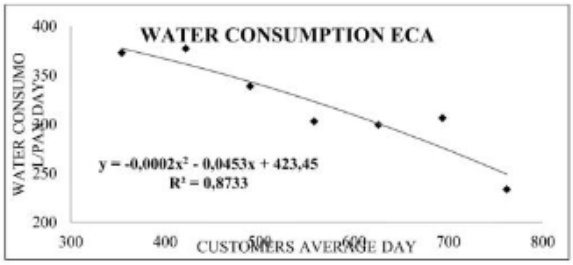
2.2.1 Water consumption in hotels without irrigation

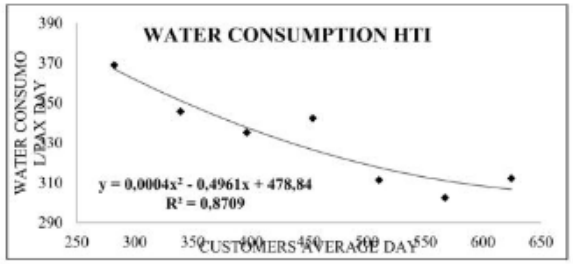
Having established the average consumption from swimming pools and irrigation, the correlation calculations of different levels of water consumption of hotels - recalling that the consumption of irrigation has not been taken into account, but the consumption of pools has -were performed. The following graphs show the different average points calculated for each hotel, according to the daily occupancy rate and daily average water consumption in litres per guest. The graphs of each hotel represent the characteristic function with a greater correlation index and a greater determination coefficient R^2 for different regression models.











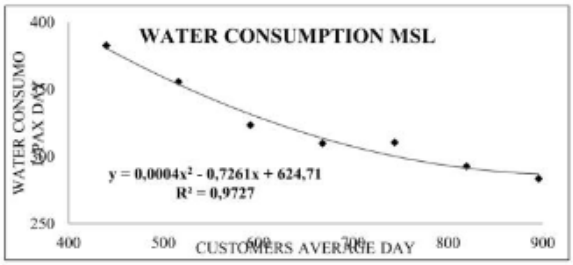


Fig. 3.Characteristic function with the greatest correlation index for each hotel for different regression models for water consumption, without considering irrigation. Source: Original.

Table 4 summarizes the calculation values of the functions of the investigated regression models, where the different values of the coefficient of determination can be checked, with the potential and polynomial correlation which best fit the graph. The increased potential of consumption is due to the declining number of guests. Since the minimum consumption of some facilities is independent of the number of guests, we consider the minimum fixed consumption to be maintained.

Table 4.Summary of functions and coefficient of determination of the different types of correlation for water consumption. Source: Original.

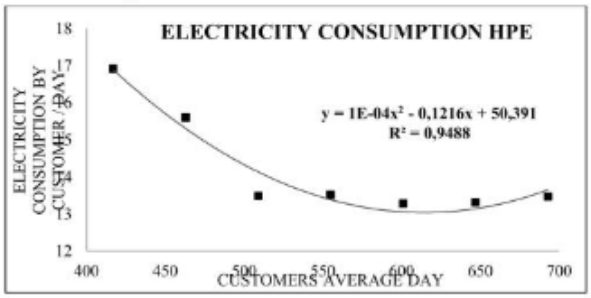
	CORRELATION TYPE	HPE	HT	ESA
WATER CUSTOMERS	Linear	y=-0,2687x + 483	y=-0,3148x + 486	y=-0,3466x + 590
	Linear R^2	0,8842	0,8496	0,7869
	Exponential	$y = 517,53e^{-8E-04x}$	$y = 552,06e^{-0,001x}$	$y = 619,13e^{-8E-04x}$
	Exponential R^2	0,9002	0,8758	0,8161
	Logarithmic	y = -147,9ln(x) + 1265,9	y = -188,7ln(x) + 1499,5	y = -163,3ln(x) + 1424,2
	Logarithmic R^2	0,9034	0,8784	0,8245
	Polynomial	$y = 0,0006x^2 - 0,8871x + 649,43$	$y = 0,0006x^2 - 1,0462x + 698,32$	$y = 0,0006x^2 - 0,8853x + 710,89$
	Polynomial R^2	0,9083	0,8854	0,8162
	Potential	**$y = 5248,8x^{-0,438}$**	**$y = 15860x^{-0,626}$**	**$y = 4226,5x^{-0,377}$**
	Potential R^2	**0,9139**	**0,8929**	**0,8381**
	CORRELATION TYPE	ECA	HTI	MSL
WATER CUSTOMERS	Linear	y=-0,3142x + 494	y=-0,1759x + 411	y=-0,2056x + 460
	Linear R^2	0,8662	0,8380	0,9158
	Exponential	$y = 556,66e^{-0,001x}$	$y = 419,72e^{-5E-04x}$	$y = 487,92e^{-6E-04x}$
	Exponential R^2	0,8390	0,8377	0,9338
	Logarithmic	y = -165,4ln(x) + 1359,9	y = -77,36ln(x) + 801,65	y = -135,2ln(x) + 1198,2
	Logarithmic R^2	0,8403	0,8637	0,9554
	Polynomial	**$y = -0,0002x^2 - 0,0453x + 423,45$**	**$y = 0,0004x^2 - 0,4961x + 478,84$**	**$y = 0,0004x^2 - 0,7261x + 624,71$**
	Polynomial R^2	**0,8733**	**0,8709**	**0,9727**
	Potential	$y = 8995,3x^{-0,533}$	$y = 1352,2x^{-0,232}$	$y = 4582,4x^{-0,41}$
	Potential R^2	0,8013	0,8591	0,9653

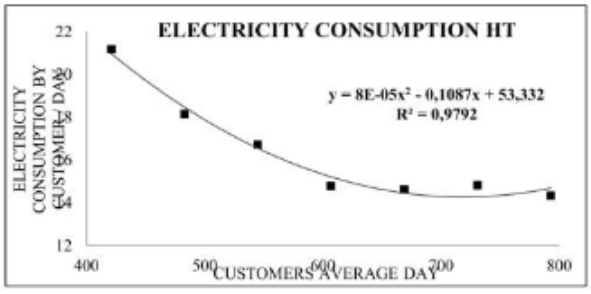
2.3 Electricity consumption

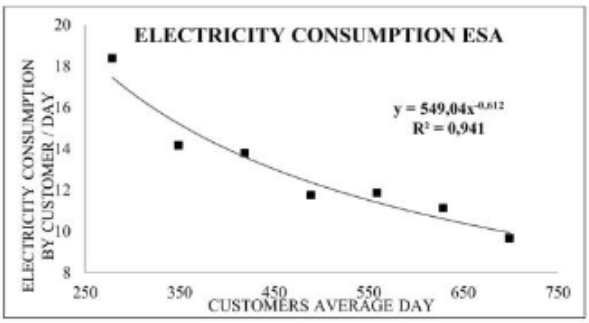
Electricity in hotels is the main source of energy used in them, since most of the equipment and facilities work with this type of energy. Electricity consumption represents about 70% of the total energy consumption of hotels. In the hotels in this study, all electric power is supplied externally, not counting the establishments with any active generation or cogeneration system, so their external dependence is total. This external dependence clashes with the possibility of obtaining buildings with ZEB or nZEB, so it is necessary to model their consumption and check their behaviour according to occupancy rates, seeking alternatives to this external dependence through self-supply of electricity with different types of power generation systems based on renewable energy.

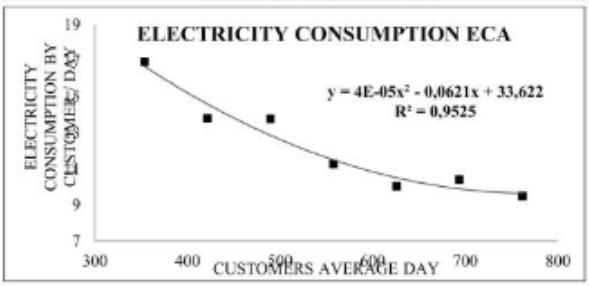
For comparison of electricity consumption, the use of water from the public supply or from the hotel's own desalinationseawater reverse osmosis plants (SWROP) has to be taken into account, which represent between 10% and 15% of hotels' total consumption. This can be seen in the following table5 of values from2013, where the average energy consumption fromdesalinations about 4.77 kWh/m^3, taking into account the SWROPand pumping brackish or saltwater from acatchpit.

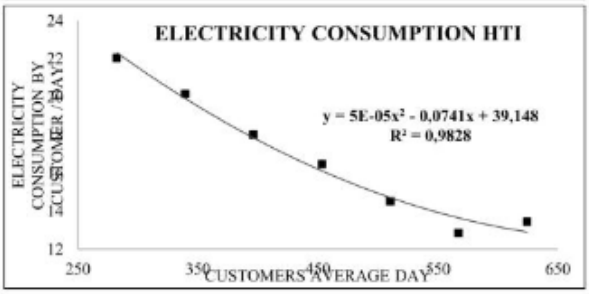
To perform the calculations formodellingthe consumption of electricity, the consumption of SWROPare not considered, as there are hotels without desalination plants. The following graphs show the different average points for electricity consumption calculated for each hotel according to the average daily occupancy rates and the average daily electrical energy consumption in kWh per guest. They represent in all the graphs the line of tendency according to the correlation function with greater determination coefficient R^2.











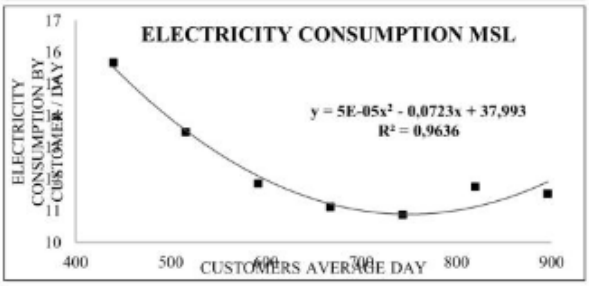


Fig. 4. Characteristic function with the greatest correlation index for each hotel for different regression models for electricity consumption, without considering the desalination plant. Source: Original.

Table 6 summarizes the calculations performed to obtain the functions of the regression models of consumption of electricity per customer per day, checking the different values of the coefficient of determination, which indicate the degree of correlation between data. The high correlation of the values of occupancy and consumption of electricity is tested, the polynomial correlation being the one which best fits in almost all cases, except in the case of ESA hotels.

Table 5.Consumption of electrical energy for desalination in hotels, 2013. Source: Original.

TYPE (2013)	*HPE*	*HT*	*HTI*	*MSL*	*TOTAL*
ELECTRICITY	2.830.578	4.025.026	3.045.352	2.822.006	12.722.962
DESALINATION	357.115	391.600	292.212	420.801	1.461.729
% Desalination	13%	10%	10%	15%	**11%**
Desalinated water	68.676	78.320	76.898	82.510	306.404
ConsumptionkWh/m3	5,20	5,00	3,80	5,10	**4,77**

Table 6.Summary of functions and coefficient of determination of the different types of correlation for energy consumption. Source: Original.

	TYPE	HPE	HT	ESA
ELECTRICITY CUSTOMERS	Linear	y=-0,0117x + 21	y=-0,0169x + 27	y=-0,0174x + 21
	Linear R^2	0,6536	0,7952	0,8605
	Exponential	$y = 21{,}941e^{-8E-04x}$	$y = 29{,}509e^{-1E-03x}$	$y = 24{,}094e^{-0,001x}$
	Exponential R^2	0,6578	0,8195	0,9083
	Logarithmic	y = -6,692ln(x) + 56,414	y = -10,36ln(x) + 82,512	y = -8,278ln(x) + 63,854
	Logarithmic R^2	0,7167	0,8607	0,9169
	Polynomial	**$y = 1E-04x^2 - 0{,}1216x + 50{,}391$**	**$y = 8E-05x^2 - 0{,}1087x + 53{,}332$**	$y = 4E-05x^2 - 0{,}0562x + 30{,}182$
	Polynomial R^2	**0,9488**	**0,9792**	0,9260
	Potential	$y = 240{,}9x^{-0,419}$	$y = 760{,}9x^{-0,603}$	**$y = 549{,}04x^{-0,612}$**
	Potential R^2	0,7202	0,8802	**0,9410**
	TYPE	ECA	HTI	MSL
ELECTRICITY CUSTOMERS	Linear	y=-0,0172x + 22	y=-0,0275x + 29	y=-0,0079x + 18
	Linear R^2	0,8859	0,9505	0,5869
	Exponential	$y = 25{,}85e^{-0,001x}$	$y = 34{,}496e^{-0,002x}$	$y = 18{,}283e^{-5E-04x}$
	Exponential R^2	0,9126	0,9555	0,5861
	Logarithmic	y = -9,445ln(x) + 71,674	y = -12,07ln(x) + 90,206	y = -5,493ln(x) + 47,902
	Logarithmic R^2	0,9293	0,9748	0,6821
	Polynomial	**$y = 4E-05x^2 - 0{,}0621x + 33{,}622$**	**$y = 5E-05x^2 - 0{,}0741x + 39{,}148$**	**$y = 5E-05x^2 - 0{,}0723x + 37{,}993$**
	Polynomial R^2	**0,9525**	**0,9828**	**0,9636**
	Potential	$y = 1320{,}6x^{-0,747}$	$y = 1235{,}8x^{-0,71}$	$y = 182{,}49x^{-0,417}$
	Potential R^2	0,9418	0,9657	0,6803

2.4 Energy Performance

Hotels currently use multiple primary energy sources to meet their energy needs. To make comparisons, it is necessary to transfer such energy sources to a common unit of reference, in this case kWh.

Table 7.Factors of conversion for combustible fuel energy in kWh. Source: IDAE.

COMBUSTIBLE TYPE	ENERGY CONVERSION FACTORS	
DIESEL OIL	10,28	KWh/L
LPG PROPANE	12,75	kWh/kg
Wood Pellets (humidity<15%)	5,01	kWh/kg
Pellets generally	4,57	kWh/kg

The main types of energy used in hotels are:

- Electricity: generic use in all facilities. Between 60 and 75% of energy.
- LPG: kitchens, DHWheating and acclimatization of pools. Between 10 and 30% of energy.
- Diesel: DHW heating and acclimatization of pools. Between 10 and 30% of energy.
- Biomass: DHW heating and acclimatization of pools. Usually replacingLPG or diesel oil boilers in the same proportion, representing between 10 and 30% of energy.
- Thermal Solar: DHW heating and acclimatization of pools. Between 5 and 20% of energy.

The following table lists the different types of energy consumption in 2011, where the importance of electricity consumption can be seen. Renewable energy does not yet represent a significant percentage of consumption. From 2014, HTI diesel cats switched to biomass, which means an increase to 15% of renewable energy, this value being too low to obtain ZEB or nZEB buildings.

The following chart can be used to check the distribution of energy consumption in percentages by energy type for the year 2011, highlighting the importance of electricity consumption in hotels, where it represents 67% of total consumption, and the low importance of renewable energies in that year, representing only 4% fromthermalsolar energy.

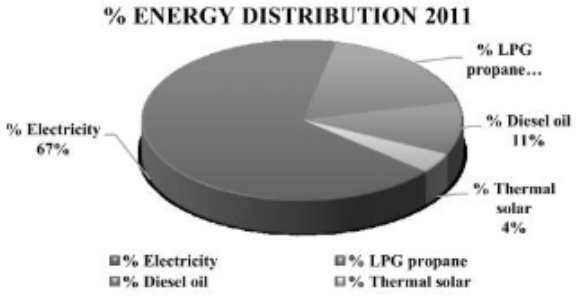
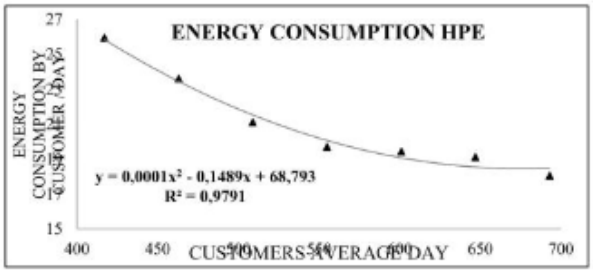


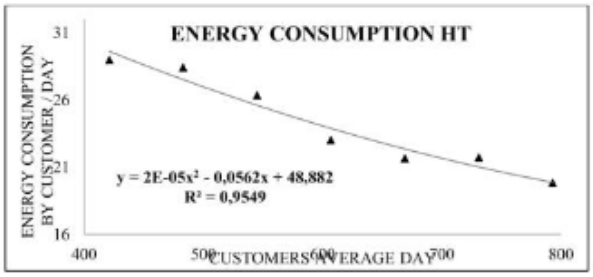
Fig. 5. Distribution of energy consumption in hotels study 2.011. Source: Original.

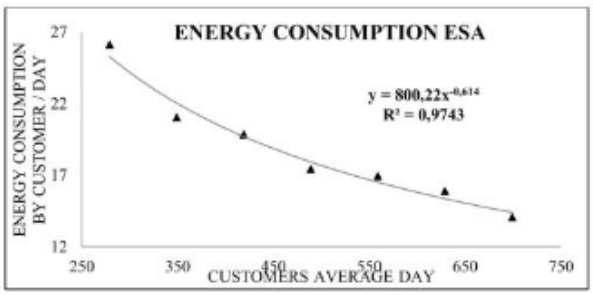
Table 8.Summary of energy consumption from hotels in study from 2,011. Source: Original.

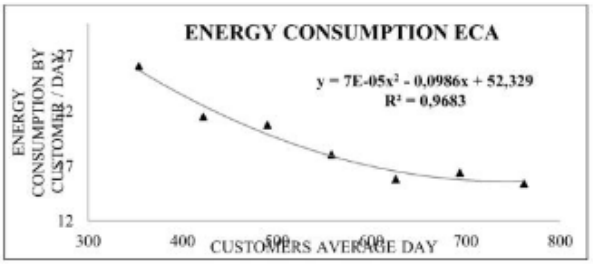
ENERGY TYPE	HPE	HT	ESA	ECA	HTI	MSL	TOTAL
ELECTRICITY	3.596.447	3.855.650	2.394.797	2.372.912	2.978.048	3.021.838	18.219.692
% Electricity	72%	68%	70%	63%	62%	67%	**67%**
LPG PROPANE	1.372.410	1.801.014	194.081	272.582	906.895	307.224	4.854.206
% LPG propane	28%	32%	6%	7%	19%	7%	**18%**
DIESEL OIL			822.400	1.099.960	544.316	441.989	2.908.664
% Diesel oil	0%	0%	24%	29%	11%	10%	**11%**
THERMAL SOLAR					350.842	739.200	1.090.042
% Thermal solar	0%	0%	0%	0%	7%	16%	**4%**
TOTAL ENERGY	4.968.857	5.656.664	3.411.278	3.745.454	4.780.100	4.510.250	27.072.603

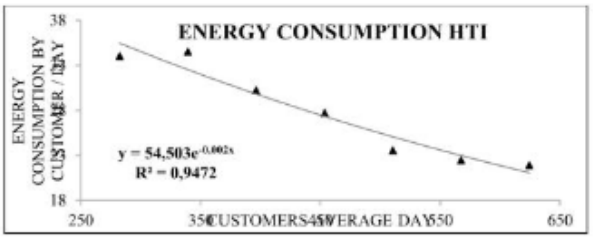
In the calculations of the modellingof energy consumption, theconsumption of desalination plants is not taken into account. The following graphs show the average points of energy consumption calculated for each hotel according to the average daily occupancy rates and the average daily consumption of energy per guest in kWh. The line of tendency is represented in all the graphs, according to the correlation function with the greatest determination coefficient R^2.











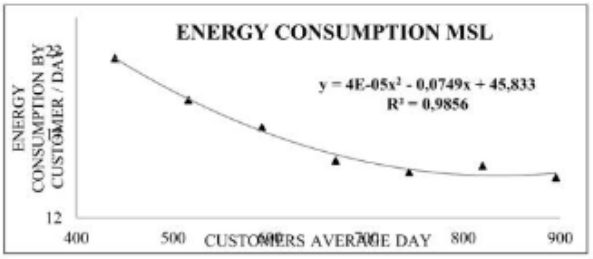


Fig. 6.Characteristic function with the greatest correlation index for each hotel for the different regression models for total energy consumption, without considering desalination plants. Source: Original.

Table 9 summarizes the calculations performed to obtain the functions of regression models of total energy consumption per customer per day, checking the different values of the coefficient of determination, which indicates the degree of correlation between the data. The high correlation values of occupancy and energy consumption is tested, the polynomial correlation being that which best fits consumption, except in the case of ESA, where it is the potential, and HTI, where it is the exponential.

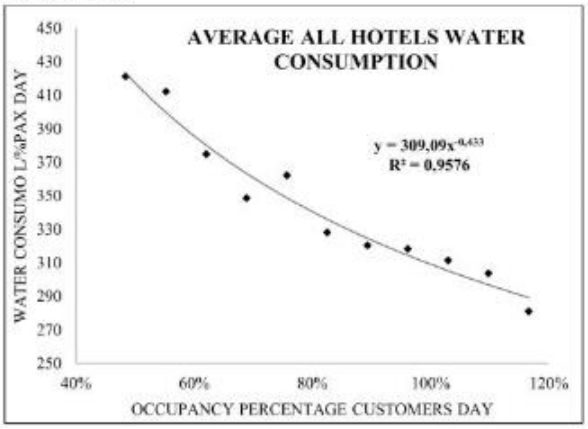
Table 9.Summary of functions and coefficient of determination of the different types of correlation for total energy consumption. Source: Original.

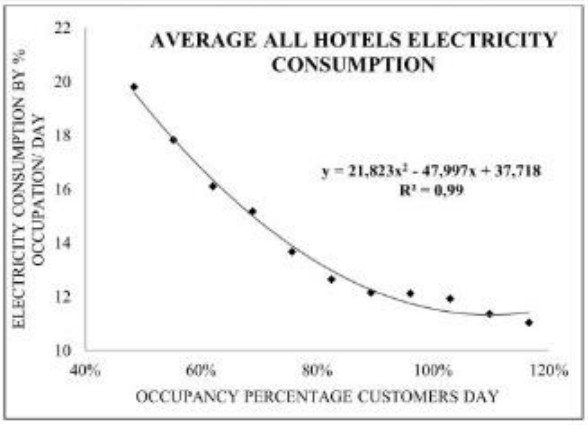
	TYPE	HPE	HT	ESA
ENERGY CUSTOMERS	Linear	y=-0,0267x + 36	y=-0,0262x + 40	y=-0,0252x + 31
	Linear R^2	0,8834	0,9452	0,9073
	Exponential	$y = 41,405e^{-0,001x}$	$y = 46,225e^{-0,001x}$	$y = 35,024e^{-0,001x}$
	Exponential R^2	0,9072	0,9514	0,9488
	Logarithmic	y = -14,84ln(x) + 114,53	y = -15,49ln(x) + 123,22	y = -11,9ln(x) + 91,935
	Logarithmic R^2	0,9226	0,9523	0,9566
	Polynomial	**$y = 0,0001x^2 - 0,1489x + 68,793$**	**$y = 2E-05x^2 - 0,0562x + 48,882$**	$y = 5E-05x^2 - 0,0748x + 42,206$
	Polynomial R^2	**0,9721**	**0,9549**	0,9615
	Potential	$y = 1571,9x^{-0,686}$	$y = 1386x^{-0,635}$	**$y = 800,22x^{-0,614}$**
	Potential R^2	0,9408	0,9511	**0,9743**
	TYPE	ECA	HTI	MSL
ENERGY CUSTOMERS	Linear	y=-0,0247x + 33	y=-0,0421x + 47	y=-0,0151x + 27
	Linear R^2	0,8807	0,9405	0,8549
	Exponential	$y = 37,91e^{-0,001x}$	**$y = 54,503e^{-0,002x}$**	$y = 29,695e^{-9E-04x}$
	Exponential R^2	0,9085	**0,9472**	0,8758
	Logarithmic	y = -13,61ln(x) + 104,75	y = -18,17ln(x) + 138,32	y = -10,04ln(x) + 81,849
	Logarithmic R^2	0,9323	0,9354	0,9153
	Polynomial	**$y = 7E-05x^2 - 0,0986x + 52,329$**	$y = 3E-05x^2 - 0,0672x + 52,174$	**$y = 4E-05x^2 - 0,0749x + 45,833$**
	Polynomial R^2	**0,9683**	0,9442	**0,9856**
	Potential	$y = 1402,2x^{-0,685}$	$y = 1464,7x^{-0,655}$	$y = 683,88x^{-0,574}$
	Potential R^2	0,9472	0,9326	0,9286

2.5Study mathematical model

Since the hotels in this study have different maximum capacities, the same number of clients translates to different percentages of occupancy. This requires changing the ratios of consumption per guest to consumption by percentage of occupancy, since, in this way, we can compare the occupancy rates of different hotels in balance with the conditions of occupancy. With the amount of data from all the hotels, it was found that the occupancy intervals used and on which we have data, cover occupancy values of between 45% and 120%. Once we divided by intervals and filtered them, we performed the correlation calculations for the calculated mean values.

With the calculations performed, the following graphs were generated, representing the midpoints for consumption of water, electricity and energy for all the hotels combined. The line of tendency is represented in all the graphs, according to the correlation function with the greatest determination coefficient R^2.





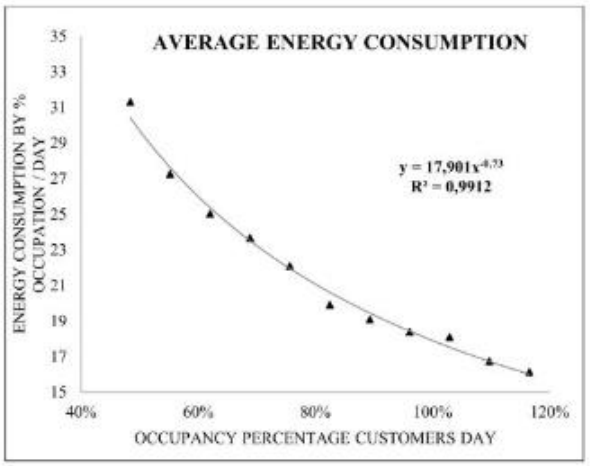


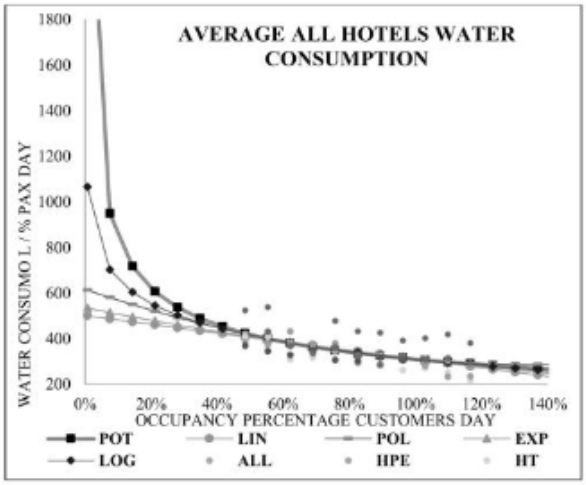
Fig. 7.Characteristic function with the greatest correlation index for the consumption of water, electricity and energy of all hotels. Source: Original.

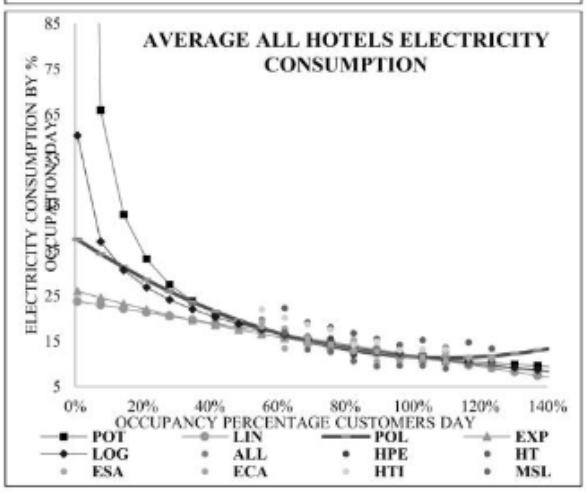
In the following table 10, thecalculations performed to obtain the functions for the regression models of water, electricity and energy are summarized. A strong correlation was found between the consumption of water and energy, which fits almost perfectly with the potential function. Thebestfitfor consumption of electricity is a type of polynomial function, although the potential function also has a high degree of correlation.

After verifying the strong correlation between the systems of polynomial regression in electricity and potential in water and total energy, the suitability of these functions can be confirmed, comparing the actual values of the averages for the hotels with values of the functions generated by the regression models. All the regression models have been compared on the same graph, calculating the values of the functions from an occupancy rate of 1% to 140%, which is shown in Figure 8. It can also be seen how the values of the regression functions have been paired for values of between 40% to 120% occupancy, for which, among these values - which are where the average occupancy rates for the hotels are usually found - the mean values of supplies with any of the functions can be approximated, although taking into account that the optimum fit has to use the potential or polynomial function.

Table 10.Summary of functions and coefficient of determination of the different types of correlation for consumption of water, electricity and energy. Source: Original.

TYPE	*DATA FOR ALL HOTELS*		
	WATER CUSTOMERS	*ELECTRICITY CUSTOMERS*	*ENERGY CUSTOMERS*
Linear	$y = -190,38x + 500,91$	$y = -11,988x + 23,879$	$y = -20,312x + 38,362$
Linear R^2	0,9247	0,8838	0,9257
Exponential	$536,13e^{-0,547x}$	$y = 27,163e^{-0,826x}$	$y = 45,157e^{-0,919x}$
Exponential R^2	0,9412	0,9212	0,9647
Logarithmic	$y = -151,6\ln(x) + 309,16$	$y = -9,732\ln(x) + 11,762$	$y = -16,33\ln(x) + 17,868$
Logarithmic R^2	0,9542	0,9476	0,9733
Polynomial	$y = 180,19x^2 - 487,69x + 615,18$	**$y = 21,823x^2 - 47,997x + 37,718$**	$y = 27,706x^2 - 66,027x + 55,931$
Polynomial R^2	0,9547	**0,9900**	0,9882
Potential	**$y = 309,09x^{-0,433}$**	$y = 11,803x^{-0,564}$	**$y = 17,901x^{-0,73}$**
Potential R^2	**0,9576**	0,9700	**0,9912**





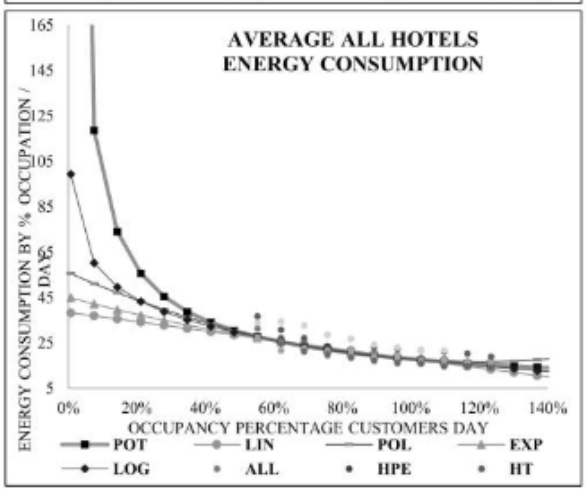
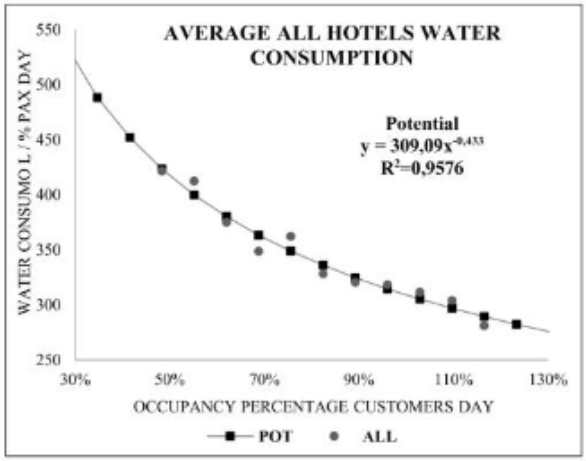
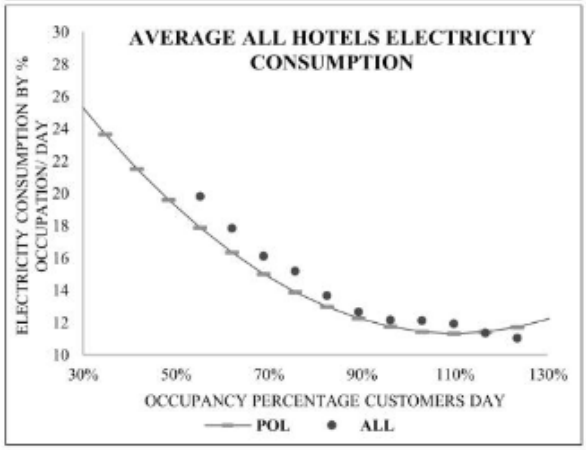


Fig. 8. Representation of regression functions between 1 and 140% occupancy with respect to the midpoints of water,

3. Results and discussion

It was found that the values of the midpoints for the levels of consumption of the hotels approximately fit the values of the calculated functions. The next step was to check that the calculated mean values for all hotels fit with the generated function in order to demonstrate the validity of the models calculated for the average occupancy values, which range in a generic sense between 30% and 130%. In the following graphs, representations of the functions of water, electricity and energy appear.





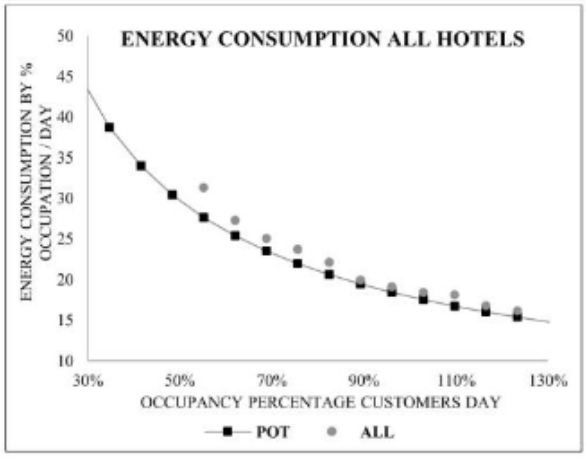


Fig. 9. Representation of regression functions between 30 and 130% occupancy with respect to the midpoints of the average consumption of water, electricity and energy calculated for all hotels. Source: Original.

In reviewing the representation of the functions, it was found that the average data fits the graphs generated, so the potential function can be used for the approximation of the values of water and energy consumption, and the polynomial for electricity consumption for a group of four-star hotels with similar characteristics such as those studied here.

The functions that bring us the values of monthly consumption, taking into account the average daily occupancy, air temperature for water consumption for irrigation and desalinated water production for specific consumption, are summarized as follows:

➢ Water

Consumption without irrigation:

$$W_{TT} = (309,09x^{-0,433})d$$

Consumption with irrigation:

$$W_{TTirr} = \Big((309,09x^{-0,433}) + \big(3,34A_g(0,0371t - 0,0152)\big)\Big)d$$

➢ Electricity

Consumption without irrigation:

$$El_{TT} = (21,832x^2 - 47,997x + 37,718)d$$

Consumption desalinationSWROPwithout irrigation:

$$El_{TTdw} = \Big((21,832x^2 - 47,997x + 37,718) + (W_{TT}C_{dw})\Big)d$$

Consumption desalinationSWROPwith irrigation:

$$El_{TTdwirr} = \Big((21,832x^2 - 47,997x + 37,718) + (W_{TTirr}C_{dw})\Big)d$$

➢ Energy:

Consumption without irrigation:

$$E_{TT} = (17,901x^{-0,73})d$$

Consumption desalination SWROPwithout irrigation:

$$E_{TTdw} = (17,901x^{-0,73}) + (W_{TT}C_{dw})d$$

Consumption desalinationSWROPwith irrigation:

$$E_{TTdwirr} = \Big((17,901x^{-0,73}) + (W_{TTirr}C_{dw})\Big)d$$

Where "x" is the percentage of average occupancy, "C_{dw}" is the specific consumption of the plant in kWh/r m^3 of water generated, "A_g" is the surface area of gardens, "d" is the number of days of calculation and "*t*" the average temperature in the area where the hotel is located on the islands.

The main reasons for the increase in specific consumption, even with decreasing occupancy, are related to the need for facilities to be in place and consuming energy or water at the hotel, with or without guests, since thesectorization of equipment or systems cannot be carried out in most of the hotels studied, implying that the minimum consumption is always due to the ongoing maintenance of facilities.

Conclusions

Using the method described, a model of the typical consumption of water, electricity and energy for a hotel in a determined segment, which may be reproduced for any other hotel in the sector, was obtained, thus making it possible to check and compare consumption. With the application of statistical functions and correlation, optimum consumption models can be generated for a group of homogeneous hotels, taking into account that the more data obtained, the more reliable will be the generated models. The basic procedure followed and demonstrated leaves the field open to more complex and precise research, applicable to any type of supply for hotels.

With the different correlation models studied, it has been found that, in most cases, the potential or polynomial models is applicable, with very little difference between the correlation coefficients. The calculated values, from which we can consider similar approximations for both models, are between 40% and 120% occupancy, being that lower or higher occupancy rates have very large differences from which no equivalent can be made.

The peculiarity of hotels with a desalination seawater reverse osmosis plants SWROP where energy consumption is directly related to water consumption and influence the type of irrigation used - is studied. This proves the need to improve the efficiency of the desalination plants SWROP in reducing water consumption and irrigation in order to achieve a proportional energy reduction in the hotels.

The use of renewable energy is highly unrepresented in the hotels from the study. This can and should be improved, mainly through using renewable energy sources for domestic hot water (DHW), which represents 22% of energy consumption in hotels. In this way, external energy dependence could be reduced.

This study leaves open the way to further investigation into the importance of hotel occupancy rates, with the carbon footprint generated by energy consumption being due to the activity of tourist accommodation, as well as the importance of water desalination in hotels in the Canary Islands, which is a determinant factor in the consumption of energy.

By comparing the different methods and systems for energy efficiency and developing the method studied, improvements can be simulated for application in facilities in order to compare the most optimal and effective models to be adopted, verifying this as hotels get closer to energy independence and achieving the objective of becoming ZEB or nZEB hotels.

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ANEXO 5. Congreso: 6Th International conference on advances in civil, architecture and environmental engineering (ICCAEE-2018) Reduction Of Energy Consumption In Hotels With Aerothermal Energy. Case Study: Canary Islands (Spain).

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ACCEPTANCE LETTER

6TH INTERNATIONAL CONFERENCE ON ADVANCES IN CIVIL, ARCHITECTURE AND ENVIRONMENTAL ENGINEERING (ICCAEE)

Date: July 2, 2018

Ref. No. : ICONTES-2018-06-19/1701

Title: Reduction of Energy Consumption in Hotels With Aerothermal Energy. Case Study: Canary Islands (spain)

Authors: Francisco Javier Diaz Perez, David Chinarro, Maria Rosa Pino Otin, Ricardo Diaz Martin, Adib Guardiola Mouhaffel

Dear Assist. Prof. Francisco Javier Diaz Perez,

On behalf of the Organizing Committee of **6TH INTERNATIONAL CONGRESS ON TECHNOLOGY - ENGINEERING & SCIENCE (ICONTES)**, it is our pleasure to inform you that your submitted paper has been selected after the peer review for presentation in the congress that will be held in Kuala Lumpur, Malaysia at 19-20 July, 2018 and publication in the International Journal of Engineering and Technology.

Please, visit the Congress Web page in order to get information for your presentation date after 15 July, 2018.

Please do not hesitate to contact for any further clarification.

Sincerely Yours,
ICONTES Coordinator
M. Feiz Husaain
contact@icontes.org

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ICONTES 6TH INTERNATIONAL CONGRESS ON TECHNOLOGY ENGINEERING & SCIENCE JULY 19-20, 2018, KUALA LUMPUR - MALAYSIA

REDUCTION OF ENERGY CONSUMPTION IN HOTELS WITH AEROTHERMAL ENERGY. CASE STUDY: CANARY ISLANDS (SPAIN)

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Abstract

This article presents a management model and control of energy efficiency in hotels adapted to the consumption patterns that ensure the comfort requirements of customers and integrated into the environment of an intelligent tourist complex. The analysis of the hot water system (DHW) of two hotels in the Canary Islands (Spain) in relation to their occupation, yields a solution based on renewable energies using high temperature heat pumps with aerothermal dissipation and supported by boilers of existing LPG propane. The control by programmable automatons (PLC) integrated in a system of control and acquisition of data (SCADA) optimizes the systems to maintain the maximum accumulated energy during the periods of cheapest electric tariff, by means of a system of opening and closing of hydraulic Valves that It manages to adjust the demand of DHW consumption to achieve the highest energy accumulation during the hours with the cheapest electricity tariff. The result after two and a half years of activity registration is a faster return on investment due to the optimized energy management of the system, through the control of operating hours adjusted to the needs of customers and the hourly rate. It has also been predicted that during the estimated 12 years of the system will have saved more than € 1,179,737 and thermal 8,780,005 kWh in a hotel 1 and € 1,315,104 and thermal 9,522,301 kWh in the hotel 2. This model shown can be seen how economically and energetically very efficient.

Index Terms – DHW, energy efficiency, hotels, aerothermal energy, SCADA, PLC.

I. INTRODUCTION

The constant increase of tourism in Spain is a fact, and this past year 2017 has again increased by 4.4% tourist GDP, now standing at 11.5% of total Spanish GDP [1] and giving work to 13 % of the employed population, which has led the sector to outstanding positions in the Spanish economy and enables both hotel and extra hotel accommodation have begun to remodel their facilities and equipment. Within these initiatives of improvements, and due to the new awareness of customers towards the environment, great efforts have been made in favour of the sustainability of the tourist destination and energy efficiency of the facilities. The hotel companies have worked in recent years, in the implementation of energy saving and efficiency measures in multiple facilities, betting on the reduction of consumption and greenhouse gas emissions (GHG), through the implementation of energy management methods and of information and communication technologies in monitoring and control systems. This new "green revolution" of the tourism business is well encouraged by the

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European Union (EU), defining goals in reducing CO_2 emissions to 20% by the year 2020 compared to the 1990s and establishing that 20% of the Total energy consumption is supplied by renewable energies (EERR) ***[2]***. In addition, new objectives have already been established for future stages [3], setting a reduction of 40% in emissions by 2012, compared to 1,990, 27% of EERR, increase in energy efficiency by 27-30% and 15% electric interconnection, that is, that the electricity generated in the EU can be transported to other member states. By the year 2050, the EU has imposed an 80-95% reduction in greenhouse gas emissions compared to 1990 levels. With these guidelines for improvement in energy management and saving, the tourism sector has launched a "green revolution", based on the implementation of technologies to reduce consumption and the certification of establishments and destinations, which leads to an increase in the different certification systems and certified companies, as can be seen in ***Table 1*** , where the main current environmental management and energy management certifications are being applied is the hotel establishments.

NAME	CERTIFICATOR
Ecolabel Europa ***[4]***	European Comission
AITO Star ***[5]***	Association of International Tour Operators
Biosphere ***[6]***	Biosphere Responible Tourism
Earthcheck ***[7]***	EC3 Global
EMAS ***[8]***	European Comission
Green Globe ***[9]***	Green Globe Ltd
ISO 14001 ***[10]***	International Organization for Standardization (ISO)
ISO 50001 ***[11]***	ISO
LEED ***[12]***	U.S. Green Building Council
Travelife ***[13]***	Travelife Ltd
STEP ***[14]***	Sustainable Travel Internationsal
Eco lideres ***[15]***	Tripadvisor

Table 1. Main environmental and energy certificates.

The importance of these changes is due to two clear reasons. The first is the need to reduce the energy consumption of the facilities, meeting the expectations of customers without reducing the services offered. The second is due to the change in mentality of customers, who begin to value destinations and establishments in response to the environmental sustainability of their facilities and services. Within these tourist destinations, we have taken as example two establishments in the Canary Islands (Spain), where the tourism sector is the main engine of the economy, representing 34.3% of GDP in 2016 and generating 39.7% of GDP. % of employment in the islands ***[16]*** and being an important factor in their labour mobility ***[17]***. Tourist stays have increased by 27% from 2010 to 2016 ***[18]*** in an archipelago where 63% of its territory is declared a biosphere reserve by UNESCO ***[19]***. In this singular tourist area, we focus our attention on the study of the DHW systems of two hotel establishments on the island of Fuerteventura.

The reason is that it has been proven in multiple investigations as the sum of the air conditioning and the DHW are the main energy consumers, depending on the percentage of each of the geographical area of study. For example, in Caribbean hotels, 48% of electric power is consumed in air conditioning (AA) ***[20]***, in Hong Kong AA accounts for 45% of electricity consumption ***[21]***, in hotels in the Balearic Islands the total energy consumption is between 22% for the DHW, the AA 14% and the heating 21% ***[22]***, in the hotels in the United States the consumptions are divided in a general way with the air conditioning 31% AA the 15% and the DHW 17% and the rest for other uses ***[23]***, in Britain the typical

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distribution is 47% in heating and 20% in DHW ***[24]***, and in Greece the typical distribution is 35% in heating, 15% in AA and 22% in DHW ***[25]***. Considering the consumption of customers per day, which vary according to zones and type of hotel, we can verify the importance of reducing these consumptions on the total energy needed for a hotel, which has been studied by several authors ***[26, 27, 28, 29, 30]***.

II. METHODOLOGY

The installations analysed belong to two four-star hotels of 333 and 354 rooms, designated as H1 and H2 respectively, as they cannot be named due to the data protection of both companies, where their DHW-based heating systems have been replaced, propane LPG boilers, by systems based on aerothermy technology of high temperature heat pumps. The data that are initially counted are the annual occupation and the total consumption of LPG propane. By means of the studies of previous facilities of hotels of the same category and climatic zone, and of the norms of calculation ***[31]***, it has been verified that the average consumption of the clients is of about 70 L/day of DHW, and the percentage of consumption of total LPG propane by the DHW with respect to the remaining consumers -furniture and laundry according to cases- is between 60% and 75% of total consumption ***[32]***. With this starting data and once the possible heating systems were chosen, the possibility of using a system based on aerothermy and biomass was studied, whose forecasts of operating expenses and initial investments can be checked in ***Table 2***, where it was calculated a theoretical coefficient of performance (COP) for heat pumps of 2.4, much lower than the real one. To make forecasts as accurate and real as possible, it is necessary to have the greatest number of exact values and not estimates, for which the energy management of the establishments is fundamental to be able to perform these calculations of energy system improvements.

PREVIOUS	**HOTEL H1 (333 rooms)**	**HOTEL H2 (354 rooms)**
Total hotel LPG expenditure in kg/year	*100,455 kg*	*142,260 kg*
Total GLP expense in DHW in kg/year	*70,318 kg*	*99,582 kg*
Thermal needs DHW in kWh/year	*801,839 kWh*	*1,135,531 kWh*
LPG cost €/year	*123.057*	*174.268*
PROJECTED	***HEAT PUMP***	***HEAT PUMP***
Necessary investment	*135.000 €*	*145.000 €*
Consumption electric in kWh/year	*334.100*	*473.138*
Cost of electricity	*30.069 €*	*42.582 €*
Saving compared LPG	*92.988 €*	*131.686 €*
Amortization in years	*1,45*	*1,10*

Table 2. Projection of consumption and installation expenses.

The chosen result of the alternatives analysed has been aerothermy as a system to be implemented in both hotels, considering the number of companies that know these technologies and that the biomass fuel in the Canary Islands is not yet widespread and its performance is reduced due to transport, as has been demonstrated in several studies ***[33,34,35]***. The solution consists of high temperature heat pumps of 151.2 and 201.6kW in the H1 and H2 hotels respectively, which are supported in a timely manner by the existing

boilers and regulated by a PLC-based control system with connection to a computer through a SCADA system.

For the calculations of the system so that it complies with the current regulations, the European Commission's guidelines for estimating values that can consider energy from renewable sources in operation of heat pumps according to dissipation systems have been considered ***[36]*** and considering the data on the efficiency of the equipment that regulates the seasonal yield factor (SPF) ***[37].*** For its part, the Institute for Energy Diversification and Saving (IDAE) has a document (it does not replace the standard) and according to this ***[38]***, the SPF will be calculated multiplying its nominal benefits (COP) by a factor called representative weighting factor (FP) and by a correction factor (FC) for the different technologies and applications of electrically driven heat pumps.

III. CALCULUS

Initially we performed the calculations of the total COP of the equipment considering the operating temperature and the environmental dissipation for Fuerteventura and in the tables of the manufacturer the values of electric consumption and thermal generation are obtained. Considering the system used for high temperature heat pumps with dissipation by aerothermy, which are formed by an external LG brand machine, model ARUN 160 LTE4, unit capacity of 50.4 kW, EER 4.30: SEER 7.27; COP 4.42 and 2 internal units of hydrokit brand LG model ARNH 08 GK3A2, with 25.2 kW of heat power, 80ºC of maximum water outlet temperature, and in each hotel is formed by 3 or 4 systems to get the 151.2 or 201.6 kW thermal.

$$COP\ a\ 60ºC = E_{Thermal} / (E_{Elect\_inside} + E_{Elect\_outside}) =$$

$$50.4\ kWt / (7.68 + 2\ x\ 4.87)\ kWe = 50.4\ kWt / 17.42\ kWe = 2.89$$

To determine the SPF of the heat pump we need to know the corresponding FP and FC. The FP will be obtained in the tables of the IDAE ***[38]*** 4.1 according to the climatic zone of the hotel site and to the type of heat pump used and the FC in the table of the IDAE 4.2 with a COP calculated for 60ºC. Fuerteventura is an area of climatic severity in winter A ***[39]*** and the type of heat pump is aerothermal. Centralized equipment, so FP = 0.87. The temperature chosen for the preparation of the ACS is 60 ° C, so FC = 1

$$SPF = COP_{nominal\ 60ºC}\ x\ FP\ x\ FC = 2.89\ x\ 0.87\ x\ 1 = 2.51$$

Once it has been verified that the SPF of the pump exceeds the minimum of SPF = 2.5, it can be considered that the heat produced by the pump comes from a renewable source of both facilities. Now the amount of renewable energy is calculated, in accordance with the decision of the commission on calculation guidelines ***[40]*** , is calculated with the following formula:

$$E_{res} = Q_{useful}\ x\ (1\text{-}1/SPF)$$

$$Q_{useful} = H_{hp}\ x\ P_{rated}$$

Where are you the amount of renewable energy supplied by heat pump technologies, Q_{useful} estimated total useful heat provided by heat pumps [GWh], H_{hp} equivalent hours of full load operation [h] and P_{rated} power of installed heat pumps, considering the duration of the different types of heat pumps [GW].

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Values for hotel H1:

$$Q_{useful1} = 1170 \times 151.2 \times 10^{-6} = 0.176904\ GWh$$

$$E_{res\_min1} = 0.176904 \times (1-1/2,5) = 0.106142\ GWh$$

$$E_{res1} = 0.176904 \times (1-1/2,51) = 0.106424\ GWh$$

$$Percentage\ of\ renewable\ energy = 0.106424 / 0.176904 = 60.16\%$$

Values for hotel H2:

$$Q_{useful2} = 1170 \times 201.6 \times 10^{-6} = 0.235872\ GWh$$

$$E_{res\_min2} = 0.235872 \times (1-1/2,5) = 0.141523\ GWh$$

$$E_{res2} = 0.235872 \times (1-1/2,51) = 0.141899\ GWh$$

$$Percentage\ of\ renewable\ energy = 0.141899 / 0.235872 = 60.16\%$$

Figure 1 shows the operating scheme of the hotel's DHW system, with both hotels being the same. The systems consist of 5 accumulators of 5000L -three for direct heating by boilers / heat pumps and 2 for preheating by recovering air conditioning (AA) -, the corresponding exchangers and circulation pumps. The primary boiler circuits are 2 boilers 280kW in the H1 hotel and 2 boilers 290kW in the H2. The circuits of the heat pumps in the H1 hotel are 3 heat pumps and in the H2 it is formed by 4 heat pumps as well. The principle of operation is as follows: priority to the heat pumps for the heating of the 3 DHW, ACS 3, 4 and 5 accumulators, and in case 45 min did not reach the set temperature (61ºC) they would enter the boilers as a support system, motivated by Legionella control regulations ***[41].*** The AA recovery system preheats the 2 ACS 1 and 2 accumulators. Two motorized valves have been added to this system, which are indicated in the diagram as "night valves", which are activated when the AA system is not operating and in the most economical electricity tariff schedule P6, to accumulate the largest amount of water at the working temperature, for which the operating temperature setpoint of the high temperature heat pumps (2nd set point) is also increased, at 65ºC, in order to accumulate in the 5 existing accumulators the maximum possible energy during the periods of lowest price of the same and in this way, reduce the average price of the useful electric kWh used for the heating of the DHW of the establishments. In the SCADA you can put the different the different pump controls, system

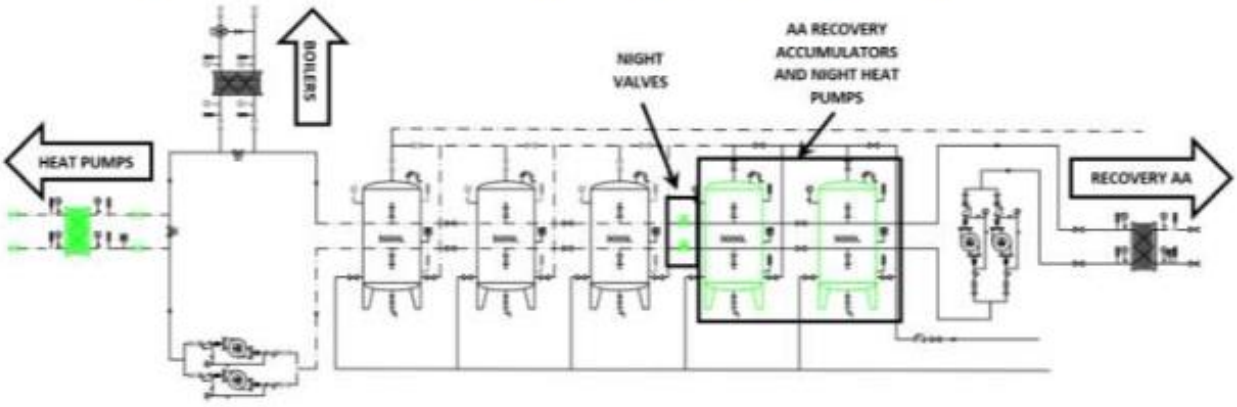


Figure 1. Diagram of operation of the DHW system of the study hotels.

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temperatures, access to the programming of the operating hours and the operating status of the equipment.

IV. RESULTS AND DISCUSSION

The systems were launched in the hotels in September and December 2015 at the H1 and H2 hotel respectively. The results, after two and a half years of activity, have been very satisfactory, with a return on investment faster than initially projected. Also, be checked as by means of the possibility of adjustments, of times, hours of operation and temperatures can be obtained greater savings with a correct management of the parameters as it is carried out in the hotel H1 with respect to the H2. ***Figure 2*** shows the graphs of energy consumption and expenditure per client-day of ACS of the hotels, graphically checking the decrease of these in 2016-2017 due to the new installation of aerothermy. With these new equipment, a drastic reduction of energy consumption in ACS has been achieved, as well as the emissions associated with LPG boilers, with higher savings in the H1 hotel compared to the H2 due to the adjustment of the system by the equipment hotel maintenance.

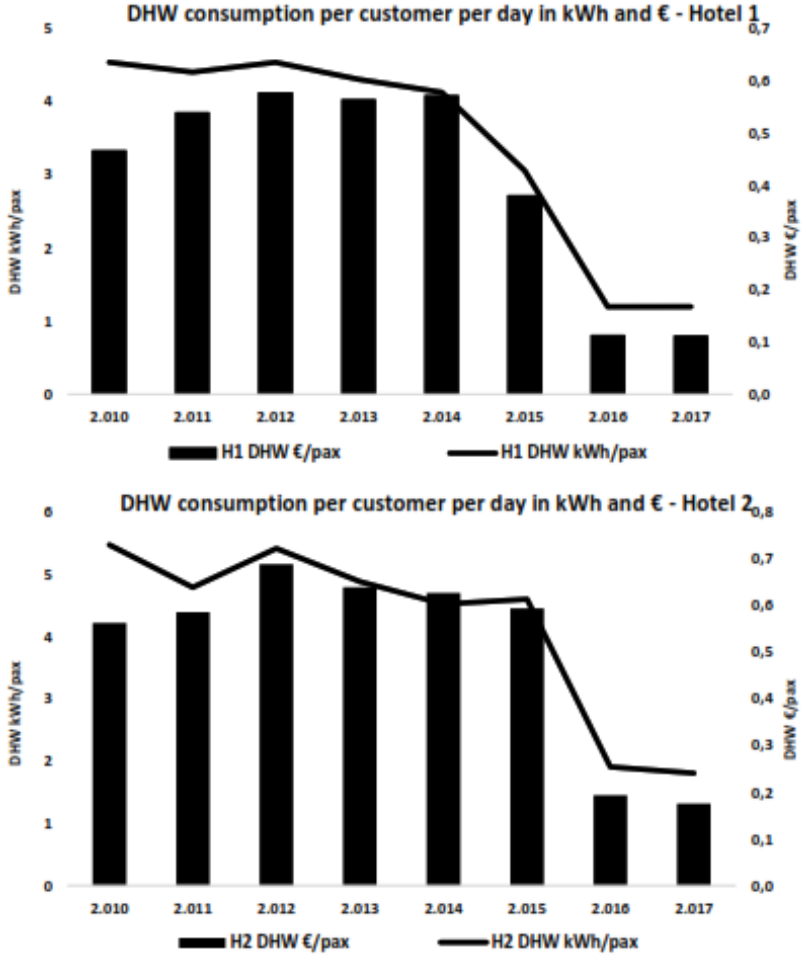


Figure 2. Graph of decrease of energy consumption and economic expense in DHW per night customer.

Table 3 shows the evolution of energy and economic costs of the establishments, with a result of a reduction in energy consumption to produce the ACS between 72.7% and 63% per hotel respectively. It also shows that the average spending on ACS per client hosted in recent years (2010-2014) compared to the 2016-2017 year has decreased by 79.4% and 70.3%, from an average of € 0.54 / customer night (=pax) and 0.62 € / pax has gone to 0.11 € / pax and 0.19 € / pax for each hotel respectively. We compare the savings data for the years 2010 to 2014, since 2015 was launched at the end of the year, it is verified that due to the price of the kg of LPG, the amortization of the equipment has taken place in less time than the one that it was estimated, since also the actual consumption has been lower than projected due to PLC control that optimizes the operation by schedules. As a result, the installation has already been amortized in the time it has been running and is currently generating benefits. The total energy saving in annual kWh is greater than 600,000 kWh in both systems. The approximate consumption of LPG by the support boilers has been considered 5% of the total gas consumption in the H1 hotel and of 15% in the H2, due to the excessive punctual consumption of DHW in peak hours, mainly during the mornings between 8:00 a.m. to 9:00 a.m. hours and afternoons between 6:00 p.m. to 7:00 p.m., with the support of the boilers being necessary so as not to oversize the installation of heat pumps. The difference in gas consumption is due to the use of more optimized control systems in the H1 hotel than the H2, with a difference of more than 35.5% between the energy consumed per client of one hotel with respect to the other.

H	Type	2010	2011	2012	2013	2014	2015	2016	2017
H1	kWh/pax	4.54	4.40	4.54	4.30	4.13	3.06	1.20	1.20
	€/pax	0.47	0.54	0.58	0.56	0.57	0.38	0.11	0.11
H2	kWh/pax	5.47	4.79	5.41	4.88	4.52	4.60	1.91	1.80
	€/pax	0.56	0.59	0.69	0.64	0.63	0.59	0.19	0.18

Table 3. Values of energy and economic consumption per customer and day obtained.

With the data obtained, the following ***Table 4*** of expenses and savings produced by this change in the energy model is generated. Considering that the equipment has an average life of 12 years of the system will have saved more than € 1,179,737 and thermal 8,780,005 kWh in a hotel 1 and € 1,315,104 and thermal 9,522,301 kWh in the hotel 2 for which it is expected to have saved more than € 1,100,000 and in the H1 hotel and more than € 1,300.00 in the H2 hotel.

H	TYPE	2.010	2.011	2.012	2.013	2.014	2.015	2.016	2.017	Forecast in 12 years
H1	Annual expenditure €	90.841	117.518	123.715	115.877	120.113	82.324	26.109	25.311	**308.518**
	Annual savings €							99.096	97.527	**1.179.737**
	Annual savings kWh							738.647	724.687	**8.780.005**
H2	Annual expenditure	117.148	143.198	167.936	154.324	152.271	142.567	48.434	44.064	**554.985**
	Annual savings							107.342	111.842	**1.315.104**
	Annual savings kWh							793.194	793.857	**9.522.301**

Table 4. Expenses to annual savings and forecast during the useful life of the heat pump system

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V. CONCLUSIONS

The investment in the reduction of energy consumption is the way forward to maintain current quality and environmental standards, without reducing services to customers and without increasing operating expenses. It has been proven how the amortizations are very fast, and the savings produced can be reinvested in further modernizing other facilities or offering more services to customers. The investment in high efficiency systems and based on heat pumps leave the possibility to get water heating systems with zero emissions if they are made with joint supplies of photovoltaic solar panels, which would achieve autonomous systems without dependence on external energy. its operation. It is in the hands of the owners or operators of the hotel facilities, the mentalizing and making these improvements in their facilities, as well as in the institutions to legislate and inform about these technologies and their application to the current buildings, in search of the long-awaited building of energy almost zero (ZEB) or almost zero (nZEB).

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