IMPROVING ENERGY EFFICIENCY IN RESIDENTIAL BUILDINGS BY MEANS OF ENVELOPE DESIGN AND INSTALLATION OF BIOMASS BOILERS

MEJORA DE LA EFICIENCIA ENERGÉTICA DE EDIFICIOS RESIDENCIALES MEDIANTE EL DISEÑO DE LA ENVOLVENTE TÉRMICA Y LA INSTALACIÓN DE CALDERAS DE BIOMASA

TESIS DOCTORAL

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Carpio, M., García-Maraver, A., Ruiz, D.P., Martínez, A., Zamorano, M., **Energy rating for green buildings in Europe** (2014) *WIT Transactions on Ecology and the* Environment 190 VOLUME 1 PP. 381 – 394 doi: 10.2495/EQ140371. Impact factor: 0.151 (Q3 Environmental Science)

Carpio, M., García-Maraver, A., Ruiz, D.P., Martín-Morales, M., **Impact of the envelope design of residential buildings on their acclimation energy demand, CO_2 emissions and energy rating** (2014) *WIT Transactions on Ecology and the Environment* 186 V1 PP. 387-398 doi:10.2495/ESUS140331. Impact factor: 0.151 (Q3 Environmental Science)

Carpio, M., Jódar, J., Rodríguez, M.L., Zamorano, M., **A proposed method for determining climatic zones and its effect energy demand and CO_2 emissions on buildings** (2015) *Energy and Buildings* 87, PP. 253-264 doi:10.1016/j.enbuild.2014.11.041. Impact factor: 2.465 (Q1 Construction & Building Technology)

Carpio, M., Martín-Morales, M., Zamorano, M., **Comparative study by an expert panel of documents recognized for energy efficiency certification of buildings in Spain**, (2015) *Energy and Buildings.* 99, PP. 98-103 doi:10.1016/j.enbuild.2015.04.022. Impact factor: 2.465 (Q1 Construction & Building Technology)

Carpio, M., García, R., Martín-Morales, M., Zamorano, M., **Environmental and economic effects of using biomass in residential thermal installations: The case of the province of Granada (Spain)** (2015) *Submitted to Renewable & Sustainable Energy Reviews.* Impact factor: 5.510 (Q1 Energy & Fuels)

García, R., Zamorano, M., **Carpio, M., Energy efficiency in buildings: The transposition of European Directive into Spanish legislation**, (2015) *Submitted to Energy and Buildings*. Impact factor: 2.465 (Q1 Construction & Building Technology)

CONGRESOS INTERNACIONALES

Carpio, M., Jódar, J., Rodríguez, M.L., Zamorano, M., **A method to determinate the climatic zone to compute the energy efficiency rating of buildings in Spain**, *5th International Conference on Approximation Methods and Numerical Modeling Environment and Natural Resources* (2013)

Carpio, M., Zamorano, M., Martín-Morales, M., García, R., **Efectos medioambientales y económicos del uso de la biomasa en instalaciones térmicas residenciales. Caso de la provincia de Granada (España)**, *1st International Congress on research in Construction and Architectural Technologies* (2014)

Carpio, M., Martín-Morales, M., Zamorano, M., **Comparativa de los documentos reconocidos para la certificación de la eficiencia energética de edificios en España**, *1st International Congress on research in Construction and Architectural Technologies* (2014)

García, R., Zamorano, M., **Carpio, M.**, **Eficiencia energética en la normativa española desde la directiva 2010/31/UE: Limitaciones y problemática**, *1st International Congress on research in Construction and Architectural Technologies* (2014)

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García-Maraver, A., **Carpio, M.**, **Factors affecting pellet quality**. Biomass pelletization: standards, production and use. (2015) *WIT Press UK.* ISBN 978-1-78466-062-8. PP. 21-36

García-Maraver, A., **Carpio, M.**, **Biomass pelletization process**. Biomass pelletization: standards, production and use. (2015) *WIT Press UK.* ISBN 978-1-78466-062-8. PP. 53-66

Carpio, M., García-Maraver, A., **Benefits from the use of pellet boilers in the energy rating of buildings**. Biomass pelletization: standards, production and use. (2015) *WIT Press UK.* ISBN 978-1-78466-062-8. PP. 159-180

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TESIS DOCTORAL

para la obtención del

GRADO DE DOCTOR POR LA UNIVERSIDAD DE GRANADA

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AIM	Approximation and Interpolation Method
APA	Accountable Public Administrations
BEG	Decree on Energy Performance of Buildings (Netherlands)
BR10	Danish Building Regulations
BREEAM	Building Research Establishment Environmental Assessment Methodology
BRO	Building Regulation Office (Malta)
CS	Climactic Severity
CTE	Código Tecnico de la Edificación (Technical Code of Edification) (Spain)
CZ	Climatic Zone
DB-HE	Documento Básico de Ahorro de Energía (Basic Document of Energy Savings) (Spain)
DEAP	Dwelling Energy Assessment Procedure (Ireland)
DECLG	Department of the Envirionment, Community and Local Government (Ireland)
DFPN	Department of Finance and Personnel Northern Ireland
DG	Average value of winter degrees/day in base 20
DHW	Domestic Hot water
DOE	Department of Energy
DPE	Energy Performance Diagnosis (France)
EAVG	Energy Performance Certificate Law (Austria)
EC	European Comision
ECCP	European Plan on Climate Change
EEI	Energy Efficiency Indicators
EEWärmeG	Renewable Heating Law (Germany)
EnEV	Energy Saving Ordinance (Germany)
EPBD	Energy Performance Building Directive
EPC	Energy Performance Certificates
ER	Energy rating
EU	European Union
GHG	Greenhouse Gases
H	Heating
IDEA	Instituto para la Diversificación y Ahorro de la Energía (Institute for Energy Diversification and Saving)
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LEPB	Law on the Energy Performance of Buildings (Latvia)
MQ	Multiquadric
NEAP	Non- Dwelling Energy Assessment Procedure
NVE	Water Resources and Energy Directorate (Norway)

NZEB	Nearly Zero-Energy Building
OIB	Austrian Institute of Construction Engineering
PER	Plan de Energías Renovables en España (Plan for Renewable Energy in Spain)
QE	Qualified Experts
RBF	Radial Basis Function
RCCTE	Regulamento das Características de Comportamento Térmico dos Edifícios (Regulation of the Characteristics of Thermal Conduct of Buildings)
REG	Regulation on Energy Performance of Buildings (Netherlands)
RITE	Reglamento de Instalaciones Térmicas en los Edificios (Regulation of Thermal Installations in Buildings) (Spain)
RSECE	Regulamento dos Sistemas Energéticos e de Climatização nos Edifícios (Regulation of Energy Systems and Climatization of Buildings) (Portugal)
SCE	Sistema de Certificação Energética (System of Energy Certification) (Portugal)
SCS	Summer Climate Severity
SEDA	Sustainable Energy Development Agency (Bulgaria)
U	U-value (thermal transmittance limit)
UNFCCC	United Nations Framework Convention on Climate Change
VEA	Flemish Energy Agency
WCS	Winter Climate Severity

Index of acronyms (countries)

AT	Austria
BE-BR	Belgium - Brussels Capital Region
BE-FR	Belgium - Flemish Region
BE-WR	Belgium - Walloon Region
BG	Bulgaria
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IEA	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
NO	Norway
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovak Republic
UK-EW	United Kingdom – England and Wales
UK-NI	United Kingdom – Northem Ireland
UK-S	United Kingdom – Scotland

RESUMEN

El sector de la edificación es uno de los principales responsables del consumo de energía primaria en Europa. En consecuencia, la certificación energética de los edificios está siendo regulada para controlar y reducir el consumo de energía. A partir de la aprobación de las Directivas Europeas, Energy Performance of Buildings Directives (EPBDs), se ha creado el marco legislativo para todos los miembros de la Unión Europea y la certificación se ha convertido en obligatoria en todos los Estados miembros. El objetivo principal de este marco legislativo es el ahorro de energía final y, en consecuencia, cualquier parámetro relacionado como energía primaria, emisiones de CO_2 o los costos de energía, todo ello sin comprometer la comodidad o la productividad.

En este contexto, para una eficiencia energética adecuada en edificios residenciales, hay que tener en consideración una serie de factores, tal y como se especifica en la certificación energética de los edificios regulada en las EPBDs. En particular, los sistemas de calefacción son esenciales para optimizar el uso de energía y también en la reducción de su costo y el impacto ambiental causado; en este sentido, el uso de fuentes de energía renovables es una interesante alternativa a los combustibles fósiles, en particular la biomasa; sin embargo, su uso en España no está muy extendido. Por otra parte entre las posibles soluciones de ahorro energético más eficaces se encuentran las relacionadas con el diseño de la construcción, así como el uso de materiales constructivos con baja transmitancia térmica; en este sentido las envolventes térmicas son la parte de los edificios más expuestas a las inclemencias del tiempo y por lo tanto tienen un impacto significativo sobre el rendimiento energético como consecuencia de mayores transferencias térmicas producidas. Por último, la precisión en la asignación de una zona climática a una ciudad es esencial para estudiar el dimensionamiento correcto de agua caliente sanitaria (ACS), calefacción y sistemas de refrigeración, así como de los materiales de construcción. En España, el sistema actual para la asignación de zonas de climáticas está regulado por el Código Técnico de la Edificación (CTE); sin embargo, los datos climáticos de las ciudades no siempre están

disponibles, por lo que el método CTE ha propuesto algunas soluciones, pero no siempre son lo suficientemente precisas.

En consecuencia, el objetivo de esta tesis ha sido el análisis de los factores indicados, y que afectan a la eficiencia energética en los edificios de viviendas, todo ello para mejorar la calificación energética y en consecuencia, reducir el consumo de combustibles fósiles, así como el impacto ambiental.

Los resultados han demostrado la importante contribución de una fuente de energía renovable, como la biomasa, en la reducción de las emisiones de CO_2, así como de los costes económicos, hasta un 95% y 88% respectivamente. Las mejoras en las soluciones constructivas utilizadas en la envolvente y destinadas a reducir los valores de transmitancia térmica, han alcanzado valores de reducción de emisiones de CO_2 entre el 65% y el 95%, de acuerdo con la solución adoptada. Todas las medidas indicadas permiten, además, la mejora de la calificación energética de los edificios.

Finalmente, la determinación de la zona climática se ha mejorado, con respecto a la propuesta existente en el método CTE, con la propuesta de un nuevo método basado en el uso de funciones de aproximación y de interpolación. La nueva clasificación generada se ha validado en áreas con datos climáticos disponibles de municipios andaluces y ha puesto de manifiesto resultados más acordes con las características climáticas de los municipios. El diseño de este método permite su uso en cualquier área ya que utiliza como datos de partida la latitud, la altitud y la longitud de la zona de estudio.

ABSTRACT

The building sector is one of the main responsible for primary energy consumption in Europe. Consequently, energy certification of buildings is being promoted under the policy to monitor and reduce energy consumption. By means of the Energy Performance of Buildings Directives (EPBDs), the legislative framework for all members of the European Union has been created and certification has become compulsory in all Member States. The primary aim of this energy framework is saving final energy and in consequence any related parameter such as primary energy, CO_2 emissions or energy costs, without compromising comfort or productivity.

In this context, adequate energy efficiency in any residential building calls for a number of factors to be taken into account as specified in the energy certification of buildings under EPBDs. In particular, the heating systems are essential to optimize the use of energy and also in reducing its cost and the environmental impact caused; in this sense the use of renewable energy sources is an interesting alternative to fossil fuels, particularly biomass, however its use in Spain is not enough widespread. However, building envelopes are the part of the buildings most exposed to the inclement weather and thus have significant impact on the energy performance as a consequence of higher thermal transfers produced. Among the possible energy-savings solutions the most effective are not only those related to the construction design but also those that consider constructive materials with low thermal transmittance. Finally, the accuracy in assigning a climatic zone to a city is essential for studying the correct sizing of domestic hot water, heating, and cooling systems, as well as of construction materials. In Spain, the current system for allocating climate zones is one proposed by the *Código Técnico de la Edificación* (CTE) (Technical Building Code); however the climatic data of cities is not always available, so the CTE method has proposed some solutions, but they are not always precise enough.

In consequence the objective of this thesis has been the analysis of these factors affecting energy efficiency in residential buildings to improve energy rating and, in consequence, reduce fossil fuel consumption as well as environmental impact.

The results have shown the important contribution of a renewable energy source like biomass to lead to a reduction in the environmental footprint. Furthermore, these underline the influence of the climate in reducing CO_2 emissions and economic costs, up to 95% and 88% respectively, and improving the energy rating of buildings; just like these can be reduced when constructive solutions with low U-values are implemented in the envelope, achieving values between 65% and 95%, according to the solution adopted. These reductions make also possible the enhancement of the energy rating of the buildings.

Finally the results of a proposed method based on approximation and interpolation functions to determinate the climatic zone are closer to reality that the CTE method. The new classification have been validated in areas with available climatic data of Andalusian municipalities. Although the use of this method could be extrapolated to other areas, due to the use of latitude, altitude, and longitude data is enough to calculate a good approximation.

INTRODUCCIÓN, MOTIVACIÓN Y OBJETIVOS

La energía nunca es un producto de consumo final; es un producto intermedio para satisfacer otras necesidades, tanto en los servicios como en la producción de bienes. A pesar del marco legal desarrollado en todo el mundo para responder a la necesidad de suministrar energía en el contexto del desarrollo sostenible (IEA. 2014), el modelo energético actual, como se observa en la Fig. 1, está basado en el uso de combustibles fósiles tradicionales en el 84%, como carbón, petróleo y gas natural. Esta dependencia energética de combustibles fósiles genera grandes problemas medioambientales debido a la emisión masiva de CO_2, haciendo necesario el fomento de las energías renovables como alternativa (Devlin et al. 2013, Dion et al. 2011).

En términos generales, como se observa en la Fig. 1, el consumo mundial de energía se ha duplicado en los últimos 40 años (1973-2012), manteniéndose la proporción de consumo por combustible muy similar (International Energy Agency. 2014).

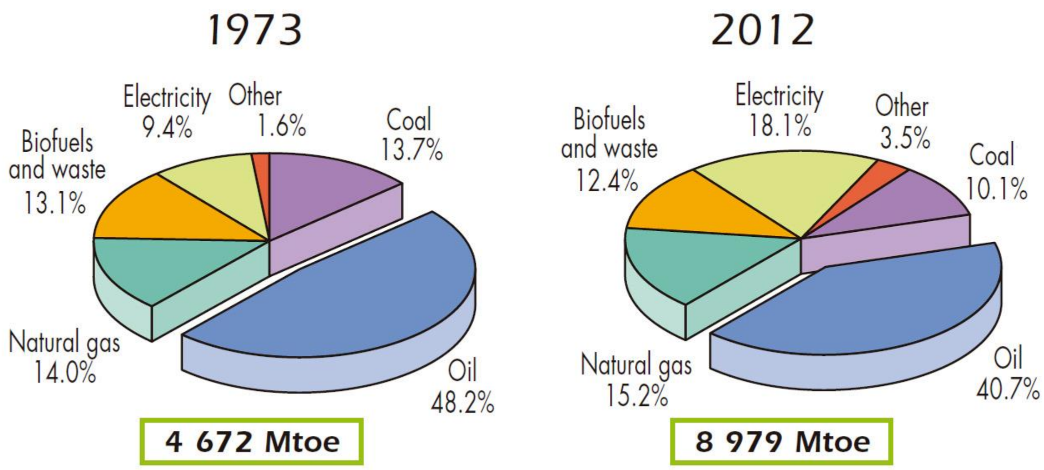

Fig. 1. Porcentajes de combustible de consumo final de 1973 y 2012 (International Energy Agency. 2014).

Como resultado de esta situación, el bienestar social y el crecimiento económico se ven amenazados por la vulnerabilidad de nuestro modelo energético actual para futuros problemas de suministro de energía (Marcos-Martín. 2001). El aumento del precio de la energía convencional es consecuencia del uso de combustibles fósiles como el gasóleo, gas natural, etc., escasos y no renovables, lo que genera una lucha por el control de los recursos energéticos. Además, en los últimos años otro factor ha contribuido, sin duda, a un cambio en la percepción del mundo de los asuntos energéticos: el cambio climático provocado por las emisiones de gases de efecto invernadero, en el que el uso de combustibles fósiles genera un importante impacto ambiental (Carpio et al. 2013, Omer. 2008).

Debido a la gravedad de estos problemas a escala mundial, se ha hecho necesario que todos los países desarrollen medidas ambientales y energéticas destinadas a reducir los efectos negativos sobre el planeta como consecuencia de la utilización de combustibles fósiles . La alternativa a estos combustibles con mayores ventajas, tanto ambientales como económicas (Milan et al. 2012), así como la garantía de una continuidad en el tiempo, se hace presente mediante las energías renovables en todas sus variantes (Omer. 2008).

En 1997, 37 países industrializados y la Unión Europea establecieron el **Protocolo de Kyoto** (Kyoto 1997). Este acuerdo buscaba la reducción de gases de efecto invernadero, con respecto a los niveles de 1990, durante el período de cinco años 2008-2012; la reducción variaba de unos países a otros, y se estimó en un promedio del 5%. En 2012, al final del primer período de compromiso del Protocolo de Kyoto, el Grupo Intergubernamental de Expertos sobre el Cambio Climático (IPCC) indicó la necesidad de incrementar los porcentajes de reducción de emisiones; por este motivo se negoció y ratificó una nueva extensión para el período 2013-2020, en la cual la reducción de emisiones alcanzó un 20%.

Para jugar un papel de liderazgo en la reducción de las emisiones de gases de efecto invernadero, la Unión Europea precisa del desarrollo de una posición común en la lucha contra el cambio climático, lo que supone la implementación de medidas propias que le permitan hacer frente al mismo. Para ello la Unión Europea, en el **Plan Europeo sobre el Cambio Climático** (ECCP) (EUCEP 2008-2020), ha establecido los siguientes objetivos, a los que se les conoce como *objetivos 20-20-20*:

(i) Reducir las emisiones de gases de efecto invernadero en un 20% para 2020.
(ii) Aumentar la eficiencia energética para ahorrar un 20% del consumo energético de la UE para el año 2020.
(iii) Alcanzar el 20% de energías renovables en el consumo total de energía en la UE en 2020.

El sector de la edificación es una gran fuente de emisiones de gases de efecto invernadero y tiene un gran potencial como fuente de reducción de las mismas (Pouffary et al. 2009). Así en la Unión Europea (UE), el sector de la edificación es responsable de más del 40% del consumo de energía (Andaloro et al. 2010, Tronchin and Fabbri. 2008) y del 36% de las emisiones de CO_2 a la atmósfera (Directive 2010/31/EU). En el caso particular del sector de la edificación, la energía se transforma para producir servicios de confort para el usuario final tales como luz, electricidad, calefacción, refrigeración y agua caliente sanitaria (ACS), entre otros (IDAE. 2007b).

Con las tecnologías probadas y disponibles en el mercado, el consumo de energía en los edificios nuevos y existentes se puede reducir entre un 30% y un 50%, sin aumentar significativamente los costos de inversión (Cheng et al. 2008). Por ello, y basándose en el Protocolo de Kyoto, la Unión Europea estableció la **Energy Performance Building Directive (EPBD)** (2002/91/CE). Esta Directiva introdujo la certificación energética obligatoria de edificios desde 2006 y ha jugado un papel clave en la política común para controlar y reducir el consumo de energía (Andaloro et al. 2010). Posteriormente, la refundición de la EPBD en 2010 (2010/31/EU) pretendió aclarar ciertos aspectos respectos a 2002, ampliando su alcance, fortaleciendo ciertas disposiciones, y dando al sector público un papel de liderazgo en la promoción de la eficiencia energética. Las EPBDs han sustituido a una serie de Directivas previas como la Directiva 92/42/ CEE, relativa a las calderas, la Directiva 89/106/CEE, relativa a los productos de construcción, y las disposiciones relacionadas con los edificios correspondientes al programa SAVE (Decision 647/2000/EC, Decision 96/737/EC).

De acuerdo a las EPBDs, la estimación de la energía necesaria para cumplir con las demandas de un edificio en condiciones normales de ocupación y funcionamiento se conoce como el **calificación de eficiencia energética**. Mediante la comparación de una serie de indicadores de la media del uso de energía en edificios modelo de referencia, un edificio real puede ser calificado y certificado en una escala de energía establecido para este fin (Carpio et al. 2014a). Una correcta calificación energética de los edificios, así como la elección de los sistemas de calefacción y refrigeración, desde el punto de vista de los usuarios finales, son la garantía para una temperatura interior confortable, reducción de las emisiones de CO_2 a la atmósfera y un ahorro económico (Ruiz and Romero. 2011).

Cada país europeo es responsable de incorporar las directrices en el marco legislativo nacional y cuentan con provisiones destinadas a futuras subvenciones para residencias que fomenten la eficiencia energética. Las transposiciones de la EPBD han creado una serie de normas con el mismo origen pero no homogéneas entre sí, con diferentes escalas de energía, métodos de cálculo, así como los requisitos para los profesionales. En el caso de **España**, la normativa que regula la calificación energética de los edificios se ha adaptado parcialmente a través del *Reglamento de Instalaciones Térmicas en los Edificios* (RITE) (RD 1027/2007), el *Código Técnico de la Edificación* (CTE) en su *Documento Básico de Ahorro de Energía* (DB-HE) (RD 314/2006) y el Real Decreto 47/2007, *Procedimiento Básico para la Certificación de Eficiencia Energética de Edificios de Nueva Construcción*, derogado por el **Real Decreto 235/2013**. El Real Decreto 47/2007, anteriormente aplicable únicamente a los nuevos edificios, derogada por el Real Decreto 235/2013, aplicable a todas viviendas que se compran, vendan o alquilen en los edificios existentes. El objeto de este decreto es establecer las condiciones técnicas y administrativas para la certificación de eficiencia energética de los edificios y la metodología de la calificación energética, considerando aquellos factores que tienen el mayor impacto en el consumo de energía, así como la adopción de etiqueta de eficiencia energética como común distintivo en todo el territorio nacional.

La calificación energética de un edificio se determina por medio de simulaciones térmicas teóricas. El uso de softwares diseñados para este propósito se inició en la década de los 80 (Newton et al. 1988); a partir de este momento han surgido herramientas más sofisticadas, incluyendo registros exhaustivos climáticos, bibliotecas de materiales con diferentes soluciones constructivas, y la integración completa de diseño asistido por ordenador (CAD). Los diferentes programas se diferencian en términos de cómo se definen las características del edificio como entrada de datos, y en la salida de resultados (Carpio et al. 2015c, Crawley et al. 2008). En España la metodología de cálculo descrito en el Real Decreto 235/2013 se lleva a cabo con **documentos reconocidos** en forma de software. De forma concreta hay cuatro documentos reconocidos: CALENER VYP con un método de referencia general, y CE3, CEX y CERMA con la opción simplificada de carácter prescriptivo, cuyo cálculo indirecto se basa en los documentos del método general. Estos documentos están destinados a simular la demanda de energía de edificios y su **certificación energética** con el objetivo de la comparación de diferentes edificios a través de una calificación global y la medición de su eficiencia energética. En cualquier caso, los aspectos más influyentes en la calificación energética de un edificio son tres: combustible utilizado en los sistemas térmicos, diseño de la envolvente del edificio y la zona climática (Carpio et al. 2013, Carpio et al. 2014b, Carpio et al. 2015b).

Debido consumo de energía para calefactar un hogar es de aproximadamente 55% del total, seguido de calentamiento de ACS, electrodomésticos, la cocina y la iluminación (19%, 19%, 4% y 3%, respectivamente) (Eurostat. 2011), el estudio previo de los sistemas térmicos a instalar es esencial, En este sentido la adecuada elección del combustible es un factor clave a la hora de evaluar el impacto ambiental en el sector de la edificación y de compromiso para reducirlo, además de conseguir hasta un 88% de ahorro económico (Carpio et al. 2015a, Carpio et al. 2013). Hasta ahora, la mayoría de los sistemas de calefacción en los edificios han utilizado fuentes convencionales de energía (Junta de Andalucía. 2014), lo que lleva a altos niveles de emisiones de CO_2, alrededor de 44 $kgCO_2/m^2$ por año para el gas natural y de 58 $kgCO_2/m^2$ por año con el uso de gasoil (Carpio et al. 2013). Sin embargo el uso de combustibles a partir de fuentes renovables sería una contribución valiosa a la solución del problema de las emisiones de CO_2 en los edificios, ya que se pueden reducir hasta en un 95% en el uso de energías renovables (Carpio et al. 2013). Concretamente la **biomasa** es una clara alternativa de combustible para los sistemas de ACS, calefacción y refrigeración, ya que es una fuente económica y accesible de energía que prácticamente no tiene impacto ambiental (González et al. 2004). Sin embargo, a pesar de sus ventajas, la biomasa no se usa muy ampliamente como combustible en edificios en países como España.

El consumo energético de los edificios se ve afectado, principalmente, por las condiciones climáticas locales, temperatura interior, factor de forma, relación ventanas y cerramientos y de rendimiento de la **envolvente del edificio**. Por lo tanto, se requieren nuevas soluciones para la envolvente de los edificios, ya que es la parte más expuesta a las inclemencias del tiempo y, por tanto, donde se producen las mayores transferencias térmicas (Carpio et al. 2014b). En consecuencia, un diseño adecuado de las propiedades térmicas de los cerramientos llevaría a un ahorro de energía en los edificios residenciales. Varios estudios han analizado la mejora de la eficiencia energética de las envolventes existentes en la actualidad (Fang et al. 2014, Friedman et al. 2014, Güçyeter and Günaydın. 2012, Huang et al. 2014, Nagy et al. 2014, Pisello et al. 2014, Wang et al. 2014). Sin embargo, las técnicas de construcción para mejorar una envolvente existente difieren de los que se pueden aplicar a las unidades de nueva construcción.

Finalmente, la precisión en la asignación de una **zona climática** a una ciudad es esencial para el estudio del dimensionamiento correcto de ACS, calefacción y sistemas de refrigeración, así como de materiales de construcción. Una zona climática se define como un área donde las condiciones externas comunes para el cálculo de la demanda de energía se definen mediante unos pocos parámetros; este concepto es aplicable a la hora de definir la calificación energética (Rakoto-Joseph et al. 2009). Por ello la precisión en la definición de la zona climática de un municipio es esencial para un cálculo correcto así como para diseñar un edificio con la máxima eficiencia energética. Los métodos actuales definidos en el CTE (Orden FOM/1635/2013, Orden VIV/984/2009) son válidas para asignar una zona climática a un municipio, pero estos muestran diferencias significativas respecto a los datos sobre el clima real. Detectadas las deficiencias, en al año 2013 se llevó a cabo una revisión (Orden FOM/1635/2013), sin que se hayan tenido resultados precisos; se requiere, por tanto, una segunda revisión del método.

Por todo lo indicado el objetivo principal de este trabajo es **mejorar la eficiencia energética en los edificios residenciales por medio del diseño de la envolvente y la instalación de calderas de biomasa**. Para lograr este objetivo, se definieron los siguientes objetivos secundarios:

i. Análizar el marco legal relativo a la eficiencia energética de la edificación en Europa y su transposición en España.
ii. Evaluar la capacidad de potencia instalada en los edificios en un área representativa de España, teniendo en cuenta los diferentes sistemas de calefacción, refrigeración y ACS.
iii. Determinar las ventajas ambientales y económicas del uso de la biomasa en los edificios residenciales en comparación con las fuentes de energía convencionales.
iv. Evaluar la influencia del diseño de la envolvente de los edificios en la demanda de energía, emisiones de CO_2 y calificación energética.
v. Proponer un método alternativo para determinar las zonas climáticas.

INTRODUCTION, MOTIVATION AND OBJECTIVES

Energy is never a product for final consumption; it is an intermediate product to meet other needs, both in services as well as in the production of goods. Fig. 1 shows the current energy model bases 84% of consumption on the use of traditional fossil fuels, such as coal, oil and natural gas, despite the legal framework developed worldwide to respond to the need to supply energy in the context of sustainable development (IEA. 2014). As shown in Fig. 1, the use of electricity, natural gas and renewable fuels (biofuels, waste and others) has increased with time (1973-2012), while the use of oil and coal has decreased. In general terms the world energy consumption has doubled in the last 40 years.

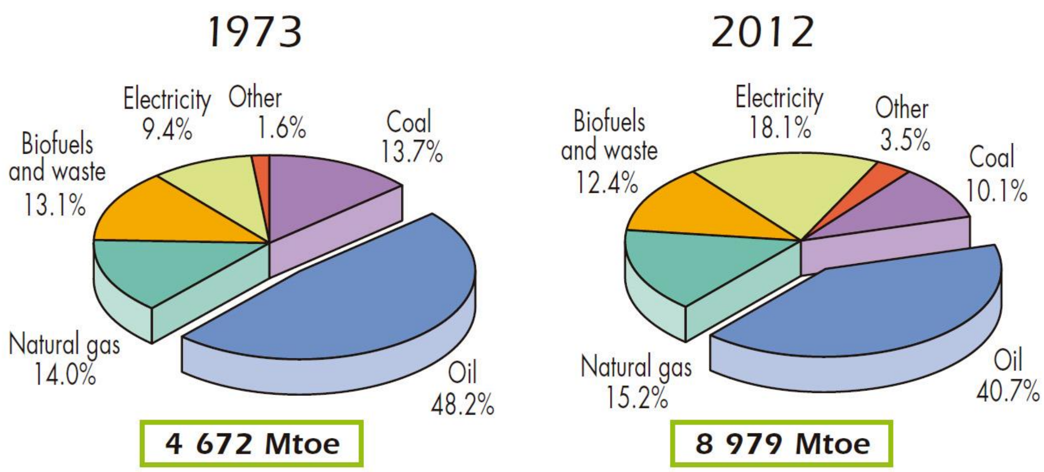

Fig. 1. 1973 and 2012 fuel shares of total final consumption (IEA. 2014).

As a result of this situation, social welfare and economic growth are threatened by the vulnerability of our current energy model to future energy supply problems (Marcos-Martín. 2001). The increase of the conventional energy price is caused because of being generated by fossil fuels such as gasoil, natural gas, etc., which are scarce and non-renewable. This situation creates a struggle over the control of energy resources. In addition, in recent years another factor has undoubtedly been contributing to a change in world perception of energy issues: climate change brought about by greenhouse gas emissions (Omer. 2008), where the use of fossil fuels generates a major environmental impact (Carpio et al. 2013).

Because of the seriousness of these world-scale problems, it has become necessary for all countries to develop environmental and energy measures to reduce the negative effects on the planet of the use of fossil fuels. For this reason in 1997, 37 industrialized countries and the European community established the **Kyoto Protocol** (Kyoto 1997) for reducing greenhouse gases (GHG) emissions to an average of 5% against 1990 levels over the five-year period 2008-2012, varying among the different developed countries. By the end of the first commitment period of the Kyoto Protocol in 2012, a new extension for the period 2013-2020 was negotiated and ratified in order to deliver the stringent emission reductions up to 20%. The Intergovernmental Panel on Climate Change (IPCC) had clearly indicated were needed.

To play a leading role in the reduction of greenhouse gases emissions, the European Union wanted to develop as quickly as possible a common position in the fight against climate change, and thus implemented its own measures to deal with climate change. Furthermore, the European Union established the 20-20-20 targets with the following objectives specified in the **European Plan on Climate Change** (ECCP) (EUCEP 2008-2020) to combat climate change in general:

(i) To reduce emissions of greenhouse gases by 20% by 2020.
(ii) To increase energy efficiency to save 20% of EU energy consumption by 2020.
(iii) To reach 20% renewable energy in total energy consumption in the EU by 2020.

In the particular case of the **building sector**, energy is transformed to produce comfort services for the final user such as light, electricity, heating, cooling and domestic hot water (DHW), among others (IDAE. 2007b). In the European Union (EU) the building sector is responsible for more than 40% of energy consumption (Andaloro et al. 2010, Tronchin and Fabbri. 2008) and the 36% of CO_2 emissions into the atmosphere (Directive 2010/31/EU), both in developed and developing countries (Pouffary et al. 2009). Therefore, the building sector is a large source of GHG emissions and has significant potential as a source of cost-effective emissions reductions (Cheng et al. 2008). With proven and commercially available technologies, the energy consumption in both new and old buildings can be cut by an estimated 30–50 percent without significantly increasing investment costs (Cheng et al. 2008).

Therefore, based on the Kyoto Protocol, the European Union established the **Energy Performance Building Directive (EPBD)** (2002/91/EC); it introduced the compulsory energy certification of buildings from 2006 and it has played a key role in the common policy to monitor and reduce energy consumption (Andaloro et al. 2010). The recast of the EPBD in 2010 (2010/31/EU) seeks to clarify certain aspects of the 2002 Directive, extend its scope, strengthen certain provisions, and give the public sector a leading role in promoting energy efficiency. The EPBDs replaces previous Directive 92/42/CEE, regarding boilers, Directive 89/106/CEE, regarding the products of construction, and the provisions related with buildings corresponding to the program SAVE (Decision 647/2000/EC, Decision 96/737/EC).

According to the EPBDs, the estimation of the energy necessary to comply with the demands of a building under normal conditions of occupancy and functioning is known as the **energy efficiency rating**. By comparing a number of indicators of the mean energy use in model buildings of reference, a real building can be qualified and certified on an energy scale established for this purpose (Carpio et al. 2014a). The energy rating of buildings and their systems of heating and cooling stand, from final users point of view, as a guarantee about the energy requirements for a comfortable interior temperature, reduced emissions of CO_2 to the atmosphere, and economic savings (Ruiz and Romero. 2011).

Governmental energy strategies feature provisions for future grants for residences that have optimal energy ratings. Each European country is responsible for incorporating the guidelines into the domestic legislative framework. These transpositions of the EPBD have created a series of regulations with the same origin but not homogeneous among themselves, like different energy scales, calculation methods as well as requirements for professionals. In **Spain**, the normative that regulates the energy rating of buildings was partially transposed through the *Reglamento de Instalaciones Térmicas en los Edificios* (RITE) (Regulation of Thermal Installations in Buildings) (RD 1027/2007) and the *Código Técnico de la Edificación* (CTE) (Technical Code of Edification) in its *Documento Básico de Ahorro de Energía* (DB-HE) (Basic Document of Energy Savings) (RD 314/2006) and the Royal Decree 47/2007*, Procedimiento Básico para la Certificación de Eficiencia Energética de Edificios de Nueva Construcción* (Basic Procedure for Certification of Energy Efficiency of Buildings New Construction, repealed by the **Royal Decree 235/2013**. The Royal Decree 47/2007 was formerly applicable only to new buildings, repealed by Royal Decree 235/2013, applicable to all living units to be bought, sold or rented out in existing buildings. The object of this decree is to establish the technical, methodological and administrative procedures for the achievement of energy efficiency certificates in the building sector. The energy rating obtained depends on those factors with high impact on the energy consumption and is labelled with a common distinctive throughout the national territory.

The energy rating of a building is determined by means of theoretical thermal simulations. The use of software designed for this purpose began in the 1980´s (Newton et al. 1988); and eventually sophisticated tools arose, including exhaustive climate records, libraries of materials with different constructive solutions, and complete CAD integration. The various programs differ in terms of how the characteristics of the building are introduced as input, and in the output provided (Carpio et al. 2015c, Crawley et al. 2008). In Spain the calculation methodology described in Royal Decree 235/2013 is carried out with **recognized documents** as software. There are four recognized documents: CALENER VYP with a general method of reference, and CE3, CEX and CERMA with the simplified option of a prescriptive nature, whose indirect calculation is based on the general method. These documents are destined to simulate the energy demand of buildings and their corresponding **energy certification** with the objectives of comparing different buildings through an overall rating and measuring their energy efficiency.

The most influential aspects on energy rating in a building are three: fuel used in thermal systems, design of the envelope and climate zone (Carpio et al. 2013, Carpio et al. 2014b, Carpio et al. 2015b).

The space heating accounts for more than half of all residential energy consumption (55%), whereas the remaining percentage is consumed for water heating (19%), cooking (4%), lighting (3%), and miscellaneous uses (19%) (Eurostat. 2011). This fact makes evident that it is essential to analyze the thermal system to be installed. As described in previous studies, the source of energy together with the appliance used for the space heating of a building may result not only in a lower environmental impact, but also in economic savings up to 88% (Carpio et al. 2015a, Carpio et al. 2013). Up to now, most heating systems in buildings have used conventional sources of energy (Junta de Andalucía. 2014), leading to high levels of CO_2 emissions, around 44 $kgCO_2/m^2$ per year for natural gas and 58 $kgCO_2/m^2$ per year for gasoil (Carpio et al. 2013). The choice of fuel is thus a key factor when assessing the environmental impact of fuel consumption in the building sector and undertaking measures to reduce it. The use of fuel from renewable sources would make a valuable contribution to solving the problem of CO_2 emissions in buildings, as they can be reduced by up to 95% by the use of renewable energies (Carpio et al. 2013). **Biomass** is clearly a good fuel alternative for heating, cooling and DHW systems, as it is an economical and accessible source of energy which has virtually no environmental impact (González et al. 2004). Nevertheless, in spite of its advantages, biomass is not used very extensively as fuel in buildings in countries such as Spain.

Acclimation energy consumption of buildings is mainly affected by local climatic conditions, indoor temperature, shape factor, windows-to-wall ratio and building envelope performance. Therefore, new solutions for **building envelopes** are required because they are the part of the buildings most exposed to the inclement weather and thus where higher thermal transfers are produced (Carpio et al. 2014b). Accordingly, a proper design of the thermal properties of building envelopes would lead to energy-saving in residential buildings. Several studies have studied the improvement of the energy efficiency of currently existing envelopes (Fang et al. 2014, Friedman et al. 2014, Güçyeter and Günaydın. 2012, Huang et al. 2014, Nagy et al. 2014, Pisello et al. 2014, Wang et al. 2014). Nevertheless, the construction techniques to improve an existent envelope differ from those that can be applied to new construction units.

The accuracy in assigning a **climatic zone** to a city is essential for studying the correct sizing of DHW, heating, and cooling systems, as well as of construction materials. A climatic zone is defined as an area for which common external conditions for calculating the energy demand are defined using a few parameters. This concept is applicable to define energy rating (Rakoto-Joseph et al. 2009). For all these reasons, the precision defining the climate zone of a municipality is essential for a right calculation. Current methods defined in the CTE (Orden FOM/1635/2013, Orden VIV/984/2009) are valid to assign a climatic zone to a municipality, but these show significant differences from the real climate data. Therefore a second review of the method is required. The first one was carried out in 2013 (Orden FOM/1635/2013), without accurate results. The differences between methods could imply a previous bad building design because the precision in correctly assigning a climatic zone to a dwelling is essential to design it with correct energy efficiency. For these reasons a new revision of the method is necessary.

Therefore, the main objective of this work is to **improve energy efficiency in residential buildings by means of envelope design and installation of biomass boilers.** In order to achieve this objective, the following secondary objectives were defined:

i. Comparative analysis of the different transpositions of the EPBD within the European appointed countries and the current documents recognized.
ii. Evaluate the installed power capacity in buildings in a representative area of Spain, considering the different systems for heating, cooling and DHW.
iii. Determine the environmental and economic advantages of using biomass in residential buildings as opposed to conventional energy sources.
iv. Evaluate the influence of the envelope design of buildings in the energy demand, CO_2 emissions and energy rating.
v. Propose an alternative method to determine climatic zones.

CHAPTER 1.-

REGULATORY FRAMEWORK FOR ENERGY PERFORMANCE OF BUILDINGS IN EUROPE[1]

[1] The results shown in this chapter were presented in: **Carpio, M.**, García-Maraver, A., Ruiz, D.P., Martínez, A., Zamorano, M., **Energy rating for green buildings in Europe** (2014) *WIT Transactions on Ecology and the Environment* 190 V. 1 PP. 381 – 394.

1.1. Introduction

The attenuation of climate change is a global priority due to the fact that CO_2 emissions are one of the greatest precursors of it (Florides et al. 2013). With this purpose, the European Union created a legislative framework for all its member countries based on the Kyoto Protocol (Kyoto 1997) by carrying out the corresponding transposition according to the necessities of each country. This framework is composed of the Directives 2002/91/EC and 2010/31/EU on EPBD.

Buildings dedicated to living quarters are responsible for 40% of the energy consumed and 36% of the CO_2 emissions to the atmosphere in Europe (Directive 2002/91/EC, Directive 2010/31/EU). Therefore these normative regulations were necessary to reduce this environmental impact generated by the building sector. The regulation in terms of energy efficiency in buildings is critical for the assignment of the Qualified Experts (QEs) that will be involved in the process, as well as for their authorization and official tools to issue Energy Performance Certificates (EPCs) (Newton et al. 1988, Pisello et al. 2012, Rey et al. 2007).

Throughout these regulations, the European objective is to achieve a Nearly Zero-Energy Building (NZEB) and thus make a comfortable building with minimum energy consumption by insulating the building envelope or encouraging the use of renewable energy in air conditioning systems, heating systems and DHW, amongst other improvements for the accomplishment of savings in energy demand, CO_2 emissions and economic factors.

Taking the situation previously described into account, the objective of this review is to make a comparative analysis of the different transpositions of the EPBD within the European appointed countries (EU-28 and Norway).

1.2. Energy framework

The current challenge for the global energy sector is double: (i) increase dramatically the access to affordable and modern energetic services in countries that lack them and (ii) find the combination of energy sources, technologies, policies and behavioural changes that will reduce adverse environmental impacts (Spalding-Fecher et al. 2005). A considerably large number of measurements have tried to be implemented as a response to the necessary fight against climate change; some of them are analysed in the section below.

The objective of the EPBDs is to promote the improvement of the energy performance of buildings within the Community, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness. These Directives lay down requirements as regards:

a) General framework for a methodology of calculation of the integrated energy performance of buildings and building units.
b) Application of minimum requirements on the energy performance of new buildings and new building units.
c) Application of minimum requirements on the energy performance of:
    (i) Existing buildings, building units and building elements that are subject to major renovation.
    (ii) Building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are retrofitted or replaced.
    (iii) Technical building systems whenever they are installed, replaced or upgraded.
d) National plans for increasing the number of nearly zero-energy buildings.
e) Energy certification of buildings or building units.
f) Regular inspection of heating and air-conditioning systems in buildings.
g) Independent control systems for energy performance certificates and inspection reports.

Together with an increased use of energy from renewable sources, measures taken to reduce energy consumption in the Union would allow the European Union to comply with the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), and to honour both its long term commitment to maintain the global temperature rise below 2 °C, and its commitment to reduce, by 2020, overall greenhouse gas emissions by at least 20 % below 1990 levels, and by 30 % in the event of an international agreement being reached.

With these purposes, the Directives require Member States to set minimum requirements on energy performance and introduce a system of energy performance certification for buildings. It also requires Member States to develop plans for low or zero carbon buildings, with the public sector leading the way.

1.3. EPBD transpositions

Table 1 shows the transposition of the EPBD to the different EU countries and Norway, as well as the Accountable Public Administrations (APAs). Due to the large volume of information that can be deduced from the different transpositions indicated in Table 1, the most important aspects have been summarized in Table 2 in a comparative analysis of the European energy rating systems.

As shown in Table 2 the information from each country has been structured, according to: (i) characteristics of the EPC (calculation methodology, types of dwellings, energy rating scale, registration, improvements and validity) and (ii) requirements of the QEs.

1.3.1. Energy Performance Certificates (EPCs)

The EPCs calculation method is very similar in all countries, using the annual energy demand of the building to calculate the energy rating. However, the calculation method in Sweden is based on the real quantity of energy used, and other countries use a combination of both methods for the energy rating of the building (Table 2).

Table 1. EPBD transpositions and APAs.

Country	EPBD Transposition	APAs
Austria (AT)	Energy Performance Certificate Law (EAVG 2012)	Austrian Institute of Construction Engineering (OIB)
Belgium - Brussels Capital Region (BE-BR)	Brussels Air, Climate and Energy Code (BE 2013)	Regional Ministry of Energy of the Government of the Brussels Capital Region
Belgium - Flemish Region (BE-FR)	Execution Order of May 11, 2005, adopted in 2009 (EO 11/05/2005-2009)	Flemish Energy Agency (VEA)
Belgium - Walloon Region (BE-WR)	Calculation Procedures and Minimum Requirements for New and Existing Buildings (MB du 22/06/2012), Certification of New Buildings (MB du 05/09/2011), Certification of Existing Residential Buildings (MB du 07/06/2010) and Certification of Existing Non-Residential Buildings (MB du 03/11/2011)	Department of Energy and Sustainable Buildings
Bulgaria (BG)	Energy Efficiency Act (SG 24/12.03)	Sustainable Energy Development Agency (SEDA), supported by the Ministry of Economy and Energy and the Ministry of Regional Development
Croatia (HR)	Physical Planning and Building Act (Official Gazete 76/2007) and Energy Efficiency Act (Official Gazete 152/2008)	Ministry of Construction and Physical Planning
Cyprus (CY)	Law for the Regulation of the Energy Performance of Buildings (Law 142(I)/2006)	Ministry of Energy, Commerce, Industry and Tourism
Czech Republic (CZ)	Regulation on Energy Performance of Buildings (Regulation 148/2007)	Ministry of Industry and Trade
Denmark (DK)	Danish Building Regulations (BR10)	Ministry of Business and Growth
Estonia (EE)	Minimum Energy Performance Requirements (Decree 258/2009)	Ministry of Economic Affairs and Communications
Finland (FI)	National Building Code (NBD 2013)	Ministry of Environment and Ministry of Employment and the Economy
France (FR)	Energy Performance Diagnosis (DPE) (Décret 2011-413)	Ministry of Ecology and Sustainable Development Energy and Ministry of Territories and Housing
Germany (DE)	Energy Saving Ordinance (EnEV 2009) and Renewable Heating Law (EEWärmeG 2009)	Federal Ministry of Transport, Building and Urban Development and Federal Ministry of Economics and Technology, under the supervision of the Federal Ministry for Environment, Nature Conservation and Nuclear Safety
Greece (EL)	Law 3361 (Law 3661/2008), KENAK (Regulation for Energy Performance of Buildings) (Ministerial Decision D6/B/5825-2010), Presidential Decree 100/NG177 (Presidential Decree 100/NG177-2010)	Ministry of Environment, Energy and Climate Change
Hungary (HU)	Ministerial Decree on the Establishment of Energy Characteristics of Buildings (MD TNM 7/2006) and Decree of Minister about Determination of Energy Efficiency of Buildings (Decree 40/2012)	Ministry of Interior
Ireland (IE)	Dwelling Energy Assessment Procedure (DEAP) and Non-Dwelling Energy Assessment Procedure (NEAP) (SI 243/2012)	Department of the Environment, Community and Local Government (DECLG)
Italy (IT)	Decree on the Promotion of the Use of Energy from Renewable Sources (Decree 28/2011)	Ministry for Economic Development
Latvia (LV)	Law on the Energy Performance of Buildings (LEPB 2012)	Ministry of Economy
Lithuania (LT)	Law Energy Performance of Buildings (STR 2.01.09)	Ministry of Environment and Ministry of Energy
Luxembourg (LU)	Grand-Ducal Regulation on the energy performance of buildings. Memorial and Functional (Règlement 173/2010)	Ministry of Economy and Foreign Trade and Ministry of Sustainable Development and Infrastructure
Malta (MT)	Legal Notice of Minimum Requirements on the Energy Performance of Buildings (Legal Notice 238/2006), Legal Notice of Energy Performance of Buildings Regulations (Legal Notice 261/2008) and Legal of Energy Performance of Buildings Regulations (Legal Notice 376/2012)	The Building Regulation Office (BRO)

Table 1. EPBD transpositions and APAs. (Continued)

Country	EPBD Transposition	APAs
Netherlands (NL)	Decree on Energy Performance of Buildings (BEG 2006) and Regulation on Energy Performance of Buildings (REG 2009)	Ministry of the Interior and Kingdom Relations
Poland (PL)	Construction Act Journal (Laws 191/2009)	Ministry of Infrastructure and Ministry of Economy
Portugal (PT)	System of Energy Certification (SCE) (Decreto-Lei 78/2006), Regulation of Energy Systems and Climatization of Buildings (RSECE) (Decreto-Lei 79/2006) and Regulation of the Characteristics of Thermal Conduct of Buildings (RCCTE) (Decreto-Lei 80/2006)	Ministry of Public Works, Transport and Communications Works
Romania (RO)	Law of Energy Performance of Buildings (Law 372/2005)	Ministry of Regional Development and Public Administration
Slovak Republic (SK)	Act on the Energy Performance of Buildings and on Amendment and Supplements to Certain Acts (Act 555/2005)	Ministry of Construction and Regional Development and Ministry of Economy
Slovenia (SI)	Regulation on Energy Performance (REP 2010)	Ministry of the Economy, Energy and Mining Inspectorate and Ministry of Environment and Spatial Planning
Spain (ES)	Basic Procedure for Certification of Energy Efficiency of Buildings (RD 235/2013), Regulation of Thermal Installations in Buildings (RITE) (RD 1027/2007) and Technical Code of Edification (CTE) (RD 314/2006)	Ministry of Industry, Energy and Tourism and the Ministry of Development
Sweden (SE)	Law on Energy Declaration of Buildings (Law 2006:685), Performance Certificates for Buildings Ordinance (Ordinance 2006:1592) and Regulations by the National Board of Housing, Building and Planning (NBHBP)	Ministry of Enterprise, Energy and Communications and Ministry of the Environment
United Kingdom – England and Wales (UK - EW)	Building Regulations (amendments) Regulations (Statutory Instrument 2012/3119), Energy Performance of Buildings (Statutory Instrument 2012/3118)	Welsh Government
United Kingdom – Northem Ireland (UK - NI)	Building Regulations (SR 192/2012) and Energy Performance of Buildings (Certificates and Inspections) (SR 170/2008)	Department of Finance and Personnel Northern Ireland (DFPNI)
United Kingdom – Scotland (UK - S)	Building Act 2003, Building Regulations 2004, Building Procedure and Forms 2007, Energy Performance of Buildings Regulations (EPBR 2008)	Directorate for the Built Environment
Norway (NO)	Criteria for Passive Houses and Low Energy Buildings (NS 3701/2012)	Water Resources and Energy Directorate (NVE)

In case of calculating the EPC by using the annual energy demand of the building, it is necessary to be very precise in defining the building envelope, materials, thermal bridges, heating and cooling, DHW, etc. This is due to the fact that this method is based on a prediction. This method has the advantage of knowing how the building is going to work before use in normal conditions. However, calculating the real amount of energy used, the measurement may vary between identical buildings in the same climate zone because of the human factor involved in the calculation method (Zabalza et al. 2009), although a more individualized result to each dwelling is obtained.

Table 2. Characteristics of EPCs and Qes.

Country		EPCs									QEs	
		Method		Typology		Scale		Others			Quality	
		Demd	AEC	New	Exist	Levels	Cont	Reg	Imp	Valid	Cou	Ex
AT		X	-	X	X	9	-	-	-	10	-	-
BE	BR	X	-	X	X	17	-	X	X	5 to 15	X	-
	FR	X	-	X	X	-	X		X	10	X	X
	WR	X	-	X	X	8	-	X	-	10	-	-
BG		X	X	X	X	7	-	-	-	3 to 10	-	X
HR		X	-	X	X	8	-	X	X	10	X	X
CY		X	-	X	X	7	-	X	X	10	-	X
CZ		X	-	X	X	7	-	X	-	10	X	X
DK		X	-	X	X	8	-	-	-	7 to 10	-	-
FI		X	-	X	X	8	-	X	X	10	-	-
FR		X	X	X	X	7	-	X	X	10	-	X
DE		X	-	X	X	-	X	X	X	10	-	-
EE		X	-	X	X	8	-	X	-	10	X	X
EL		X	-	X	X	9	-	X	X	10	X	X
HU		X	-	X	X	9	-	X		10	X	-
IE		X	X	X	X	15	-	X	X	10	-	X
IT		X	-	X	X	8	-	X	-	10	X	X
LV		X	X	X	-	-	X	X	-	10	-	X
LT		X	-	X	X	9	-	X	-	10	X	X
LU		X	X	X	X	9	-	X	X	10	-	-
MT		X	X	X	X	7	-	X	-	10	X	-
NL		X	-	X	X	9	-	X	X	10	-	X
PL		X	-	X	X	-	X	X	-	10	X	X
PT		X	X	X	X	9	-	X	X	2 to 6	X	X
RO		X	X	X	X	7	-	X	X	5	X	X
SK		X	-	X	X	8	-		X	10	X	X
SI		X	X	X	X	7	-	X	-	10	X	-
ES		X	X	X	X	9	-	X	X	10	-	-
SE		-	X	X	X	7	-	X	X	10	-	X
UK	EW	X	-	X	X	7	-	X	X	10	-	-
	NI	X	-	X	X	7	-	X	X	10	-	-
	S	X	X	X	X	7	-	X	X	10	-	-
NO		X	-	X	X	7	-	X	X	10	-	-

Demd: Demand; AEC: Actual energy consumption; Exist: Existing; L: Levels; Cont: Continuous; Reg: Registry; Imp: Improvements; Valid: Validity (years); Cou: Course; Ex: Exam

From the transposition of the EPBD, the EPC is carried out in the project phase in all countries except in Latvia, where the EPC is also performed in the existing buildings that are going to be sold or rent. As an exception, the EPC is not required in Sweden when the dwelling is going to be sold or rent to a member of the owner´s family.

Table 2 shows the scale to carry out the energy rating. As it can be observed, not all EU countries have adopted the same scale, ranging from scales with 7 levels (BG, CY, CZ, FR, MT, RO, SE, UK and NO) to scales of 17 levels (BE-BR). On the other hand, some of the countries have adopted a continuous scale (BE-FR, DE, LV and PL).

The registry of the EPC is mandatory in the majority of States. Moreover, it is compulsory to include proposals for energy improvement in the EPC. The validity of the EPC is 10 years generally, varying in some States due to variations such as the power of the heating and cooling facilities.

Regarding the price of the EPC, in the majority of the countries the price corresponds to the market price. Only Hungary has a fixed price that is established by the government.

1.3.2. Qualified Experts (QEs)

As it is shown in Table 2, not all the countries have the same requirements for QEs. In some countries, a degree in architecture or engineering is required, whereas in other countries it is necessary to pass a course and/or an exam in addition to a university degree. The accreditation to QE may be given by the State, but the State can delegate this function to other bodies such as professional associations that would perform the courses and exams needed.

To know the available QEs, some States have online registers that can be consulted by the public. In other States it is necessary to go to professional associations where there are lists of the QEs. On the other hand, there are some States where this information is not public.

Another feature is that QEs can be divided into different categories. In countries with only one category of QEs, the inspection of buildings and facilities can be performed by the same expert, whereas there are countries with different categories of QE depending on building typologies and/or power of the facilities.

1.4. Conclusions

The transposition of the European framework to each country has created a series of regulations with the same origin but not homogeneous among themselves.

With the current transpositions it is impossible to compare the energy efficiency of two identical buildings in different States, even having the same climatic conditions, because the energy scales are different, as well as the calculation methods (energy demand, real consumption or both).

A QE in a State could not work in another State of the European Union as a QE because of the different requirements of each one. This fact impedes the free circulation of professionals.

Therefore, this study states the importance of a more homogeneous transposition of the EPBD in the different countries of the European Union, showing substantial differences between them in spite of being developed to achieve the same objective, which is the reduction of the energy consumption in dwellings by a proper building design.

CHAPTER 2.-

CALCULATION METHOD IN THE ENERGY RATING OF BUILDINGS IN SPAIN[2]

[2] The results shown in this chapter were presented in: **Carpio, M.,:** García-Maraver, A., **Benefits from the use of pellet boilers in the energy rating of buildings**. Biomass pelletization: standards, production and use. *WIT Press UK* (2015).

2.1. Introduction

To carry out the method for obtaining the calculation efficiency classes –used in the following chapters– is necessary to consider the concept of climate zone to shown the impact in the method. Just as different energy efficiency indicators in the energy rating of buildings. In the following sections these concepts are developed. This method is for Spain and the regulations applied are the CTE, in section DB-HE (Orden FOM/1635/2013), and the Royal Decree 235/2013.

2.2. Climatic zoning

The climatic zone is defined as an area for which common external conditions for calculating the energy demand are defined using a few parameters (RD 314/2006). The assignment of a correct climate zone is crucial, because the building faces different requirements depending on the climate zone, that affect the final energy rating. The classification of climatic zones chosen for use in this chapter to study the benefits of pellet boilers in the energy rating is a variation of the Köppen classification (Chen and Chen. 2013). It involves the assignment of 5 different climatic zones for winter and 4 different climatic zones for summer (RD 314/2006). The winter climates are designated by a letter (A, B, C, D and E) corresponding to the winter climate severity (WCS), whereas a number (1, 2, 3 and 4) represents the summer climate severity (SCS). As shown in Table 3, the different combinations of these intervals amount to a total of 20 possible climatic zones. Yet some are hardly feasible and could not be identified in Europe —for instance an Antarctic climate or a Sahara desert climate (RD 314/2006). Table 3 shows the thresholds of WCS and SCS.

2.3. Energy Efficiency Indicators method

The energy efficiency rating is the estimation of the energy necessary to comply with the demands of a building under normal conditions of occupancy and functioning . A real building can be qualified and certified on an energy scale comparing a number of indicators of the mean energy use in model buildings of reference (RD 235/2013, RD 47/2007).

Table 3. Climatic zones (RD 314/2006).

		Summer Climate Severity (SCS)			
		1	**2**	**3**	**4**
		SCS≤0.6	**0.6<SCS≤0.9**	**0.9<SCS≤1.25**	**SCS>1.25**
Winter Climate Severity (WCS)	**A** **WCS≤0.3**	A1	A2	A3	A4
	B **0.3<WCS≤0.6**	B1	B2	B3	B4
	C **0.6<WCS≤0.95**	C1	C2	C3	C4
	D **0.95<WCS≤1.3**	D1	D2	D3	D4
	E **WCS>1.3**	E1	E2	E3	E4

The Energy Efficiency Indicators (EEI) in residential buildings are: (i) EEI heating demand; (ii) EEI cooling demand; (iii) EEI of heating emissions; (iv) EEI of cooling emissions; (v) EEI of emissions for DHW; and (vi) EEI of total emissions.

2.3.1. Energy Efficiency Indicator heating demand

It is the ratio between the heating demand of the studied building and the reference heating demand. For residential buildings, the heating demand is the reference corresponding to the average value of similar new buildings that conform with the regulations of a given year (in this case 2006).

This mean value depends on the locality in which the building is located. It is different for single-family houses and residential buildings.

2.3.2. Energy Efficiency Indicator cooling demand

This is the ratio between the cooling demand of the studied building and the reference cooling demand. In the case of residential buildings, the cooling demand is the reference corresponding to the average value of similar new buildings in conformity with the regulations in a given year (in this case 2006).

This mean value depends on the locality in which the building is located, and it is also different for single-family houses and residential buildings.

2.3.3. Energy Efficiency Indicator of heating emissions

It is the ratio of CO_2 emissions due to heating service in the studied building and CO_2 emissions of reference for the heating service.

2.3.4. Energy Efficiency Indicator of cooling emission

It is the ratio of CO_2 emissions due to cooling service in the studied building and CO_2 emissions of reference for the cooling service.

2.3.5. Energy Efficiency Indicator emission for DHW

This is the ratio of CO_2 emissions due to DHW service in the studied building with respect to CO_2 emissions of reference for the DHW service.

2.3.6. Energy Efficiency Indicator of total emissions

It is the ratio between the total CO_2 emissions caused by all the services considered in the building object and total CO_2 emissions of reference for the same services. Total CO_2 emissions of the building as well as the building object reference are obtained by adding the CO_2 emissions for each service considered.

2.4. Method for obtaining efficiency classes

The rate of energy rating, C1, is obtained from the value of the indicator of energy efficiency (IEE) by Eq. 1:

$$C_1 = \frac{(IEE \times R) - 1}{2 \times (R - 1)} + 0.6$$

Eq. 1. Rate of energy rating.

where R is the ratio between the value of the indicator for the percentile 50% and the percentile 10% of new residential buildings of 2006 according to the housing census.

Table 4 shows the values of R (dispersion of the IEE, to use in total emissions).

Table 4. Values of R (IDAE. 2009a).

		Summer Climate Zone			
		1	2	3	4
Winter Climate Zone	A			1.60	1.60
	B			1.60	1.55
	C	1.50	1.50	1.55	1.55
	D	1.45	1.50	1.50	
	E	1.45			

The limits of the scale are expressed through the energy rating index C1, based on Table 5. This scale comprises seven levels, the most efficient one denoted by A, and the least efficient one designated by G, which are represented in Fig. 2. No new buildings would have levels F or G, as these are used only for renovated structures (IDAE. 2009b).

Table 5. Limits of efficiency classes (IDAE. 2009a).

Level	Limits	
A	C1	< 0.15
B	0.15 ≤ C1	< 0.50
C	0.50 ≤ C1	< 1.00
D	1.00 ≤ C1	< 1.75
E	C1	> 1.75

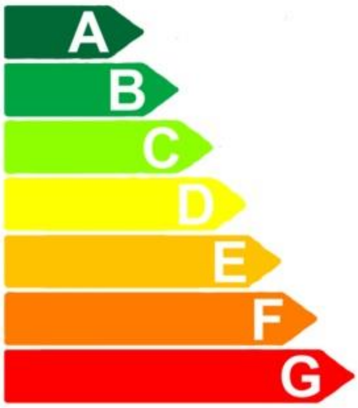

Fig. 2. Energy rating. Scale of seven levels (RD 314/2006).

CHAPTER 3.- ANALYSIS OF DOCUMENTS RECOGNIZED FOR ENERGY EFFICIENCY CERTIFICATION OF BUILDINGS[3]

[3] The results shown in this chapter were presented in: **Carpio, M.**, Martín-Morales, M., Zamorano, M., **Comparative study by an expert panel of documents recognized for energy efficiency certification of buildings in Spain**, (2015) *Energy and Buildings.* 99 PP. 98-103.

3.1. Introduction

In terms of functionality, energy simulation is a key tool for the energy-related assessment of a building (Newton et al. 1988). It entails the use of computerized programs that can point out or predict any drawbacks deriving from construction characteristics and execution, as well as ways to remedy them.

According with Chapter 2, the methodology for calculating the energy performance of buildings in Spain has to include the use of one of the recognized documents included in the Royal Decree 235/2013. In this sense Ministry of Industrial, Energy and Tourism meant the recognition of four software documents created for the energy simulation of buildings. CALENER VYP (Industria. 2010) applies a general method of reference with a higher level of detail, whereas CE3 (APPLUS. 2013), CEX (CENER. 2013) and CERMA (ATECYR. 2011) apply the simplified option of a prescriptive nature, whose indirect calculation is based on the general method. The simplified method is limited in that openings in the façade must constitute less than 60% of its total surface, and the percentage of skylights must be under 5% of the covered surface. Furthermore, excluded from the procedure are buildings whose enclosures consist of non-conventional constructive solutions.

All the above mentioned software documents are valid, as they are their results, which may rely on different parameters such as calculations, variables, means of data input, calculating engine, output report, etc. Consequently, the final results may be different both in CO_2 emissions and level of energy efficiency. Thus, the present contribution is a comparative analysis of the four documents mentioned above, based on a survey carried out with the active participation of professionals from the sector. Then, a horizontal comparison by means of a case study was performed to discern differences regarding the calculations of CO_2 emissions and the final energy rating of a residence.

3.2. Material and methods

In this section it has been defined the expert panel that carried out the survey about the documents recognized for the energy efficiency certification of buildings. The purpose of the survey is to analyze the strengths and weaknesses of each document, as well as to know the preferences of the experts. In addition, a standard building is defined as a model to develop the energy simulation with the different documents in order to compare the results obtained.

3.2.1. Documents recognized

The pertinent documents consulted were the CALENER VYP (general procedure for buildings in project or terminated), and the CE3, CEX and CERMA, the latter three involving simplified procedures for existing buildings, described in the Royal Decree 235/2013. In addition, CERMA is valid to study new buildings in the design phase of the project (ATECYR. 2011), but for this study only the option of existing buildings will be analyzed.

3.2.2. Panel of experts

For the purposes of this study, we first generated an expert panel. This resource for data collection is commonly used in a wide range of fields, from medicine (Borden et al. 2014, Fox et al. 2013, Hens et al. 2013, Rosenthal. 2012), to education (Lawrenz et al. 2012, Worthen. 2007), or biology (Oraguzie et al. 2009), as well as construction (Gambatese et al. 2008).

The expert panel consisted of 105 technicians: 63 from the architecture sector and the other 42 from the engineering sector. They were identified through professional associations and universities in Spain. The experts have been selected attending to their professional relationship with the different documents, as well as considering their experience in energy performance certificates. All the experts of different professional associations interested in taking part have been represented. The participants are competent technicians that are qualified for elaborating reports on energy efficiency according to the Royal Decree 235/2013.

An *ad hoc* questionnaire, shown in Table 6, was provided to the panel of experts. The structure of the survey and the items it contained were intended to determine the priority of the different experts when choosing one of the software tools of study, how they appraised it, and which strong points and weak points they encountered.

Data gathering through the surveys was carried out using Google Drive software (Google. 2014), and the data obtained were statistically processed with predictive analytical software SPSS 20.0.0 (IBM. 2011), licensed to the University of Granada.

3.2.3. Building type

A representative building was chosen in view of the predominating geometric and construction characteristics in Spain, a typology determined based on data from the National Statistical Institute of Spain (INE. 2013) and reports issued by the Upper Council of the Schools of Architects (CSCAE. 2014).

As seen in Fig. 3, the prototype building consists of a single-family residence structured on one floor and separated into different spaces: living room (17.60 m^2), kitchen (8.16 m^2), bathroom (4.42 m^2), hall (5.29 m^2) and two bedrooms (9.42 m^2 and 10.46 m^2). The total useable space amounted to 55.35 m^2. The most important materials in the thermal covering and thermal transmittance (U) used were: plain roof (0.48 W/m^2K), sloping roof (0.45 W/m^2K), unaccessible roof (0.75 W/m^2K), exterior vertical closures (0.40 W/m^2K), wooden door (2.20 W/m^2K) and windows (1.87 W/m^2K). The principal façade is oriented toward the southwest. A comfortable indoor temperature of 17 °C to 20 °C in winter, and between 24 °C and 26 °C in summer, was estimated. The climatic data were obtained from the database of the regional Environmental Council of the Junta de Andalucía (Junta de Andalucía. 2014).

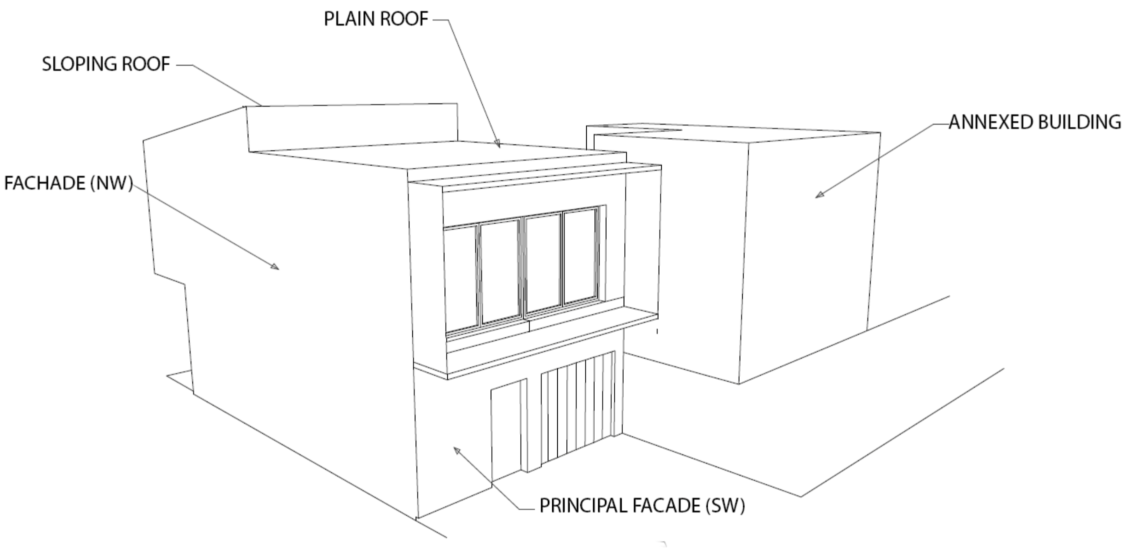

Fig. 3. Prototype residence.

As the heating system, a natural gas heater that provides for heating throughout the residence while also providing DHW was adopted, with the following specifications: heating potential 20 kW, efficiency 90%, temperature of water expulsion 50°C for ACS and 80°C for heating, and DHW volume of 31 liters/day. The living room and bedrooms were air conditioned by a multi-zone installation with conducts having a potency of 7.1 kW and an air flow of 1500 m^3/h.

The representative residence was located in the city of Jaén (Southern Spain). According to Köppen Climate Classification (Chen and Chen. 2013), Jaén features a Temperate Climate (Type C) with a C4 climatic zone (Carpio et al. 2015b). The Temperate Climate predominates in Spain as a whole (IMP and AEMET. 2011).

Table 6. Structure of the ad hoc questionnaire given to the panel of experts.

	Question	Answer
Technician´s background data	1.1.Degree	Architect; Architectural Technician/Building Engineer; Industrial Engineer; Industrial Technical Engineer; Civil Engineer; Technical Engineer of Public Works; Others Degrees (Specify)
	1.2.Province	52 provinces
	1.3.Professional association	Yes/No (Where)
	1.4Sex	Man/Woman
	1.5.Age	18-99
Preferences	2.1.Geometric definition considered more accurate	Predefined types; Surface and orientation; DXF blueprints
	2.2.Geometric definition used	Predefined types; Surface and orientation; DXF blueprints
	2.3.Preferences of document acknowledged by sectors	
	2.3.1.Interface	CALENER VIP; CE3; CEX; CERMA
	2.3.2.Input data	CALENER VIP; CE3; CEX; CERMA
	2.3.3.Final report	CALENER VIP; CE3; CEX; CERMA
	2.3.4.Material database	CALENER VIP; CE3; CEX; CERMA
	2.3.5.Calculating engine	CALENER VIP; CE3; CEX; CERMA
	2.3.6.Intuitive	CALENER VIP; CE3; CEX; CERMA
	2.3.7.Global	CALENER VIP; CE3; CEX; CERMA
	2.4.Other documents used	Yes/No (Wich one)
Times and surfaces	3.1.Single-family residence	
	3.1.1.Time per certification	Hours
	3.1.2. Average surface	m^2
	3.2.Multi-family residence	
	3.2.1.Time per certification	Hours
	3.2.2. Average surface	m^2
	3.3.Small teritiary sector	
	3.3.1.Time per certification	Hours
	3.3.2. Average surface	m^2
Qualification of document	4.1.CALENER	1-10
	4.2.CE3	1-10
	4.3.CEX	1-10
	4.4.CERMA	1-10
Recommendations for energy improvement suggested by the software	5.1.Insulation in opaque closures	CALENER VIP; CE3; CEX; CERMA
	5.2.Modification/substitution of openings	CALENER VIP; CE3; CEX; CERMA
	5.3.Installation/modification of solar protection	CALENER VIP; CE3; CEX; CERMA
	5.4.Improvements in systems, fuels, performance	CALENER VIP; CE3; CEX; CERMA
	5.5.Global	CALENER VIP; CE3; CEX; CERMA

The Government of Spain, using statistical data from numerous case studies categorized by climate zone (IDAE. 2011, IDAE. 2013a, IDAE. 2013b), elaborated tables indicating cases where a similar residence would lose or win a grade on the energy scale

(7 levels) because CALENER VYP was the document of reference. Table 7 shows the statistics corresponding to the climate and house type of study (residence in a block of apartments in climatic zone C4).

Table 7. Comparison of the energy class with the different documents acknowledged. CALENER VYP is the reference (Industria. 2014).

	Gains one level	Same level	Loses one level	Loses two levels
CE3	0.00%	76.73%	22.06%	1.21%
CEX	0.21%	69.24%	18.39%	12.17%
CERMA	0.00%	88.14%	11.86%	0.00%

3.3. Results and discussion

3.3.1. Comparative study of documents

3.3.1.1. Population

Shown in Fig. 4 are the characteristics of the 105 technicians on the expert panel. The most representative participating group was that of Architectural Technician/Building Engineers (51 participants), followed by Industrial Engineers (18), Industrial Technical Engineers (18), Architects (12) and other technical degrees (6) (3 Civil Engineers, 2 Public Works Engineers and 1 Mining Engineer). On the one hand, and according to Chapter III of the *Ley de Ordenación de la Edificación* (LOE) (Law of Building Ordinance) (Ley 38/1999. 1999) related to the agents of the construction, only Architects and Architectural Technicians/Building Engineers have competence in residential edification. However, and basing on Article 1.3.p. and on the Fourth Additional Provision (Other technicians authorized) of the Royal Decree 235/2013, all the technicians considered for this expert panel, as well as those listed in Resolution of 15th January 2009 (Resolución 15/01/2009), can issue official certification of energy efficiency.

Of the 105 experts, 94 were members of Professional Associations, while 11 —equally distributed geographically, from all over Spain— affirm that it is not necessary for the execution of their profession. A breakdown by sex shows that 95 are male, 10 are female; and as for age, most are between 31 and 45 years of age (61), followed by age 46 to 60 (26), 18 to 30 (15) and age 61 or over (3). Fig. 4 depicts the corresponding percentages.

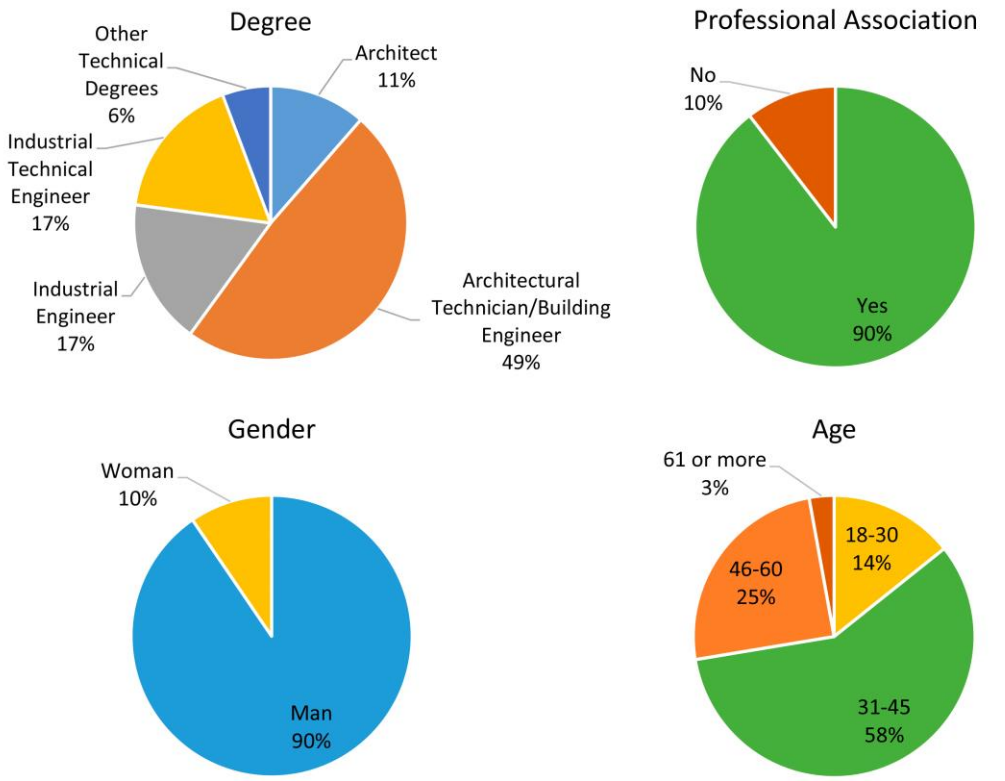

Fig. 4. Population surveyed.

3.3.1.2. Preferences

In view of the number of experts offering an opinion about the different documents, those most frequently used by the experts to perform the energy efficiency certification (N) are CE3 and CEX (both having N=90), followed by CALENER VYP (N=82) and finally CERMA (N=43). The low number of expert users of CERMA indicates that it is not the most common document to carry out the energy efficiency certificates. This situation does not affect the evaluations of the document, since only experts using CERMA have valued the document. The standard deviations of CALENER VYP, CE3 and CEX have very similar values (1.985-2.099), whereas CERMA shows a substantially greater value (2.228), reflecting wider discrepancies among the participants.

Overall, the mark received per document is not very high. As seen in Fig. 5, on the scale of 0 to 10, not one single document surpassed a mark of 7. However, with the understanding that a mark less than 5 would be a negative evaluation, it can be said that no method fails. The document best appraised, far above the rest, was CEX, rated 6.64 on the average, followed by CALENER VYP, CERMA and CE3, these three obtaining similar averages around 5.

The four documents of study use different procedures to introduce the geometry of the living quarters. There were manifest differences of opinion about the means used by technicians and the one considered most precise. Thus, 73% of the experts participating in this study used as input data the surface and orientation, followed by 20% who relied on the DXF blueprints, whereas 7% use predefined types. Most experts hold that the most precise means is DXF blueprints (60%), while surfaces and orientation are supported by 37%. Just 3% advocate the predefined types, whose low acceptance rate suggests they are not considered reliable by experts. Although a majority affirms that the most widely used method is the one based on surfaces and orientation, most reportedly consider it more exact to introduce the data by means of DXF blueprints. Such a contradictory message, affirming that one is used but the other is more precise, can be explained by the data input procedure. Indeed, introducing DXF prints is more complex; yet equally valid results, according to the legal norm, can be obtained using the simpler procedures (RD 235/2013).

As for choice of sections (Table 8), the preferred document in all categories except one is CEX. The exception is the calculating engine, where CALENER VYP is preferred, as all the other documents are based upon it. In this part of the survey, the participating experts (N) were the total number of participants. In other words, the least used documents, as observed earlier, were the ones less selected by sections, as is the case of the CERMA –despite being better appraised than the CE3, it harvested the lowest evaluation overall.

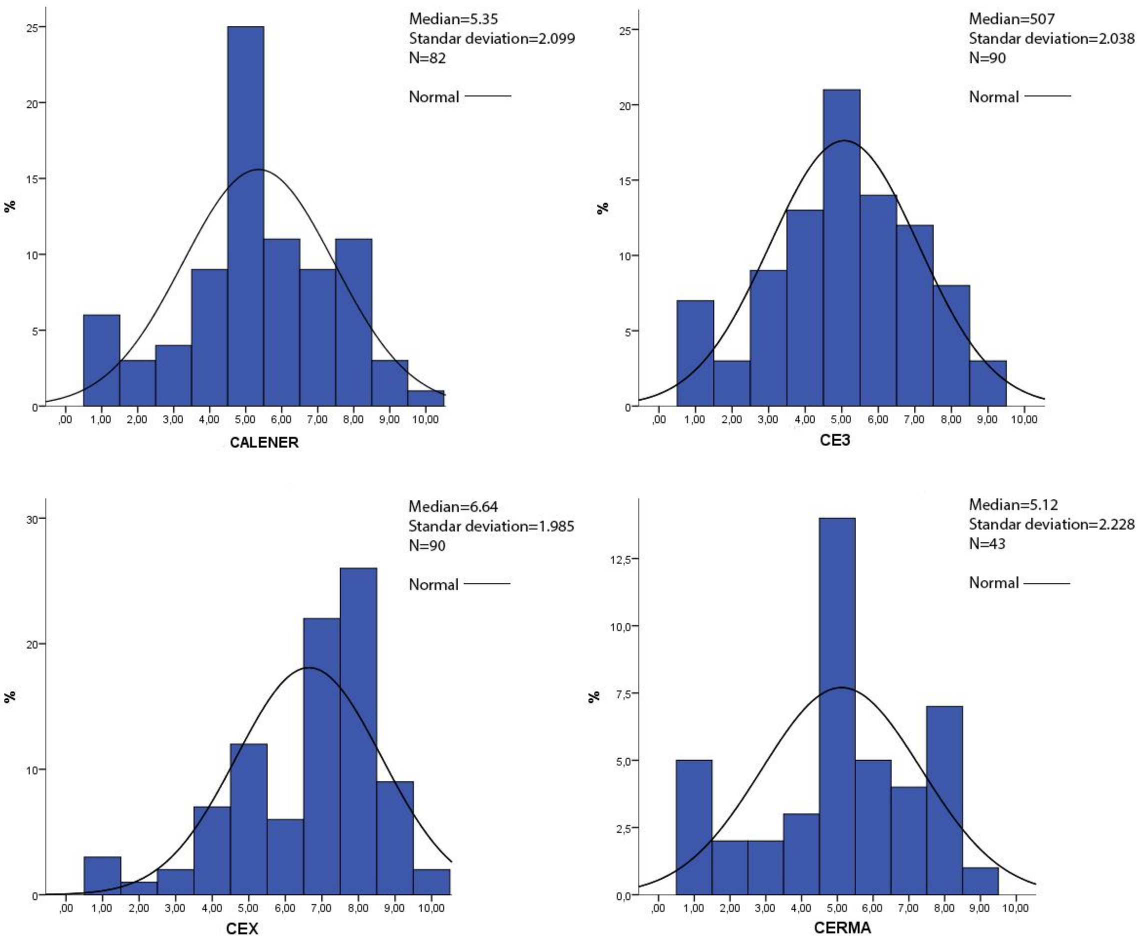

Fig. 5. Evaluation of the documents acknowledged.

Table 8. Preference of document, as acknowledged by sections.

N=105	CALENER VYP	CE3	CEX	CERMA
Interface	7.6%	31.4%	59.0%	1.9%
Input data	4.8%	36.2%	55.2%	3.8%
Final report	14.3%	28.6%	50.5%	6.7%
Material database	34.3%	25.7%	37.1%	2.9%
Calculating engine	38.1%	26.7%	30.5%	4.8%
Intuitive	3.8%	30.5%	64.8%	1.0%
Global	16.2%	31.4%	49.5%	2.9%

Finally, in terms of the energy improvements suggested by the software, as seen in Table 9, the document gaining the highest consideration in all the categories was CEX, followed by CE3, CALENER VYP and CERMA.

Table 9. Preference of recommendations of energy improvement by document acknowledged.

N=105	CALENER VYP	CE3	CEX	CERMA
Insulation in opaque closures	19.0%	35.2%	41.0%	4.8%
Openings in façade	16.2%	35.2%	43.8%	4.8%
Solar protection	20.0%	32.4%	44.8%	2.9%
Systems, fuels, performance	18.1%	34.3%	44.8%	2.9%
Global	15.2%	32.4%	48.6%	3.8%

3.3.2. Practical case study

By applying the different documents to the prototype residence adopted in this study, differences appear in terms of CO_2 emissions and the corresponding energy certification for the same building type (Table 10). For comparative purposes, CALENER VYP was taken as the reference, as it is the only document that uses the general method.

Table 10. CO_2 emissions and energy rating with the different documents.

	CALENER VYP	CE3	CEX	CERMA
CO_2 emissions (kg/m^2 year)	54.4	55.6	40.1	41.1
A-G	E	E	D	E

The analysis of the results carried out by the authors with the different documents shows that use of the CE3 means a 2.21% increase in the calculation of CO_2 emissions. In contrast, documents CEX and CERMA present lower values for emissions, with respective reductions of 26.29% and 24.49%. Despite the fact that this discrepancy introduces the same values with the different documents, it generates serious errors. These results could be future mistakes in the calculation of the right materials needed for the thermal envelope or the thermal system.

With regard to the energy certification, on a scale of 7 levels (A-G) (RD 235/2013), all the documents except one obtained the grade of E. The exception was CEX, which overall gave a better result, D. The fact that one may obtain a better or worse result depending on the document of choice may have considerable implications for the market value of a building. Moreover, it may impede getting subventions for residential energy rehabilitation.

Comparing these results with the statistics provided by the Government of Spain (Table 7), it is seen that the use of document CE3 enables one to obtain the same rating in 76.73% of cases; with CERMA the same E certification is similarly obtained in 88.14% of the cases. In sharp contrast, however, with CEX a grade one level higher is attained (0.21% of cases). In view of these results, it can be stated that the document recognized as representing the lowest CO_2 emissions and the best energy certification would be the CEX.

3.4. Conclusions

Consultation with a panel of experts who evaluated the documents used for the energy certification of buildings leads to two noteworthy conclusions. First, although all the documents acknowledged have the same validity when processing an energy certification, most experts prefer a user-friendly interface, as is the case of CEX. Generally speaking, it is the most widely used document by the expert panel, together with CE3, followed by CALENER VYP and CERMA; it is also the best appraised one (6.64), followed by CALENER VYP (5.35), CERMA (5.12) and CE3 (5.07).

The application of the four documents to a single residential type gave diverse results. In the case of CO_2 emissions, there is a substantial discrepancy of 26%, which means a higher or lower final level of energy certification. Currently, the government reports are CE3 Vs CALENER, CEX Vs CALENER and CERMA Vs CALENER. This first study is a starting point for a future analysis of the four documents with real cases in parallel (CE3 Vs CEX Vs CERMA Vs CALENER).

In view of the results reported here, entailing subjective appraisals on the part of the expert panel and objective findings regarding CO_2 emissions and energy certifications, it can be said that the outstanding software document for energy certifications is the CEX. Further studies are necessary to harmonize all the recognized documents in order to ensure more homogenous results than the ones reflected here.

CHAPTER 4.- ENVIRONMENTAL AND ECONOMIC EFFECTS OF USING BIOMASS IN RESIDENTIAL THERMAL INSTALLATIONS: THE CASE OF THE PROVINCE OF GRANADA (SPAIN)[4]

[4] The results shown in this chapter were presented in: **Carpio, M.**, García, R., Martín-Morales, M., Zamorano, M., **Environmental and economic effects of using biomass in residential thermal installations: The case of the province of Granada (Spain)** (2015) *Submitted to Renewable and Sustainable Energy Reviews.*

4.1. Introduction

In Europe, policy on energy and climate protection has been expressed in three strategic objectives which make up the "20-20-20 targets", designed to reduce the consumption of primary energy and greenhouse gas emissions in the European Union, helped, among other measures, by a greater contribution from renewable energies (EUCEP 2008-2020). These objectives are also applied to the building sector, however, not all the countries have implemented renewable energy technologies in buildings. To achieve these targets we need to act in the priority areas of energy generation and consumption. and emissions, assuming the commitments specified in the European Directive (Directive 2009/28/EC).

The study of the present chapter looks at the installed power capacity in buildings in the province of Granada in the first decade of the twenty-first century, considering the different systems for heating, cooling and DHW. Because of its varied climate the province can be taken as representative of Spain. An assessment is made of the fuels used at present and their replacement by biomass, showing the environmental and financial benefits that would be obtained from the use of biomass as fuel for the above purposes in the building sector.

4.2. Materials and methods

4.2.1. Geographical scope

As can be seen in Fig. 6 the province of Granada, Spain, was chosen for this study, which covered 169 municipalities. The province has the greatest range of altitudes in the Iberian Peninsula, from sea level on the coast in the south to the highest peak in the Iberian Peninsula, Mulhacén (3,479 m), in the Sierra Nevada, Penibaetic System (BCN500. 2012).

Climate zones can be classified according to the severity of the climate in winter and in summer, and the combined influence of outside temperature and solar radiation. The scale used depends on the country of the European Union considered (Kyoto 1997). In Spain 12 of the 20 possible world climate zones are found (RD 314/2006), and the province of Granada, because of differences in altitude and the distinctive morphology of the terrain, contains examples of 11 of Spain's 12 zones. It can, therefore, be considered an area representative of the whole country from the point of view of climate (Carpio et al. 2015b).

Fig. 6. Location of the province of Granada. The dot is the capital.

4.2.2. Data collection

The data necessary for the study, described below, are drawn from the Government of Andalusia Ministry of Innovation, Science and Enterprise's database for heating and air-conditioning equipment and DHW (Junta de Andalucía. 2014).

To obtain a representative sample different types of boilers installed in different municipalities in the province of Granada in the last ten years (2003-2013) were studied, a valid sample of 2,213 records with 6,234 boilers being obtained. Each of the records covers a building, which may be a single-family home or a multi-family residential unit. There may thus be more than one boiler per building. The data for boilers provide information regarding the different fuels used, whether a single type (electricity, gasoil, natural gas, propane or biomass) or a combination (gas-electricity, electricity-biomass, electricity-gasoil), the systems' installed capacity, and the number of units per system.

4.2.3. Measurement of emissions, cost and time of use

Theoretical CO_2 emissions for the different types of fuel were calculated according to the equivalence ratios specified in the *Plan de Energías Renovables en España 2011-2020* (Plan for Renewable Energy in Spain 2011-2020) (PER 2011-2012), as shown in Table 11, and the primary energy used, as calculated from official test data (PER 2011-2012).

The cost of using the different types of fuel, in €/kWh (Table 11), is the official cost recorded in regular reports published by the Spanish government (CNE. 2014, Geoportal. 2014, IDAE. 2014).

Finally, average figures for annual use, according to average conditions for the climate zone (Carpio et al. 2013), are those calculated by the *Instituto para la Diversificación y Ahorro de la Energía* (IDAE) (Institute for Energy Diversification and Saving) using statistical data for recent years. The following figures were used: cooling 360 hours/year; heating 1,500 hours/year; DHW 365 hours/year and heating+DHW 1,850 hours/year (IDAE. 2007a).

Table 11. Equivalence ratios and financial costs.

Fuel	CO_2 emissions (kg CO_2/kWh)	Cost (€/kWh)
Gasoil	0.287	0.109
Natural gas	0.204	0.059
Propane gas	0.254	0.111
Electricity (Iberian Peninsula)	0.649	0.130
Biomass	Neutral	0.058
Solar	0	0
Mixed (Gasoil-electricity)	0.468	0.119

4.2.4. European plan on climate change

In this chapter we are going to analyse the effects of applying measures designed to achieve the following objectives specified in the European Plan on Climate Change (EUCEP 2008-2020) to combat climate change: Reduce emissions of greenhouse gases by 20%, increase energy efficiency to save 20% of EU energy consumption and reach 20% renewable energy in total energy consumption in the EU by 2020.

4.3. Results and discussion

The results obtained from the records are shown in Tables 12 to 14 and Fig. 7 and 8. These results have been analysed in terms of: (i) breakdown of fuel use, (ii) environmental benefits and (iii) financial benefits of using biomass. These results are summarised and discussed in the sections below.

4.3.1. Breakdown of fuel use

Table 12 and Fig. 7 show installed capacity and the percentage of use for different fuel types, according to the system used (cooling, heating, DHW and heating+DHW), and the overall total. It can be seen that in terms of total installed capacity, natural gas, with ≈49% and 92,424 kW, is the most extensively used, followed by substantially lower figures for electricity and gasoil. The results also show that the use of renewable energies in the area is limited, following the trends observed in other studies (IEA. 2014);

biomass, at 4.31% (8,161 kW), is the most widely used renewable energy, while solar power only accounts for 0.19% (364 kW) of use.

Table 12. Breakdown of installed capacity by fuel type in the province of Granada.

Fuel	Cooling	Heating	DHW	H+DHW	Total
Gasoil	176.00	13,828.80	1,920.70	3,271.75	19,197.25
Natural gas	3,881.30	11,893.06	4,859.35	71,789.90	92,423.61
Propane gas	824.10	496.90	1,333.80	12,501.75	15,156.55
Electricity	23,508.05	1,075.54	12.80	3,343.60	27,939.99
Biomass	694.00	4,092.16	99.00	3,275.52	8,160.68
Solar	0.00	0.00	256.30	107.73	364.03
Mixed	8,543.36	3,630.61	834.10	12,504.39	25,512.46
Others	0.00	35.00	0.00	497.90	532.90
Total	37,626.81	35,052.07	9,316.05	107,292.54	189,287.47

Measurements in kW

The analysis of results by use (Fig. 7) shows that for cooling the source of energy used most is electricity (≈62%, 23,508 kW), while gasoil (≈39%, 13,829 kW) and natural gas (≈34%, 11,893 kW) are used most for heating. Finally, in the case of DHW and H+DHW, natural gas accounts for most use, at ≈52% and ≈67% respectively. Renewable energies account for only ≈5% of the overall total of 85,245 kW, the highest figure for the use of biomass being in heating at approximately 12% (4,092 kW), while its use for DHW is insignificant (≈1%, 99 kW). These percentages, observed within the area studied, follow the general world trends for renewable energies, which record 4.50% for the use of biomass in boilers and 0.4% for solar power (REN21. 2009).

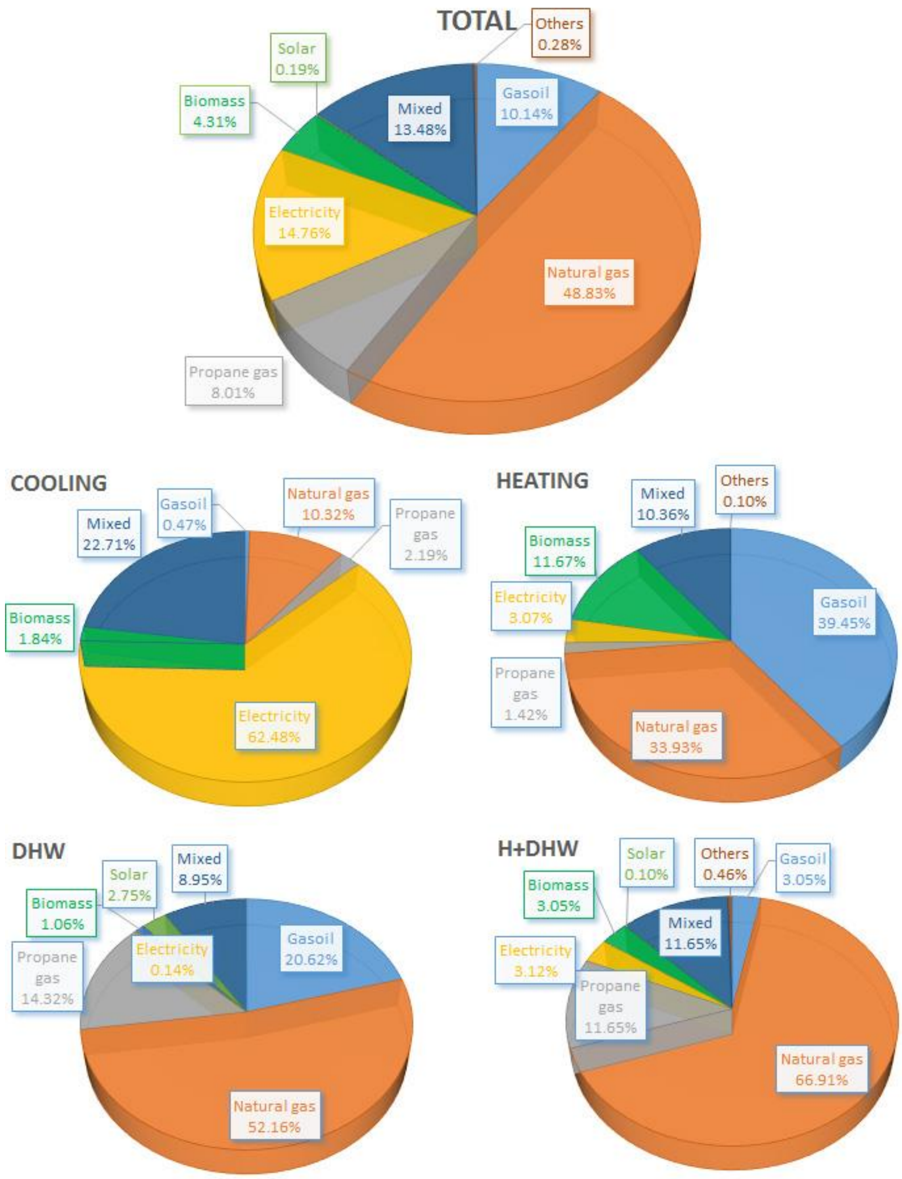

Fig. 7. Breakdown of fuel use in the province of Granada.

4.3.2. Environmental factors

The figures obtained for the use of different energy sources and the criteria described above for calculating CO_2 emissions were used to establish the emissions generated by the energy use included in the study (Table 13). It will be seen that the fuel generating most CO_2 emissions is natural gas, due to the large amount of equipment using this fuel, which accounts for 44.37%, followed by combined heating-oil and electricity, electricity, gasoil and propane gas, at 21.13%, 14.87%, 11.13% and 8.50% respectively. These results are similar to those of other European studies, concerning non-renewable fuels, which show the highest level of CO_2 emissions for gasoil at 37.40% of the total, followed by natural gas at 23.50%, percentages which depend on variables such as each country's reserves (EUCEP 2008-2020).

Table 13. CO_2 emissions by fuel type.

	Current situation							
Fuel	**Gasoil**	**Natural gas**	**Propane gas**	**Electricity**	**Biomass**	**Solar**	**Mixed**	**Total**
Colling	18	285	72	5,492	-	0	1,439	7,307
Heating	5,953	3,639	172	1,047	-	0	2,549	13,360
DHW	201	362	119	3	-	0	142	827
H+DHW	1,751	27,313	5,689	4,047	-	0	10,914	49,715
Total	7,924	31,599	6,052	10,590	-	0	15,045	71,210
	20-20-20 plan							
Fuel	**Gasoil**	**Natural gas**	**Propane gas**	**Electricity**	**Biomass**	**Solar**	**Mixed**	**Total**
Colling	15	239	61	4,613	-	0	1,209	6,138
Heating	5,001	3,057	144	879	-	0	2,141	11,222
DHW	169	304	100	3	-	0	120	695
H+DHW	1,471	22,942	4,779	3,399	-	0	9,167	41,759
Total	6,656	26,542	5,084	8,895	-	0	12,637	59,814

Measurements in t CO_2/year

Fig. 8 shows the changes required from the present until 2020 for CO_2 emissions in Granada to be reduced in line with the 20-20-20 targets (EUCEP 2008-2020). It can be seen that the installed capacity for renewable energies must increase from the current figure of 4.50% (4.31% biomass and 0.19% solar) to the 20% specified in the targets (19.15% biomass and 0.85% solar). To be a hypothesis, to achieve this an annual replacement rate of present systems by renewables of 3% is called for (Fig. 4).

To achieve the target specified in the 20-20-20 plan, in the area studied, an overall reduction in CO_2 emissions of 16.01% compared with current levels is required. The case of Spain can be compared with that of Sweden, where a 25% reduction in 1990 CO_2 emission levels was required. As a reduction of around 8% has been achieved, a further reduction of approximately 17% (Joelsson and Gustavsson. 2012) is necessary, very similar to the figure for Spain in this study.

Taking into account that CO_2 emissions are neutral for biomass, due to the life-cicle (Saidur et al. 2011), and they are zero for solar power (Florides et al. 2013), these sources of energy will always be a good choice. If it were feasible to change 100% of equipment to biomass, CO_2 emissions would be neutral. To ensure reductions in CO_2 emissions, many European countries favour biomass as an alternative to other fuels. Germany, France, Sweden and Finland are at the forefront with annual consumption of 10,000 kt, 9,000 kt, 7,000 kt and 6,000 kt respectively, while Spain is in seventh place with annual consumption of 4,000 kt (AEBIOM. 2013).

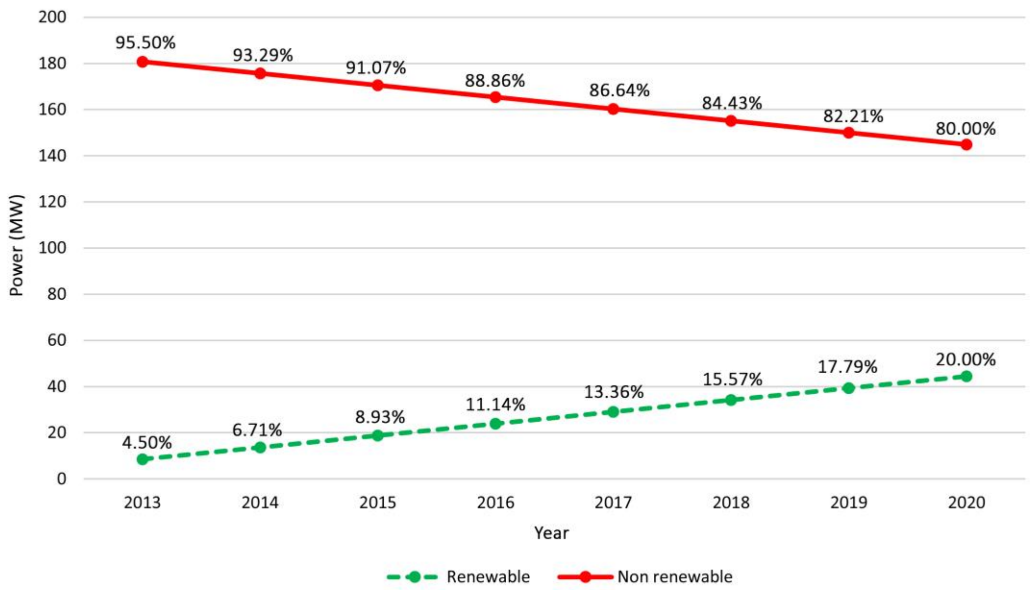

Fig. 8. Increases in renewable energy use needed to comply with 20-20-20 targets in the province of Granada.

4.3.3. Economic factors

Finally, with the costs shown in Table 11 and the information of the facilities of Tables 12 and 14,, savings for users resulting from compliance with the 20-20-20 targets

(EUCEP 2008-2020) have been calculated with 20% of energy requirements coming from renewables (19.15% biomass and 0.85% solar, proportional to current installations) (Table 14). Because the price of the facilities depended upon on several factors, only have been considered the cost of the different fuels. An overall saving of 12.99% can be seen, with similar figures for cooling, DHW and H+DHW (15.27%, 15.28% and 13.99% respectively), while there is a lower figure for heating at 7.62%.

Table 14. Comparative figures for boiler fuel (€/year).

	Current situation						
Fuel	**Gasoil**	**Natural gas**	**Propane gas**	**Electricity**	**Biomass**	**Mixed**	**Total**
Cooling	4,118	82,439	27,780	1,104,281	3,458	365,998	1,588,074
Heating	1,348,094	1,052,536	66,001	210,513	84,968	648,064	3,410,176
DHW	45,561	104,646	45,587	610	500	36,229	233,133
H+DHW	396,555	7,899,402	2,183,253	813,680	84,562	2,775,162	14,152,613
Total	1,794,328	9,139,022	2,322,621	2,129,084	173,489	3,825,452	19,383,996
	20-20-20 plan						
Fuel	**Gasoil**	**Natural gas**	**Propane gas**	**Electricity**	**Biomass**	**Mixed**	**Total**
Cooling	3,459	69,246	23,335	927,561	14,536	307,426	1,345,563
Heating	1,132,356	884,096	55,439	176,824	357,141	544,353	3,150,208
DHW	38,270	87,899	38,291	512	2,102	30,431	197,507
H+DHW	333,093	6,635,244	1,833,862	683,465	355,430	2,331,047	12,172,142
Total	1,507,178	7,676,485	1,950,927	1,788,362	729,210	3,213,257	16,865,419

Measurements in euros (€)

In the hypothetical case of replacing all systems by biomass, we calculate that savings would increase to 80.75%, a percentage similar to that quoted in other studies. If certain fuels are fully replaced by biomass, savings range from ≈70% to ≈87%, according to the type of biomass used (Carpio et al. 2013); other studies in central and northern Europe show savings of approximately 95%, while in southern Europe the replacement of fossil fuels by biomass would lead to savings of ≈75% (Pardo and Thiel. 2012); in the case of a study conducted in Ireland (Devlin et al. 2013), savings of ≈72% from the use of biomass are quoted.

4.4. Conclusions

This study has analysed the use of different types of fuel used in homes in Granada for cooling, heating and DHW. In view of the number of records considered and the climatic diversity of the area, we can consider it representative of the situation found in the rest of Spain.

We have seen that the source of energy used most extensively depends on the type of system, although there is a clear predominance of fossil fuels over renewable energies, especially natural gas which accounts for approximately half of total capacity in use. In the case of heating, the predominant source of energy is gasoil, used for approximately 40%, while natural gas accounts for 1/3 of the total. In cooling electricity is used most extensively (2/3 of the total). In all cases the use of renewable energies accounts for small percentages, irrespective of the system analysed.

These results show that we are a long way from meeting the first objectives set out in the 20-20-20 programme for the implementation of improved systems, even though their use would imply substantial environmental and economic benefits.

To meet the targets specified in the 20-20-20 programme, the use of biomass for domestic heating, cooling and DHW would involve the replacement of 20% of boilers currently installed in the area studied, leading to a reduction of approximately 16% in CO_2 emissions. These figures could be increased to 100% if all systems were changed to allow the use of biomass.

Finally, in terms of savings for users, compliance with 20-20-20 targets would lead to an estimated reduction in costs of 13%, which could rise to 81% if all conventional systems were replaced by those using biomass.

CHAPTER 5.-

IMPACT OF USING BIOMASS BOILERS ON THE ENERGY RATING AND CO_2 EMISSIONS OF RESIDENTIAL BUILDINGS[5]

[5] The results shown in this chapter were presented in: **Carpio, M.**, Zamorano, M., Costa, M., **Impact of using biomass boilers on the energy rating and CO_2 emissions of Iberian Peninsula residential buildings** (2013) *Energy and Buildings* 66 PP. 732 – 744.

5.1. Introduction

Energy use in residential buildings is responsible for about 1/3 of the total CO_2 emissions (Directive 2010/31/EU), however the use of renewable energy such as biomass is very beneficial to reduce these emissions. The estimation of the energy necessary to comply with the demands of a building under normal conditions of occupancy and functioning is known as the energy efficiency rating. By comparing a number of indicators of the mean energy use in model buildings of reference, a real building can be qualified and certified on an energy scale established for this purpose (RD 235/2013, RD 47/2007).

As shown in Table 1 of Chapter 1, in Portugal, the normative that regulates the energy rating of buildings was partially transposed through SCE (Decreto-Lei 78/2006), RSECE (Decreto-Lei 79/2006) and RCCTE (Decreto-Lei 80/2006). In the case of Spain, analogously, there are CTE (Orden FOM/1635/2013), RITE (RD 1027/2007) and Royal Decree 235/2013. Despite this legal framework, on the Iberian Peninsula, little attention was paid to the thermal performance of buildings, either during the design stage or during the construction so that a very significant percentage of buildings would fail current energy examinations. For instance, over 50% of the installed boilers run on fossil fuels (Eurostat. 2011). Given the need to reduce the CO_2 emissions, the use of renewable fuels, such as biomass, should be encouraged. At present, 80% of the world energy is supplied by fossil fuels and 14% comes from renewable sources, with 9.6% thereof coming from traditional biomass (Khan et al. 2009). This is an economically favorable alternative (Abulfotuh. 2007, Pardo and Thiel. 2012), which makes it possible to obtain beneficial energy ratings for the existing buildings.

This chapter concentrates on the impact of using biomass boilers on the energy rating and CO_2 emissions of Iberian Peninsula residential buildings. Related studies using thermal simulations have been conducted in a number of countries for various conditions. For example, Pisello et al. (Pisello et al. 2012) evaluated the influence of the climatic zone on the energy rating of buildings. Buratti et al. (Buratti et al. 2013) concluded that glazing systems and building orientation improves the thermal comfort and reduces the energy demand up to 67% in non-residential buildings. Studies in China (Cao et al. 2011), Spain (Ruiz and Romero. 2011) and United Kingdom (Wang et al. 2009) examined the energy efficiency performance in buildings using renewable energy sources for heating and DHW, including biomass (Cao et al. 2011, Ruiz and Romero. 2011) and solar DHW (Wang et al. 2009). Wang et al. (Wang et al. 2009) also applied passive design methods and advanced façade designs to minimize the load requirements for heating and cooling purposes through building energy simulations and analysis of the local climate data. All these studies analyzed factors affecting energy efficiency separately.

In this context, the specific objective of the present study is to determine the environmental and economic advantages of using biomass in systems for heating and DHW, as opposed to conventional energy sources, with reference to the energy rating of residential buildings on the Iberian Peninsula. Furthermore, this investigation allows determining the variables that bear the greatest influence on the energy rating of a building, and how the use of biomass can contribute to an improved rating. The study is conducted for six cities located in the Iberian Peninsula with different climatic conditions.

5.2. Material and Methods

5.2.1. *Simulation software used*

The Housing Ministry of Spain has an array of tools validated for rating energy use (Article 3 of Royal Decree 235/2013), which include CERMA (ATECYR. 2011), a software program based on two other well established methods, CALENER-VYP (Industria. 2010) and LIDER (Fomento. 2009). In the case of Portugal, there is no official computer program specifically developed for energy rating so that the software chosen for this study was also CERMA. As shown in Chapter 3, this software is not the most used by experts but more accurate results are obtained.

5.2.2. *Characteristics of the buildings studied*

The thermal simulations carried out using CERMA have allowed us to gather a vast amount of data. A number of construction characteristics, including geometry, orientation and materials, buildings location and local climate along with the type of fuel used in the systems for heating, DHW and cooling have been introduced. This section summarizes the main features of the buildings studied. The blueprints and measurements of the constructions were processed by means of Autocad (Autodesk. 2012).

5.2.2.1. *Geometry and materials*

Two types of buildings located in the Iberian Peninsula were selected: (i) a single-family house, and (ii) a multi-family residential building, placed among other constructions. Both types of dwelling, with the given surface areas and construction solutions, are representative of the current residential offer in Spain and Portugal, according to the census of residences of the National Statistical Institute of Spain (INE. 2013) and that of Portugal (INEPT. 2013), as well as with the reports published by professional associations of architects and technical architects, based on their official inspections (CGATE. 2014, CSCAE. 2014, Ordem dos Arquitetos. 2013).

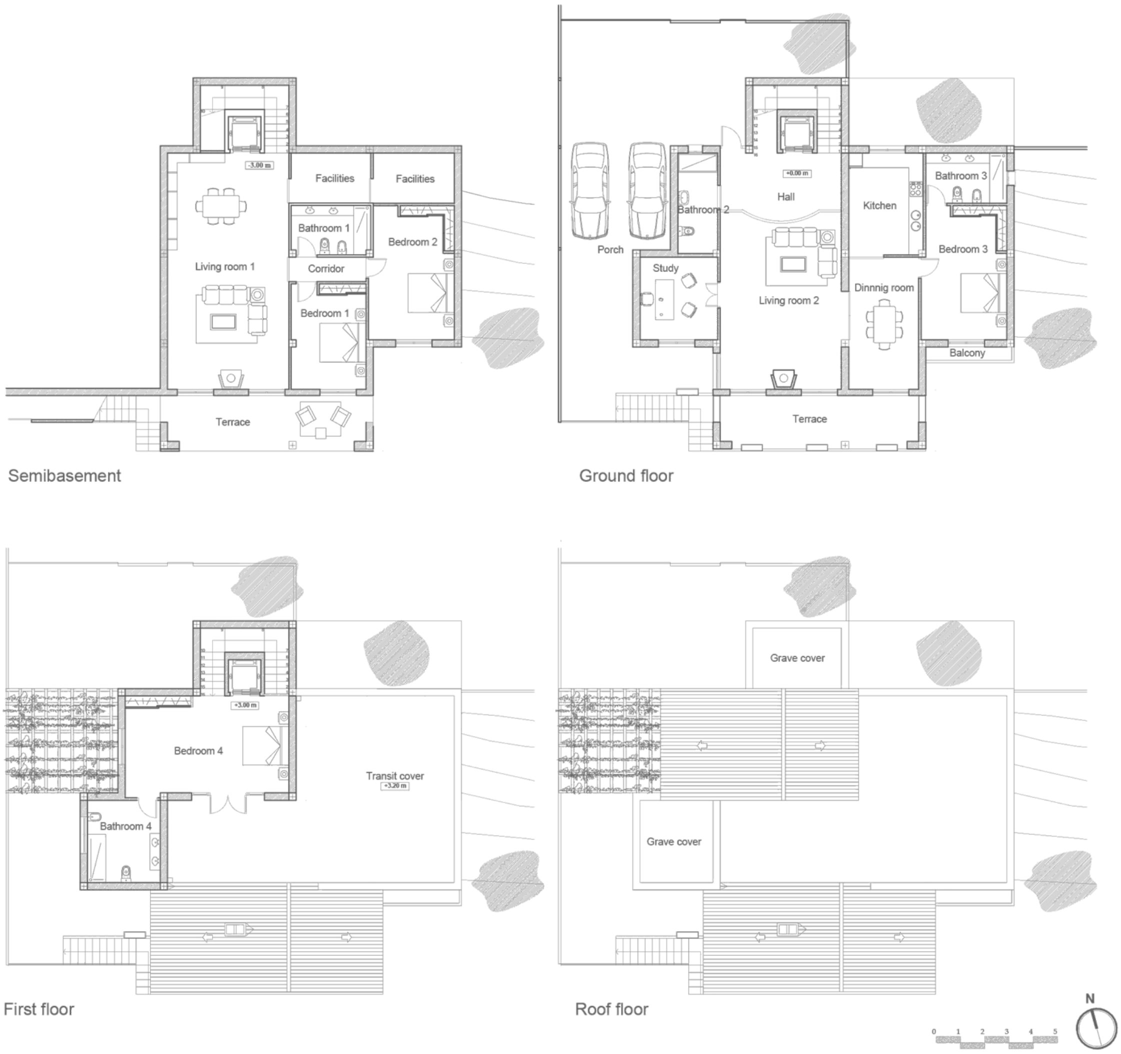

Fig. 9. Plan of the single-family house.

Fig. 9 shows the plan of the single-family house and Table 15 shows its main features. As can be seen, the single-family dwelling consists of three floors: a basement, a ground floor and a first floor. The house is located on a gentle slope, which means that the basement is completely underground on one side, yet above the ground on the other side of the house.

Similarly, Fig. 10 shows the plan of the residential building or multi-family dwelling and Table 15 shows its main features. It is seen that the residential building or multi-family dwelling has five stories: a ground floor, a first, a second and a third floor, and a tower. In this case, the building is a rectangle on a corner so that the north and east sides of it are fully in contact with other constructions, while the south and west façades are exposed.

Table 16 shows the elements and materials used in the buildings considered in this study. To ensure a low thermal transmittance limit (U), all the materials involved in the construction of the buildings have adequate thermal insulation. Emphasis is also placed on the thermal bridges, given their role in the heat losses; for instance, inadequate execution of exterior closures of a double brick wall can mean 30% more thermal losses (Theodosiou and Papadopoulos. 2008). For similar reasons, it is considered continuous insulation in the junctions with framework slab, and constant closure to the line of the doorjamb, lintel or windowsill.

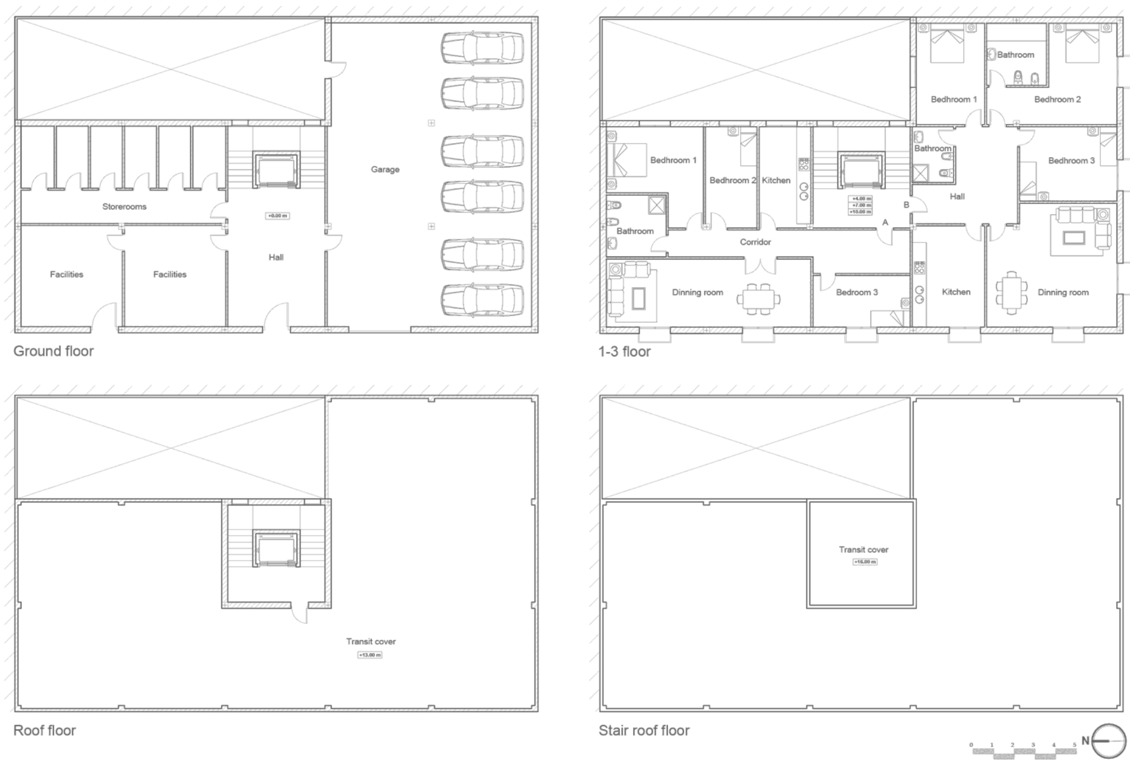

Fig. 10. Plan of the residential building or multi-family dwelling.

Table 15. Distributions of the areas in the buildings studied.

Usable area			
Single-family house		**Residential building**	
Dwelling	**Surface (m^2)**	**Dwelling**	**Surface (m^2)**
Semibasement		**Ground floor**	
Living room	48.04	Garage*	144.01
Facilities	13..77	Storerooms*	46.53
Corridor	3.18	Facilities*	48.47
Bedroom 1	12..51	Hall	31.51
Bedroom 2	17.42	Stair	9.94
Bathroom 1	6.60	**1-3 floor**	
Stairs	7.21	A-Living room	32.74
Ground floor		A-Kitchen	12.13
Living room	36.16	A-Bathroom	8.74
Dining room	15.70	A-Bedroom 1	17.97
Kitchen	13.00	A-Bedroom 2	12.13
Study	12.00	A-Bedroom 3	11.79
Bedroom 3	19.14	A-Corridor	12.25
Bathroom 2	6.90	B-Living room	36.01
Bathroom 3	6.90	B-Kitchen	17.15
Stairs	7.21	B-Bathroom 1	5.44
First floor		B-Bathroom 2	8.74
Bedroom 4	26.00	B-Bedroom 1	16.21
Bathroom 4	10.25	B-Bedroom 2	21.58
Semibasement	108.73	B-Bedroom 3	16.96
Ground floor	117.01	B-Hall	18.30
First floor	36.25	**Common Area**	
		Hall	9.02
		Stair	9.94
		Top floor	
		Transit cover	272.48
		Hall	9.02
		Stair	9.94
		Ground floor	41.45
		1-3 floor	801.30
		Top floor	18.96
Total usable	**261.99**	**Total usable**	**861.71**

**not computable for heating, DHW and cooling*

5.2.2.2. Boilers

For the thermal simulation at each building and city, boilers with similar characteristics, able to fire either gasoil, natural gas or biomass, have been chosen. The thermal load selected for each boiler was set to 24 kW. For the single-family house one boiler (24 kW) was considered, whereas for the multi-family dwelling three boilers were installed (total boiler load of 72 kW). For all boilers it was considered a thermal efficiency of 90%, with an outlet water temperature of 50 °C for DHW and 80 °C for heating. The flow rate of DHW in the single-family house was 235.80 liters/day, and in the multi-family dwelling 568.72 liters/day. Both residences have an accumulator; specifically with a capacity of 200 liters in the single-family house and 500 liters in the multi-family dwelling. In both cases the water temperature varied between 60 °C and 80 °C, with the global heat transfer coefficient (U×A) being 1 W/K.

The present study focus on the heating and DHW since this system uses fuel directly (gasoil, natural gas or biomass). Because the energy rating procedure calls for choosing a system of refrigeration as well, it is considered an electrical based refrigeration system, which is the most commonly used system in residential buildings in Spain and Portugal.

5.2.2.3. *Climatic zone, orientation and internal temperature*

Classification of the climatic zones where the present buildings are located accounts for the severity of the climate in winter and in summer, and the combined influence of outside temperature and solar radiation. The scale used depends on the country of the European Union considered (Kyoto 1997). For example, in France there are three separate zones, in Italy six, in Portugal three, and in Spain five. To establish a common criterion in order to compare the results, it was adopted as reference the CTE scale corresponding to Spain (González et al. 2011). Hence, for the winter five climate zones are considered, designated by the letters A through E, and for the summer four zones, designated by the numbers 1 through 4.

The buildings studied here are all located in the Iberian Peninsula; specifically in three Portuguese cities (Évora, Lisbon and Bragança), and in three Spanish cities (Almería, Granada and Burgos), as shown in Fig. 11. The selection process sought comparatively hot summer climates (Almería and Évora), cold winter climates (Burgos and Bragança) and moderate climates (Granada and Lisbon) (Decreto-Lei 78/2006, RD 314/2006), thereby covering most of the CTE climate classifications.

Fig. 11. Location of the cities studied.

In the case of the Spanish cities, the assignment was done automatically through the CTE DB-HE1, appendix D, Table D1; for the Portuguese cities, not included in the CTE, it was used appendix D, section 2, of the CTE DB-HE1 plus the climate records from Energy Plus (U.S. Department of Energy. 2012) —a program of thermal and energy simulation created by the US Department of Energy (DOE). Table 17 shows the equivalences that this procedure yielded.

Finally, an indoor temperature that would prove comfortable yet not wasteful in terms of energy was established; specifically, between 17 °C and 20 °C in winter, and between 24 °C and 26 °C in summer.

Table 16. Elements and materials used in the buildings studied.

System **Single-family house**	**U (W/m^{2}k)**	**Surface (m^2)**	**Orientation**	**Material**	**k (W/mK)**	**Thickness (m)**
Roof						
Roof 1	0.48	47.60		Ceramic tiles	1.00	0.006
he = 25.00 W/m^{2}K				Lime mortar for rendering d > 2000	1.80	0.024
he = 10.00 W/m^{2}K				Mortar lightweight aggregate [vermiculite perlite]	0.41	0.040
				Polyvinyl chloride [PVC]	0.17	0.001
				Mineral wool [0.04 W/[mK]]	0.04	0.060
				High Density Polyethylene [HDPE]	0.50	0.002
				Concrete with lightweight aggregate 1800<d<2000	1.35	0.100
				Floor structure	0.94	0.250
				Plaster rendering 1000 < d < 1300	0.57	0,015
				Total		**0.498**
Grave roof	0.43	19.30		Sand and gravel [1700 < d < 2200]	2.00	0.050
he = 25.00 W/m^{2}K				Sublayer felt	0.05	0.001
he = 10.00 W/m^{2}K				Polyvinyl chloride [PVC]	0.17	0.001
				Sublayer felt	0.05	0.001
				Extruded polystyrene, expanded with carbon dioxide [XPS] [0.034 W/[mK]]	0.03	0.060
				Low density polyethylene [LDPE]	0.33	0.020
				Concrete with lightweight aggregate 1800<d<2000	1.35	0.100
				Floor structure	0.94	0.250
				Plaster rendering 1000 < d < 1300	0.57	0.015
				Total		**0.498**
Sloping roof	0.45	36.90	W	Polyvinyl chloride [PVC]	0.17	0.001
he = 25.00 W/m^{2}K		24.70	E	Extruded polystyrene. expanded with carbon dioxide [XPS] [0.034 W/[mK]]	0.03	0.060
he = 10.00 W/m^{2}K				Low density polyethylene [LDPE]	0.33	0.002
				Floor structure	0.94	0.250
				Plaster rendering 1000 < d < 1300	0.57	0.015
				Total		**0.328**
External walls						
External Wall	0.54	69.00	N	Lime mortar for rendering d > 2000	1.80	0.015
he = 7.69 W/m^{2}K		66.80	W	6” perforated metric brick or Catalan brick 80 mm < G < 100 mm	0.54	0.115
		79.80	S	Slightly ventilated vertical air chamber	0.00	0.050
		91.40	E	Extruded polystyrene, expanded with carbon dioxide [XPS] [0.034 W/[mK]]	0.03	0.040
				Double hollow brick breeze-block [60 mm < E < 90 mm]	0.43	0.070
				Plaster rendering 1000 < d < 1300	0.57	0.015
				Total		**0.305**
Underground Wall	0.62	96.20		Ground		
Deep (m) = 1.00				6” perforated metric brick or Catalan brick 40 mm < G < 50 mm	0.99	0.115
he = 7.69 W/m2K				Lime mortar for rendering d > 2000	0.55	0.010
				Expanded polystyrene [EPS] [0.037 W/[mK]]	0.04	0.030
				Double hollow brick breeze-block [60 mm < E < 90 mm]	0.43	0.060
				Plaster rendering 1000 < d < 1300	0.57	0.010
				Total		**0.225**
Floor						
Ground floor -3.30	0.29	118.00		Tile	1.30	0.020
Deep (m) = 3.30				Expanded polystyrene [EPS] [0.037 W/[mK]]	0.04	0.043
Perimeter (m) = 48.70				Lime mortar for rendering d > 2000	0.55	0.010
he = 5.88 W/m^{2}K				Mass concrete 2000 < d < 2300	1.65	0.250
				Pressed adobe clay blocks [1770 < d < 2000]	1.10	0.020
				Ground		
				Total		**0.343**
Ground floor - 0.30	0.65	18.00		Tile	1.30	0.020
Deep (m) = 0.30				Expanded polystyrene [EPS] [0.037 W/[mK]]	0.04	0.043
Perimeter (m) = 21.80				Lime mortar for rendering d > 2000	0.55	0.010
he = 5.88 W/m^{2}K				Mass concrete 2000 < d < 2300	1.65	0.250
				Pressed adobe clay blocks [1770 < d < 2000]	1.10	0.020
				Ground		
				Total		**0.343**

d: density (kg/m3); E: thickness (mm)

Table 16. Elements and materials used in the buildings studied. Continuation.

System Residential building	U (W/m^2k)	Surface (m^2)	Orientation	Material	k (W/mK)	Thickness (m)
Roof						
Roof 1	0.48	272.5		Identical to single-family house		
Grave roof	0.43	20.1		Identical to single-family house		
External walls						
External Wall	0.54	144.60	N	Identical to single-family house		
		213.00	W			
		125.50	S			
		35.40	E			
Uninhabitable local	0.52	236.20		Plaster rendering 1000 < d < 1300	0.57	0.015
he = 7.69 W/m2K				Double hollow brick breeze-block [60 mm < E < 90 mm]	0.43	0.07
				Mineral wood [0.031 W/[mK]]	0.03	0.04
				Double hollow brick breeze-block [60 mm < E < 90 mm]	0.43	0.07
				Plaster rendering 1000 < d < 1300	0.57	0.015
				Total		**0.21**
Dividing Wall	0.52	267.8		Plaster rendering 1000 < d < 1300	0.57	0.015
he = 7.69 W/m2K				Double hollow brick breeze-block [60 mm < E < 90 mm]	0.43	0.07
				Mineral wool [0.031 W/[mK]]	0.03	0.04
				Double hollow brick breeze-block [60 mm < E < 90 mm]	0.43	0.07
				Plaster rendering 1000 < d < 1300	0.57	0.015
				Total		**0.21**
Floor						
Uninhabitable local	0.49	260.6		Ceramic tiles	1	0.06
he = 10.00 W/m2K				Plasterboard 750 < d < 900	0.25	0.012
				Plasterboard 750 < d < 900	0.25	0.012
				Mineral wool [0.04 W/[mK]]	0.04	0.03
				Floor structure	0.26	0.25
				Plaster rendering 1000 < d < 1300	0.57	0.015
				Total		**0.379**
Ground floor - 0.30 Deep (m) = 0.30 Perimeter (m) = 81.20 he = 5.88 W/m^2K	0.65	312.1		Identical to single-family house		

d: density (kg/m3); E: thickness (mm)

5.2.3. Energy rating

Not all European Union countries use the same criteria scale for energy ratings, and the number of levels can vary as well. For example, Austria has nine levels, Ireland has fifteen, and there are seven levels in Spain, France and Portugal (González et al. 2011). The scale used in this study comprises seven levels, the most efficient denoted by A, and the least efficient one designated by G. As no new buildings would have levels F or G, these are used only for renovated structures (IDAE. 2009b). Table 18 gives the upper and lower bounds of each energy level for each city and building type.

Table 17. Cities studied and climatic zone.

City	Country	Climatic zone (CTE)
Almería	Spain	A4
Lisbon	Portugal	B3
Évora	Portugal	C4
Granada	Spain	C3
Bragança	Portugal	D2
Burgos	Spain	E1

5.2.4. Economic considerations

In evaluating the costs of the different heating systems —gasoil and natural gas in conventional boilers; olive pit, pine chips and bulk wood pellets in biomass boilers— it was taken into account the prices of the different fuels as presented in (CNE. 2014, Geoportal. 2014, IDAE. 2014), without considering other factors such as their seasonal availability or geographic abundance. For instance, olive pit is only cost-effective if it is naturally available nearby the house since the cost of transport would be substantial (Saidur et al. 2011), while wood pellets may be costly but the supply can be guaranteed.

Table 18. Energy rating. Thresholds in the buildings and cities studied.

Single-family house						
City	**CZ**	**A**	**B**	**C**	**D**	**E**
Almería	A4	< 4.4	4.4 < 8.3	8.3 < 14.0	14.0 < 22.5	>= 22.5
Lisbon	B3	< 5.1	5.1 < 9.8	9.8 < 16.5	16.5 < 26.5	>= 26.5
Évora	C4	< 7.0	7.0 < 12.4	12.4 < 20.0	20.0 < 31.5	>= 31.5
Granada	C3	< 8.1	8.1 < 14.3	14.3 < 23.1	23.1 < 36.3	>= 36.3
Bragança	D2	< 9.6	9.6 < 15.8	15.8 < 24.5	24.5 < 37.7	>= 37.7
Burgos	E1	< 16.9	16.9 < 25.9	25.9 < 38.6	38.6 < 57.8	>= 57.8
Residential building						
City	**CZ**	**A**	**B**	**C**	**D**	**E**
Almería	A4	< 2.8	2.8 < 5.3	5.3 < 8.9	8.9 < 14.3	>= 14.3
Lisbon	B3	< 3.3	3.3 < 6.2	6.2 < 10.5	10.5 < 16.9	>= 16.9
Évora	C4	< 4.7	4.7 < 8.3	8.3 < 13.5	13.5 < 21.2	>= 21.2
Granada	C3	< 5.6	5.6 < 9.8	9.8 < 15.8	15.8 < 24.9	>= 24.9
Bragança	D2	< 6.5	6.5 < 10.7	10.7 < 16.6	16.6 < 25.5	>= 25.5
Burgos	E1	< 11.6	11.6 < 17.8	17.8 < 26.6	26.6 < 39.8	>= 39.8

Measured in kg CO_2/m^2 per year; CZ: climatic zone

Table 19 shows the characteristics of the fuels studied (gasoil, natural gas, olive pit, pine chips and wood pellets) as well as their unitary cost (CNE. 2014, Geoportal. 2014, IDAE. 2014). Based on the characteristics of each fuel and the demand of each residence, the total fuel needed was calculated. Then, based on the total fuel and cost per unit, the final cost was determined. These costs refer only to the annual fuel consumption, being the initial investment in the equipment and maintenance not considered here.

Table 19. Fuel characteristics.

Fuel	LHV	Density	Price
Gasoil	11.89 kWh/kg	850 kg/m^3	1.100 €/l
Natural gas	11.63 kWh/m^3	*n/n*	0.059 €/kWh
Olive pit	4.49 kWh/kg	*n/n*	0.060 €/kg
Pine chip	4.19 kWh/kg	*n/n*	0.0580 €/kg
Wood pellet	5.01 kWh/kg	*n/n*	0.170 €/kg

LHV: Lower heating value; n/n.: not necessary for this study

5.3. Results and Discussion

5.3.1. *Energy and environmental factors*

5.3.1.1. *Energy demand*

The indoor temperature of the residences is determined by the climate, season, and the heating/cooling system used. Fig. 12 displays the annual indoor temperature variation in Almería and Burgos, which are two cities with extremely cold climates. Burgos shows fairly even temperatures in all months of the year, except during summer, revealing that heating systems provide a very stable indoor temperature in winter (between 17 °C and 20 °C). During summer, temperatures are somewhat irregular since there is no need for cooling, with a mean temperature of 21 °C and a maximum of 24 °C. The lowest temperatures, in May and June (from 3,500 to 4,000 hours in Fig. 12), can be attributed to an interruption in the use of heating together with outdoor temperatures generally lower than 17 °C. In contrast, the dwellings situated in Almería show very irregular temperature during winter since the outdoor temperature often reaches 22 °C - 23 °C so that heating is not required, whereas during summer the indoor temperatures are regulated by the usual use of a cooling system.

Table 20 shows the energy demand, CO_2 emissions and energy rating in the buildings and cities studied. The energy demand data obtained through simulations of ideal and equivalent situations, using the CERMA software, indicate the objectives to attain in the blueprint stage; once a residence is occupied, the "user factor" affects significantly the results, depending on the residents´ particular habits, maintenance and use of the home. For example, two adjacent and identical dwellings can show up to 40% variability in their heating expenses due to excessive ventilation (Zabalza et al. 2009). This implies that real data may vary 50%-150% with regard to the theoretical calculations (UNE-EN 832).

Furthermore, minor modifications in the original configuration of the home could lead to considerable changes in energy demands. For instance, adding a glass protector of 0.35 mm provides for 6% savings in heating, but an increase of 6% in cooling. Moreover, modifying the color of the façade in view of the climate (e.g., a light color in hot climates) can lead to 2% savings in summer, but also to 2% losses during the winter in the south. Also, increasing openings in the north façade by 20% can lead to 5% savings in heating and 2% in cooling with respect to the original buildings (Ruiz and Romero. 2011).

All the houses studied in this study have the same essential features so that the only factor influencing the energy demand is the climatic zone, which has a great impact on the results. Table 20 reveals that the total energy demand ranges from 55.7 kWh/m^2 year in Almería to 164.1 kWh/m^2 year in Burgos for single-family houses, and from 44.7 kWh/m^2 year in Almería to 136.5 kWh/m^2 year in Burgos for multi-family residences. The variations are particularly high in the case of cities with harsher climates, where the heating demand is greater (Pardo and Thiel. 2012, Wang et al. 2009).

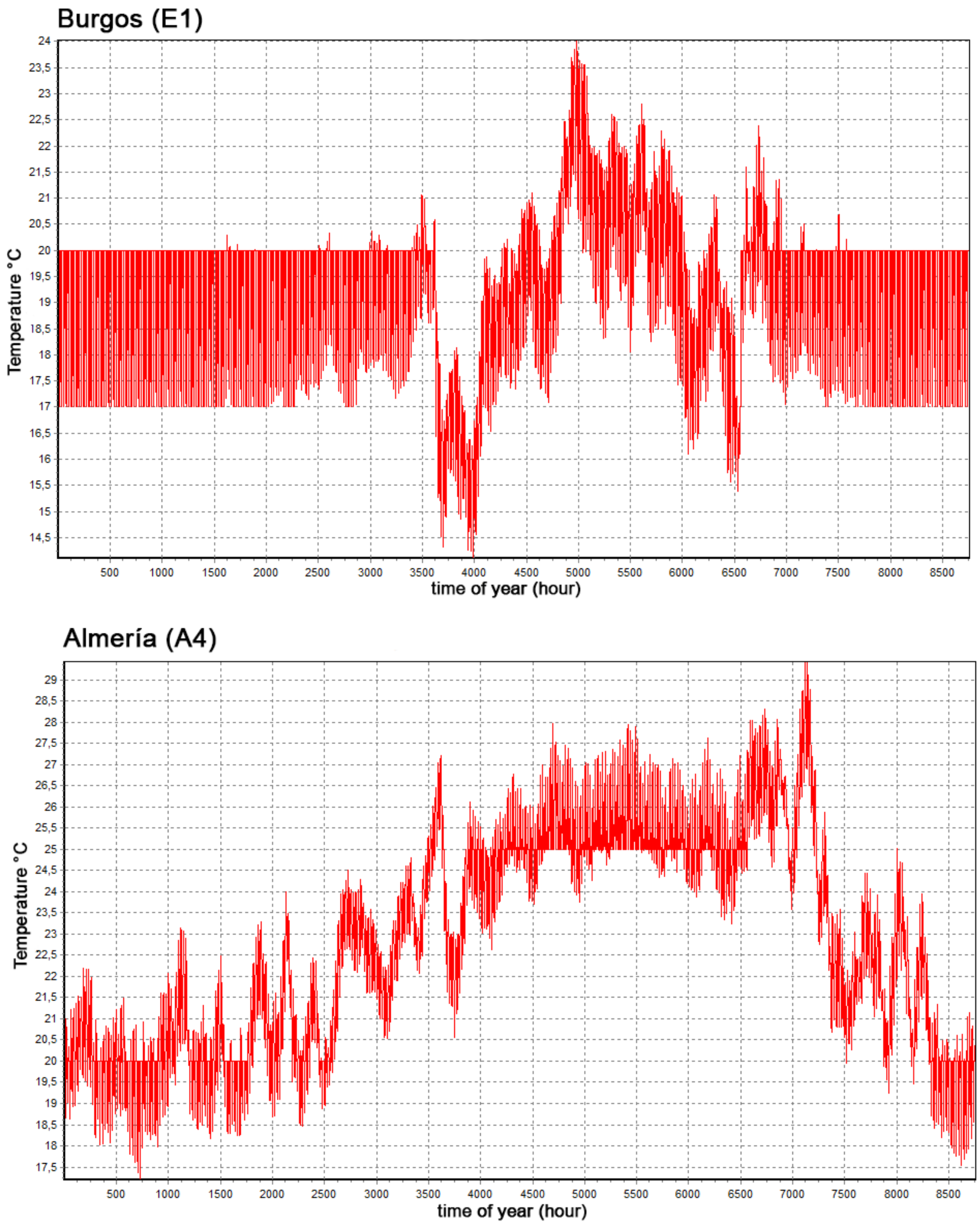

Fig. 12. Annual variation of the in-house temperature in the studied buildings located in Almería and Burgos.

It is also observed that the single-family house uses 20.22% to 24.61% more energy than the multi-family home, depending on the climatic zone. In fact, the enclosure of a building (m^2) and its volume (m^3) are 26% greater for the single-family residence, which means larger exposure to the elements. Accordingly, the total energy demand of the coldest city of the Iberian Peninsula considered here, with respect to the hottest one, is 294.6% greater for the single-family house, and 305.4% greater for the multi-family dwelling.

There is a progressive increase in energy demand from warmer to colder areas. The heating demand in Burgos is 1,048.9% greater than that in Almería for a single-family house, and 708.8% greater for a multi-family house. It may be concluded that energy demand for heating is inversely proportional to the winter outdoor temperatures.

In the case of cooling, Almería is the city with the greatest demand, requiring 204.4% more energy than the single-family residence in the second coldest city, Bragança, and 225.8% more than the multi-family house. Burgos was not included in this aspect of the study since it does not need cooling in the summer, when the outdoor temperature remains within the comfort zone. Hence, there is a progressive increase in the energy demand for cooling related to higher temperatures.

Finally, regarding DHW, the demand appears to depend largely upon the area of the living quarters. The influence of the climatic zone is minimal, giving differences between the two cities with extreme climates of 12.1% for the single-family unit and 12.5% for the multi-family unit.

Table 20. Energy demand, CO_2 emissions and energy rating in the buildings and cities studied.

	Single-family house											
	A4 Almería		**B3 Lisbon**		**C4 Évora**		**C3 Granada**		**D2 Bragança**		**E1 Burgos**	
Demand (kWh/m²year)												
Heating	13.7	C	32.5	D	47.2	D	62.3	D	76.5	D	143.7	D
Cooling	23.8	C	12.9	C	18.3	C	11.5	B	9.9	B		
DHW	18.2		18.7		18.8		18.8		19.2		20.4	
Total	55.7		64.1		84.3		92.6		105.6		164.1	
CO_2 emissions ($kgCO_2/m^2$year)												
Gasoil												
Heating	4.6	C	10.7	D	16.1	D	22.0	D	26.3	D	51.1	E
Cooling	9.1	D	4.9	D	7.0	D	4.4	D	3.8	C		
DHW	6.0	E	6.1	E	6.2	E	6.1	E	6.3	E	6.6	E
Total	19.7	D	21.7	D	29.3	D	32.5	D	36.4	D	57.7	D
Natural gas												
Heating	3.4	C	7.9	C	12.1	C	16.6	C	19.8	D	38.9	D
Cooling	9.1	D	4.9	D	7.0	D	4.4	D	3.8	C		
DHW	4.2	E	4.4	E	4.4	E	4.4	E	4.5	E	4.7	E
Total	16.7	D	17.2	D	23.5	D	25.4	D	28.1	D	43.6	D
Biomass												
Heating	0.5	A	1.0	A	2.1	A	3.4	A	3.6	A	8.8	A
Cooling	9.1	D	4.9	D	7.0	D	4.4	D	3.8	C		
DHW	0.0	A	0.0	A	0.0	A	0.0	A	0.0	A	0.0	A
Total	9.6	C	5.9	B	9.1	B	7.8	A	7.4	A	8.8	A
	Residential building											
	A4 Almería		**B3 Lisbon**		**C4 Évora**		**C3 Granada**		**D2 Bragança**		**E1 Burgos**	
Demand (kWh/m²year)												
Heating	17.1	E	35.5	E	46.8	E	60.9	E	72.0	E	121.2	E
Cooling	14.0	C	7.9	C	9.3	B	6.8	B	6.2	B		
DHW	13.6		14.0		14.1		14.0		14.4		15.3	
Total	44.7		57.4		70.2		81.7		92.6		136.5	
CO_2 emissions ($kgCO_2/m^2$year)												
Gasoil												
Heating	5.7	E	11.8	E	15.6	E	20.3	E	24.2	E	41.8	E
Cooling	5.3	D	3.0	D	3.5	C	2.6	C	2.4	C		
DHW	4.5	E	4.6	E	4.6	E	4.6	E	4.7	E	5.0	E
Total	15.5	E	19.4	E	23.7	E	27.5	E	31.3	E	46.8	E
Natural gas												
Heating	4.3	D	8.9	D	11.8	D	15.3	D	18.4	D	32.1	D
Cooling	5.3	D	3.0	D	3.5	C	2.6	C	2.4	C		
DHW	3.2	E	3.3	E	3.3	E	3.3	E	3.3	E	3.5	C
Total	12.8	D	15.2	D	18.6	D	21.2	D	24.1	D	35.6	D
Biomass												
Heating	0.9	B	1.9	B	2.4	A	3.2	A	4.1	B	8.0	A
Cooling	5.3	D	3.0	D	3.5	C	2.0	C	2.4	C		
DHW	0.0	A	0.0	A	0.0	A	0.0	A	0.0	A	0.0	A
Total	6.2	C	4.9	B	5.9	B	5.2	B	6.5	A	8.0	A

H: Heating; DHW: Domestic hot water

5.3.1.2. *CO_2 emissions*

Table 20 also shows the CO_2 emissions, expressed in kg CO_2/m^2 year, released to the atmosphere by the residential units, as a consequence of the energy demands, calculated using the CERMA software. The emissions due to the heating systems are much higher for the coldest city studied, regardless of the type of house, with values ranging from 0.5 kg CO_2/m^2 year using biomass in the single-family house in Almería to 51.1 kg CO_2/m^2 year for the single-family house in Burgos using gasoil. Some variation maybe attributed to the type of fuel used. The single-family house shows an increase of 1,110.9% in CO_2 emissions with gasoil, 1,144.1% with natural gas, and 1,760.0% with biomass; whereas in the multi-family residential building, the increases are 733.3%, 746.5% and 888.8%, respectively.

Gasoil is the fuel that releases more CO_2 during its combustion for the purpose of heating and DHW (Pardo and Thiel. 2012), while biomass is the most favorable fuel from CO_2 emissions point of view (Dion et al. 2011, Joelsson and Gustavsson. 2012, Pardo and Thiel. 2012). Table 21 compares the CO_2 emissions from systems using gasoil, natural gas and biomass. It is seen that the use of natural gas, instead of gasoil, for heating and DHW purposes leads to CO_2 emissions that are lower in 23.93% to 28.30%, respectively. Other authors (Ruiz and Romero. 2011) studied the CO_2 emissions for a single-family house using different types of fuels in the same climatic zone (C3), arriving at savings with natural gas, as compared with gasoil, that amounted to 31.31% (Ruiz and Romero. 2011). This figure is consistent with the value 24.55% obtained in this study. The small discrepancy is, most likely, due to differences in the geometry, orientation and construction materials of the buildings considered.

Table 21. CO_2 emissions from systems using gasoil, natural gas and biomass.

	Single-family house					
	A4 Almería	**B3 Lisbon**	**C4 Évora**	**C3 Granada**	**D2 Bragança**	**E1 Burgos**
Natural gas vs gasoil						
Heating	26.09%	26.17%	24.84%	24.55%	24.71%	23.87%
H + DHW	28.30%	26.79%	26.01%	25.27%	25.46%	24.44%
H + DHW + Cooling	15.23%	20.74%	19.80%	21.85%	22.80%	24.44%
Biomass vs gasoil						
Heating	89.13%	90.65%	86.96%	84.55%	86.31%	82.78%
H + DHW	95.28%	94.05%	90.58%	87.90%	88.96%	84.75%
H + DHW + Cooling	51.27%	72.81%	68.94%	76.00%	79.67%	84.75%
	Residential building					
	A4 Almería	**B3 Lisbon**	**C4 Évora**	**C3 Granada**	**D2 Bragança**	**E1 Burgos**
Natural gas vs gasoil						
Heating	24.56%	24.58%	24.36%	24.63%	23.97%	23.21%
H + DHW	26.47%	25.61%	25.25%	25.30%	24.91%	23.93%
H + DHW + Cooling	17.42%	21.65%	21.52%	22.91%	23.00%	23.93%
Biomass vs gasoil						
Heating	84.21%	83.90%	84.62%	84.24%	83.06%	80.86%
H + DHW	91.18%	88.41%	88.12%	87.15%	85.81%	82.91%
H + DHW + Cooling	60.00%	74.74%	75.11%	81.09%	79.23%	82.91%

H: Heating; DHW: Domestic hot water

Ruiz and Romero have also compared other fuels with gasoil. They obtained CO_2 emissions 16.68% higher with the use of coal, and 118.51% higher with the use of electricity (Ruiz and Romero. 2011). In addition, the present study shows that replacing gasoil by biomass leads to reductions in the CO_2 emissions that range from 82.91% to 95.28%. Similar results have been obtained by Pardo and Thiel who reported reductions of around 95% in CO_2 emissions using biomass for the Southern Europe, compared with conventional fossil fuel fired-systems (Pardo and Thiel. 2012).

Note that comparative studies such as that of Ruiz and Romero analized the CO_2 emissions solely in an exclusive climatic zone, while the present study examined a number of variables, namely, six different climate zones, renewable fuels and two types of constructions (single-family house and multi-family dwelling) to allow for more comprehensive comparisons (Ruiz and Romero. 2011).

The present study reveals that the replacement of gasoil by any other fuel for heating and DHW purposes reduces the CO_2 emissions, although the use of biomass is the most favorable. This is a very noteworthy finding since natural gas is nowadays extensively used in the Iberian Peninsula —18.96% of homes in Portugal (ERSE. 2013) and 24.5% in Spain (Industria. 2014).

Returning to Table 20, it is seen that the CO_2 emissions per square meter of living quarters are 1.4 to 1.9 higher for the single-family house than for the multi-family home in equivalent conditions. As discussed earlier regarding the energy demand, the structural characteristics of the single-family residence lead to larger exterior exposure.

Table 21 indicates that the CO_2 emissions from heating and DHW for the single-family units are quite similar to those for the multi-family unit when using gasoil. Consequently, it is the type of fuel and the climatic zone that determine the CO_2 emissions. For both types of buildings studied here, it is seen that the warmer the city, the greater the CO_2 emissions reduction, regardless of the fuel type. This tendency towards savings is reversed when cooling by electricity is included, i.e., savings in CO_2 emissions are higher in the colder cities.

To sum up and in order to assess the long term CO_2 emissions, Fig. 13 and 14 show the accumulated CO_2 emissions resulting from the three fuels studied, based on an estimated useful life of 50 years for the buildings (RD 1247/2008). It is seen that the CO_2 emissions per square meter are higher for the single-family house regardless of the fuel used (again, because of its exposure). It is also noted that the differences in CO_2 emissions from one climatic zone to another one depend not only on the energy demand, but also on the fuel type. Accordingly, for the single-family unit (Fig. 13), the CO_2 emissions resulting from the use of gasoil are higher than those resulting from the other fuels, reaching a value as high as ≈700 tons of CO_2 (57.7 kg CO_2/m^2 year) emissions accumulated over 50 years in Burgos. Yet, the accumulated CO_2 emissions for the use of biomass in the same scenario would yield just ≈60 tons of CO_2 (8.8 kg CO_2/m^2 year). The multi-family unit (Fig. 14) yields analogous results, originating ≈1,800 tons of CO_2 (46.8 kg CO_2/m^2 year) emissions in Burgos using gasoil, noting that during the entire useful life of the building the amount of CO_2 emissions would be ≈200 tons (8.0 kg CO_2/m^2 year) using biomass.

5.3.1.3. *Energy rating*

The CERMA software, based on existing legislation, marks the rating interval determined for buildings under consideration based on a calculation with respect to a model building and other reference data such as, for example, housing units available in Spain in the year 2006. Table 20 also displays the energy rating for the buildings and cities studied. It is seen that the threshold limits of the levels of energy ratings depend on the type of residence, climatic zone, and fuels used.

Improvement in the energy rating of a building is directly related with the fuel type. Gasoil and natural gas imply the assignment of rating D for single-family dwellings, and E for multi-family units in all six cities studied here. In the case of biomass, the rating depends on climate, but is independent of the housing type, with improvements associated with the lower winter mean temperatures, which may result in upgradings up to four levels, i.e., C would be the rating in the case of the hottest city, A in the coldest three cities, and B for the remaining cases.

Pérez-Lombard described the existing thresholds for the energy rating (Pérez-Lombard et al. 2009), including those those established in the Royal Decree 235/2013. Note that similar results for reductions in the CO_2 emissions may lead to different energy ratings according with the scale used because of the different number of categories in the different methods. For example, the Royal Decree 235/2013 has three savings categories (A, B and C), the CEN method (UNE-EN 15217) has two (A and B) and the Building Research Establishment Environmental Assessment Methodology (BREEAM) method (BRE. 2013) has a total amount of 15 (1 to 15).

5.3.2. *Economic factors*

To determine the costs involved in using the heating systems with the different fuels an economic analysis has been performed. Bearing in mind the fuel costs (Table

19) and the energy demand (Table 20), costs were evaluated for heating and DHW, alone and together, for each housing type in all cities considered. Table 22 summarizes the results of this analysis. It is seen that costs are directly related with the energy demand. In regard to the most economical city, Almería, the following results were obtained, regardless of the fuel used: (i) for single-family unit, costs in Lisbon were 60.50% higher, in Évora 106.90%, in Granada 154.30%, in Bragança 300.00% and in Burgos 414.42%; and (ii) for multi-family unit, costs in Lisbon were 61.24% higher, Évora 98.37%, Granada 143.97%, Bragança 181.43% and Burgos 344.62%.

It should stressed that the savings achieved by changing the gasoil by bulk wood pellets is 68.82%, by pine chips is 87.28%, and by olive pit is 87.72%. The use of natural gas instead of gasoil yield savings of 54.21%. Therefore, it may be concluded that the most economic fuel is generally biomass, although savings will depend on the type of biomass used (Fig. 15). Other studies have determinated savings of ≈95% in the Central and Northern Europe and ≈75% in the case of Southern Europe regions in comparison with conventional systems (Pardo and Thiel. 2012). These results in Southern Europe are similar to those obtained in this study.

Finally, in the warmest city of the Iberian Peninsula considered in this study (Almería), the annual production cost of DHW using any of the fuels considered here is higher than the cost of heating. This result was obtained only for the single-family house in Almería. In the remaining cities studied, the cost of heating is always higher than that of DHW. As discussed earlier, DHW is less conditioned by the atmospheric climate than is heating, so that the differences are minimal.

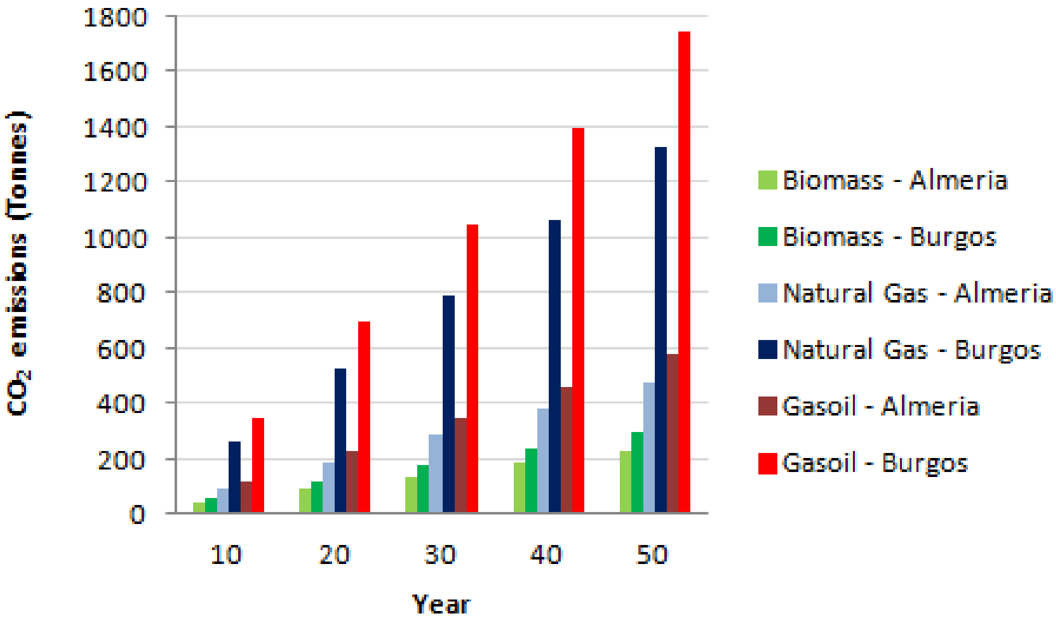

Fig. 13. Accumulated CO_2 emissions during a 50 years period for the single-family house.

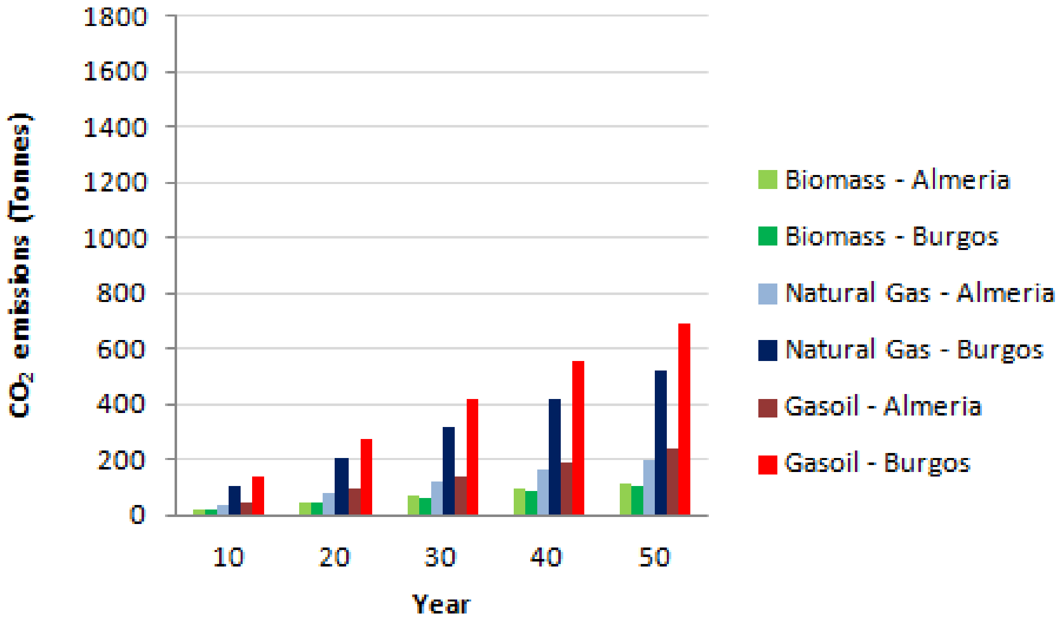

Fig. 14. Accumulated CO_2 emissions during a 50 years period for the residential building.

Table 22. Total annual cost of the different fuels.

	Single-family house											
	A4 Almería		**B3 Lisbon**		**C4 Évora**		**C3 Granada**		**D2 Bragança**		**E1 Burgos**	
	liters	**€**	**liters**	**€**	**liters**	**€**	**liters**	**€**	**liters**	**€**	**liters**	**€**
Gasoil												
Heating	327.12	359.84	776.03	853.63	1127.03	1239.73	1487.58	1636.34	1826.64	2009.31	3431.23	3774.35
DHW	434.57	478.03	446.51	491.16	448.90	493.79	448.90	493.79	458.45	504.30	487.11	535.82
H + DHW	761.70	837.87	1222.54	1344.79	1575.93	1733.52	1936.48	2130.13	2285.10	2513.61	3918.33	4310.16
	m³	**€**	**m³**	**€**	**m³**	**€**	**m³**	**€**	**m³**	**€**	**m³**	**€**
Natural gas												
Heating	284.27	195.06	674.37	462.73	979.39	672.03	1292.71	887.02	1587.36	1089.20	2981.74	2045.98
DHW	377.65	259.13	388.02	266.25	390.10	267.67	390.10	267.67	398.40	273.37	423.30	290.45
H + DHW	661.92	454.19	1062.39	728.98	1369.49	939.70	1682.81	1154.69	1985.75	1362.57	3405.04	2336.44
	kg.	**€**	**kg.**	**€**	**kg.**	**€**	**kg.**	**€**	**kg.**	**€**	**kg.**	**€**
Olive pit												
Heating	736.32	44.18	1746.75	104.80	2536.82	152.21	3348.38	200.90	4111.58	246.69	7723.31	463.40
DHW	978.18	58.69	1005.05	60.30	1010.43	60.63	1010.43	60.63	1031.93	61.92	1096.42	65.79
H + DHW	1714.50	102.87	2751.80	165.11	3547.24	212.83	4358.81	261.53	5143.50	308.61	8819.74	529.18
Pine chip												
Heating	789.04	45.76	1871.81	108.57	2718.45	157.67	3588.12	208.11	4405.96	255.55	8276.30	480.03
DHW	1048.22	60.80	1077.01	62.47	1082.77	62.80	1082.77	62.80	1105.81	64.14	1174.92	68.15
H + DHW	1837.26	106.56	2948.83	171.03	3801.22	220.47	4670.90	270.91	5511.77	319.68	9451.22	548.17
Wood pellet												
Heating	659.90	112.18	1565.45	266.13	2273.51	386.50	3000.85	510.14	3684.83	626.42	6921.69	1176.69
DHW	876.65	149.03	900.74	153.13	905.55	153.94	905.55	153.94	924.82	157.22	982.62	167.05
H + DHW	1536.55	261.21	2466.18	419.25	3179.07	540.44	3906.40	664.09	4609.65	783.64	7904.31	1343.73
	Residential building											
	A4 Almería		**B3 Lisbon**		**C4 Évora**		**C3 Granada**		**D2 Bragança**		**E1 Burgos**	
	liters	**€**	**liters**	**€**	**liters**	**€**	**liters**	**€**	**liters**	**€**	**liters**	**€**
Gasoil												
Heating	1259.54	1385.50	2614.84	2876.33	3447.17	3791.89	4485.74	4934.32	5303.34	5833.68	8927.29	9820.02
DHW	1001.74	1101.92	1031.21	1134.33	1038.57	1142.43	1031.21	1134.33	1060.67	1166.74	1126.96	1239.66
H + DHW	2261.29	2487.42	3646.05	4010.65	4485.74	4934.32	5516.95	6068.65	6364.01	7000.41	10054.26	11059.68
	m³	**€**	**m³**	**€**	**m³**	**€**	**m³**	**€**	**m³**	**€**	**m³**	**€**
Natural gas												
Heating	1094.55	751.05	2272.31	1559.19	2995.60	2055.49	3898.12	2674.78	4608.62	3162.30	7757.84	5323.20
DHW	870.52	597.32	896.12	614.89	902.52	619.28	896.12	614.89	921.72	632.46	979.33	671.99
H + DHW	1965.06	1348.37	3168.43	2174.08	3898.12	2674.78	4794.24	3289.67	5530.34	3794.76	8737.17	5995.19
	kg.	**€**	**kg.**	**€**	**kg.**	**€**	**kg.**	**€**	**kg.**	**€**	**kg.**	**€**
Olive pit												
Heating	2835.10	170.11	5885.73	353.14	7759.21	465.55	10096.92	605.82	11937.25	716.23	20094.37	1205.66
DHW	2254.81	135.29	2321.13	139.27	2337.71	140.26	2321.13	139.27	2387.45	143.25	2536.67	152.20
H + DHW	5089.91	305.39	8206.86	492.41	10096.92	605.82	12418.05	745.08	14324.70	859.48	22631.03	1357.86
Pine chip												
Heating	3038.09	176.21	6307.14	365.81	8314.76	482.26	10819.85	627.55	12791.94	741.93	21533.10	1248.92
DHW	2416.26	140.14	2487.32	144.26	2505.09	145.30	2487.32	144.26	2558.39	148.39	2718.29	157.66
H + DHW	5454.34	316.35	8794.46	510.08	10819.85	627.55	13307.17	771.82	15350.33	890.32	24251.39	1406.58
Wood pellet												
Heating	2540.83	431.94	5274.83	896.72	6953.86	1.182.16	9048.94	1.538.32	10698.25	1.818.70	18008.72	3061.48
DHW	2020.78	343.53	2080.22	353.64	2095.07	356.16	2080.22	353.64	2139.65	363.74	2273.38	386.47
H + DHW	4561.62	775.47	7355.05	1.250.36	9048.94	1.538.32	11129.15	1.891.96	12837.90	2.182.44	20282.10	3447.96

Gasoil: 1.10 €/l; Natural gas: 0.059 €/kWh; Olive pit: 0.06 €/kg; Pine chip: 0.058 €/kg; Wood pellet: 0.17 €/kg

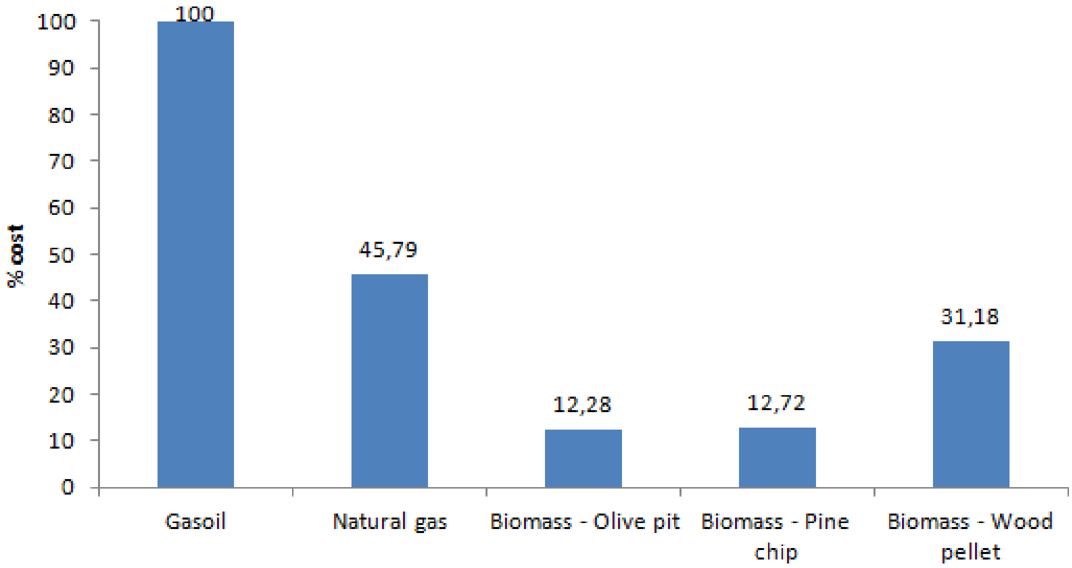

Fig. 15. Costs. Gasoil is the reference fuel.

5.4. Conclusions

This study led to the conclusion that the use of biomass in heating and DHW residential systems presents important advantages as follows: (i) reduces the environmental costs since releases significantly less CO_2; (ii) provides a very favorable energy rating; (iii) originates important economic savings. Moreover it was found that (iv) the energy demands is significantly affected by the climatic zone and the type of dwelling.

The CO_2 emissions depend directly on the climatic zone, where the house is located, in addition to the fuel used. Gasoil was found to yield the higher CO_2 emissions, regardless of the housing type. However, the use of biomass, instead of gasoil or natural gas, brings about an important reduction of the CO_2 emissions in all cases. Specifically, if gasoil is replaced by biomass reductions in CO_2 emissions of 95.25% for single-family units and 91.18% for multi-family units are achieved. Bearing in mind that 40% of the energy consumed in Europe and 36% of the CO_2 emissions to the atmosphere are produced by buildings dedicated to living quarters, the choice of fuel stands as a significant factor in evaluating emissions derived from heating and DHW.

Using biomass for heating purposes enhances the energy rating of the housing units in all cases. In the best case scenario, improvements are of four points on the scale of residential energy performance, which would put the unit into the top category, A. In comparison, with the use of fossil fuels, the best rating is D for the single-family residence and E for the multi-family one.

Cost-effectiveness is another important area where savings by means of solid biofuels are noteworthy. In comparison with gasoil, the use of wood pellets can lead to economic savings of up to 70%, and approximately 88% when wood chips or olive pits are used.

Finally, in regard to the energy demands of a residence, the climatic zone is clearly a determinant factor. The coldest cities on the Iberian Peninsula may require ten times more energy than the warmest ones, to satisfy heating demand. Likewise, for a joint demand of heating, DHW and cooling, consumption would be three times higher in a cold city. A single-family house, more exposed to the elements, proved to have substantially more energy requirements than a multi-family dwelling.

CHAPTER 6.-

IMPACT OF THE ENVELOPE DESIGN OF RESIDENTIAL BUILDINGS ON THEIR ACCLIMATION ENERGY DEMAND, CO_2 EMISSIONS AND ENERGY RATING[6]

[6] The results shown in this chapter were presented in: **Carpio, M.**, García-Maraver, A., Ruiz, D.P., Martín-Morales, M., **Impact of the envelope design of residential buildings on their acclimation energy demand, CO_2 emissions and energy rating** (2014) *WIT Transactions on Ecology and the Environment* 186 V. 1 PP. 387-398.

6.1. Introduction

As we have introduce previously, one of the aspects that affects to the energy rating in a building is the design of the envelope. In this sense the EPBD (Directive 2010/31/EU) has laid down the application of *"minimum requirements to the energy performance of building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are retrofitted or replaced"*. In consequence, as shown in Chapter 1, different transpositions of the EPBD for each European country (EU-28 and Norway) have considered the energy performance of the building envelope, with the common objective of achieving a NZEB able to combine both comfort and minimum energy consumption (Carpio et al. 2014a).

Previous researches have primarily focused on the improvement of the energy efficiency of currently existing envelopes in private and public buildings considering the weather as much in summer as in winter (Fang et al. 2014, Friedman et al. 2014, Güçyeter and Günaydın. 2012, Huang et al. 2014, Nagy et al. 2014, Pisello et al. 2014, Wang et al. 2014). Nevertheless, the construction techniques to improve an existent envelope differ from those that can be applied to new construction units.

Considering this point, the aim of the present study is to study how the different constructive solutions affect the thermal envelope of residential buildings under different climate conditions. In addition, it analyses the influence of the thermal envelope design in the energy demand, CO_2 emissions and energy rating of two different types of buildings located in six climatic zones.

6.2. Material and methods

6.2.1. Envelope of the buildings

6.2.1.1. Composition

The thermal envelope of a building is composed by the elements represented in Fig. 16, which includes all the enclosures that mark out the habitable spaces from the outside, and the interior partitions, which demarcate the living spaces from the non-habitable spaces in contact with the outside (Orden FOM/1635/2013).

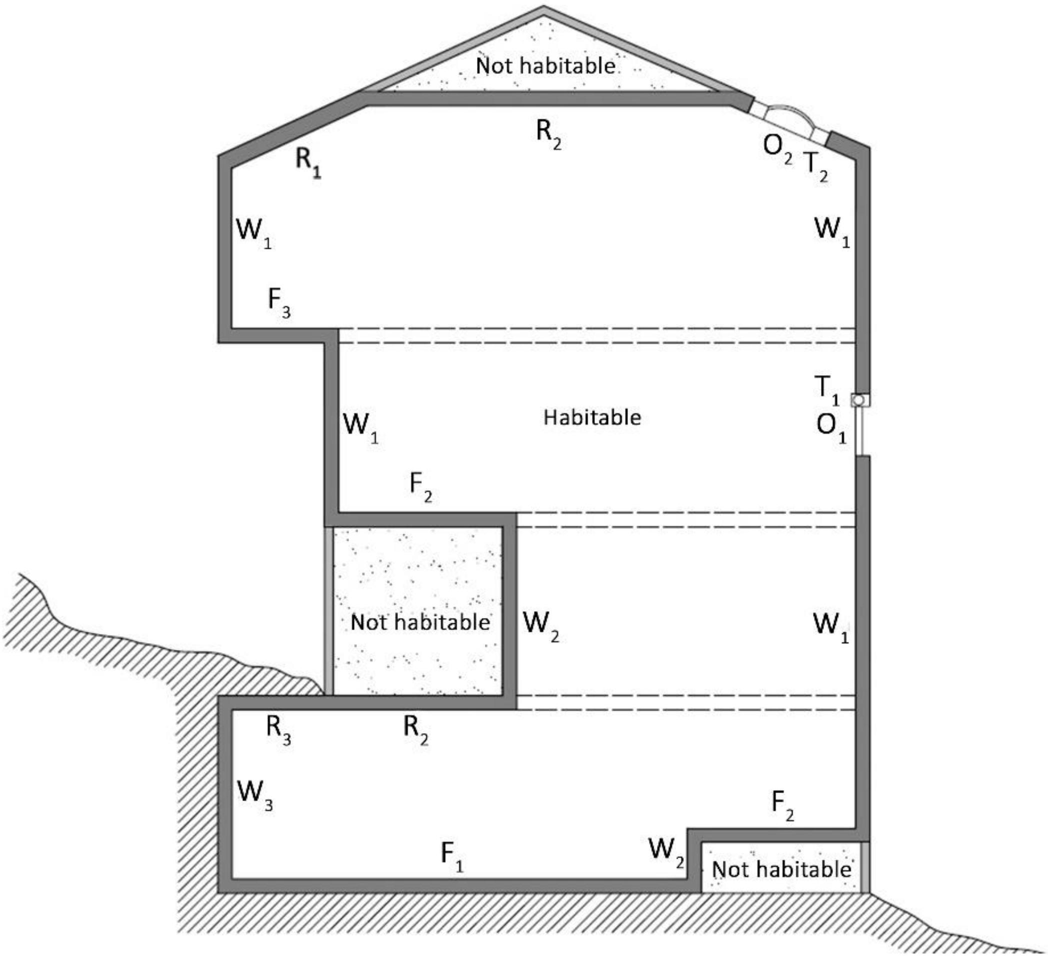

Fig. 16. Composition of the thermal envelope of a building: Vertical external walls (W); Horizontal roofs (R); Floors (F); Openings (O); and Thermal bridges (T) (RD 314/2006).

6.1.1.1. Thermal transmittance

Thermal transmittance, also known as U-value, is defined as the rate of transfer of heat under uniform conditions through one square metre of a structure, divided by the difference in temperature across the structure (the lower the U-value, the better the insulating ability). It is expressed in W/m^2 K and can be calculated by Eq.. (2) and (3), where: R_{si} is the inside resistance; R_{se} is the external resistance; and R_t is the thermal resistance of the construction material (m^2 K/W), which is formed by thermally homogeneous layers with their own resistances (R_1, R_2…R_n).

$$U = \frac{1}{R_{si} + R_t + R_{se}}$$

Eq. 2. U-value (Thermal transmittance).

$$R_t = R_1 + R_2 + R_3 + .. + R_n$$

Eq. 3. Total thermal resistance..

R-value is the thermal resistance of a solid material to conductive heat transfer (the higher the number, the better the building insulation's theoretical effectiveness).

$$R = \frac{e}{\lambda}$$

Eq. 4. R-value (Thermal resistance).

This energy flow is produced when there is a difference between the inside temperature and the temperature outside, and can be calculated by Eq. (4), where: e is the thickness of the material (m); and λ is the thermal conductivity (W/mK).

6.1.2. Buildings characteristics

6.1.2.1. Description of buildings

Two types of buildings were selected to develop this study: (i) a single-family house; and (ii) a multi-family residential building placed among other constructions. These buildings are more accurately described in the previous chapter (Fig. 9 and 10 and Table 15). In this section a summary is displayed.

The single-family dwelling consists of three floors with total usable area 261.99 m^2: a basement (108.73 m^2), a ground floor (117.01 m^2) and a first floor (36.25 m^2). The house is located on a gentle slope, which means that the basement is completely underground on one side, yet above the ground on the other side of the house.

The multi-family dwelling has five stories with total usable area 861.71 m^2: a ground floor (267.10 m^2), a first (267.10 m^2), a second (267.10 m^2), a third floor (267.10 m^2), and a tower (18.96 m^2). In this case, the building is a rectangle on a corner so that the north and east sides of it are fully in contact with other constructions, while the south and west façades are exposed.

For the thermal simulation of each building and climatic zone, boilers with similar characteristics were chosen. The fuel in all boilers is biomass. The thermal load selected for each boiler was set to 24 kW. For the single-family house, just one boiler (24 kW) was considered, whereas for the multi-family dwelling three boilers were installed (total boiler load of 72 kW). For all boilers, the thermal efficiency value adopted was 90%, with an outlet water temperature of 50°C for DHW and 80°C for heating. The flow rate of DHW in the single-family house was 235.80 liters/day, and in the multi-family dwelling 568.72 liters/day. Both types of residence featured an accumulator; specifically, it had a capacity of 200 liters in the single-family house and 500 liters in the multi-family dwelling. In both cases the water temperature varied between 60°C and 80°C, the global heat transfer coefficient (U×A) was 1 W/K.

6.1.2.2. Constructive solutions

Three different solutions have been studied to define the thermal envelope of the buildings previously described (Tables 23 and 24 and Fig. 17). Considering the thermal transmittance mentioned previously, Solution 1 was that with the highest thermal transmittance, followed by Solution 2 and being Solution 3 the constructive solution with lower U-value.

Table 23. Elements and materials used. Thermal characteristics.

		Material	*e*	λ	R
External walls	Solution 1	Lime mortar for rendering 1000<d<1250	0.015	0.550	0.027
		12 in. perforated metric brick 40 mm < G < 50 mm	0.240	1.529	0.157
		Plaster rendering 1000 < d < 1300	0.015	0.570	0.026
		U=2.63 W/m² K	**0.270**		
	Solution 2	Lime mortar for rendering d>2000	0.015	1.800	0.008
		Thermal blocks	0.290	0.426	0.681
		Plaster rendering 1000 < d < 1300	0.015	0.570	0.026
		U=1.13 W/m2 K	**0.320**		
	Solution 3	6 in. perforated metric brick 40 mm < G < 50 mm	0.115	0.991	0.116
		Lime mortar for rendering 1000<d<1250	0.015	0.550	0.027
		Expanded polystyrene [EPS] [0.037 W/[m K]]	0.080	0.037	2.162
		Double hollow brick breeze-block [60 mm < E < 90 mm]	0.075	0.432	0.174
		Plaster rendering 1000 < d < 1300	0.015	0.570	0.026
		U=0.37 W/m² K	**0.300**		
Roofs	Solution 1	Ceramic tiles	0.006	1.000	0.006
		Lime mortar for rendering d>2000	0.024	1.800	0.013
		Floor structure	0.250	1.154	0.217
		Plaster rendering 1000 < d < 1300	0.015	0.570	0.026
		U=2.49 W/m² K	**0.295**		
	Solution 2	Ceramic tiles	0.006	1.000	0.006
		Lime mortar for rendering d>2000	0.024	1.800	0.013
		Mortar lightweight aggregate [vermiculite perlite]	0.040	0.410	0.098
		Polyvinyl chloride [PVC]	0.001	0.170	0.006
		Ceramic tiles	0.030	1.000	0.030
		Slightly ventilated air chamber	0.100	0.000	0.000
		Floor structure	0.300	1.304	0.230
		Plaster rendering 1000 < d < 1300	0.015	0.570	0.026
		U=1.56 W/m² K	**0.516**		
	Solution 3	Sand and gravel [1700 < d < 2200]	0.050	2.000	0.025
		Sublayer felt	0.001	0.050	0.020
		Polyvinyl chloride [PVC]	0.001	0.170	0.006
		Sublayer felt	0.001	0.050	0.020
		Extruded polystyrene, expanded with carbon dioxide [XPS] [0.034 W/[m K]]	0.060	0.034	1.765
		Low density polyethylene [LDPE]	0.002	0.330	0.006
		Concrete with lightweight aggregate 1800 < d < 2000	0.100	1.350	0.074
		Floor structure	0.250	0.256	0.977
		Plaster rendering 1000 < d < 1300	0.015	0.570	0.026
		U=0.33 W/m² K	**0.480**		

e (mm); λ (W/m K); R (m² K/W)

Table 24. External openings. Thermal characteristics.

	Material	U (W/m² K)
Solution 1	Glass (85%): Monolithic (4)	5.700
	Frame (15%): Metallic without thermal break	5.700
	Total	5.700
Solution 2	Glass (85%): Double (4-6-4)	3.300
	Frame (15%): Low density wood	2.000
	Total	3.170
Solution 3	Glass (85%): Double low-e <0.03 (4-9-4)	1.900
	Frame (15%): Three chambers PVC	1.800
	Total	1.880

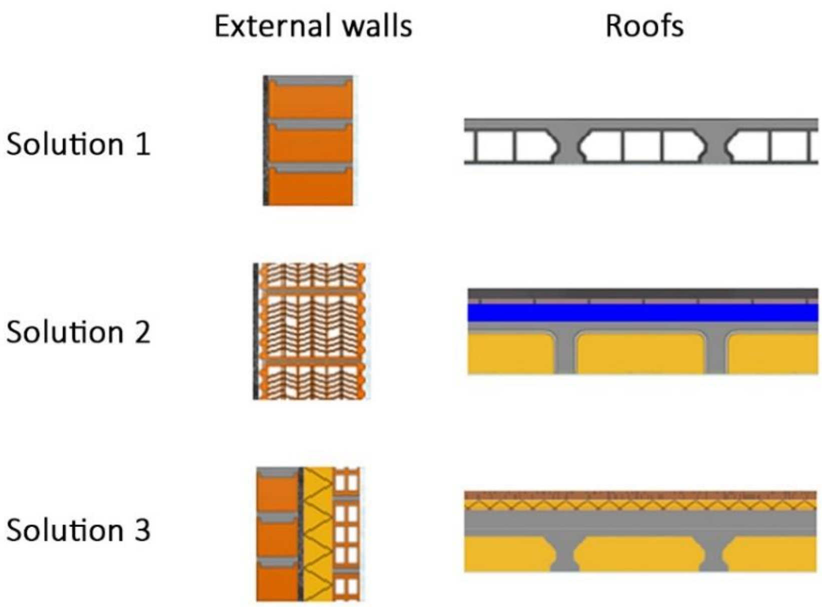

Fig. 17. Elements and materials used. Graphic details.

6.1.2.3. Climatic zones

In this study, the most common climatic zones were selected (Carpio et al. 2013, RD 314/2006), because of including extremes zones (A4 and B3 as the warmest, and D2 and E1 as the coldest) and intermediate zones (C4 and C3). The selection of these climatic zones and their correspondence with cities of the Iberian Peninsula has been explained in the previous chapter.

6.1.3. Simulation software

The energy simulation software solutions available nowadays differ in terms of how the characteristics of the building are introduced as input, and also in the output supplied (Crawley et al. 2008), but all providing valid results. In this study, CERMA has been chosen as the simulation software (ATECYR. 2011). This software calculates the energy demand, the CO_2 emissions and the energy rating basing on the constructive solutions, buildings design and location.Regarding the energy rating, this program works on the scale of seven levels (RD 314/2006), which are represented in Fig. 2.

6.2. Results and Discussion

Table 25 and Fig. 18 and 19 show the energy demand, CO_2 emissions and energy rating, which are dependent on: the envelope design of the constructive solution; the type of building (single-family or multi-family); and the climatic zone where the building is located.

6.2.1. Energy demand

Fig. 18 shows that the total energy demand ranged from 42.9 kWh/m^2 year in a multi-family building located in the climatic zone A4 with Solution 3 as a constructive solution, to 356.2 kWh/m^2 year in a single-family house with Solution 1 located in E1.

The results have revealed that A4 was the climate zone that required a lower total energy demand with any constructive solution in the both types of buildings studied. On the contrary, E1 was the climate zone that higher total energy demand required.

Regarding the envelope design characteristics of the different constructive solutions considered, and owing to the low thermal transmittance values of Solution 3 (Table 23), it was the constructive solution with the lowest energy demand for the types of buildings studied.

In the case of the single-family house, the implementation of Solution 2 supposed an increase of 49%-62% with respect to the energy demand required with Solution 3, and the same house with Solution 1 increased its energy demand within the range 130%-171% depending on the climate zone. When the multi-family building was considered, the use of the constructive Solution 2 resulted in an increment of its energy demand from 45% to 60%, and 109%-143% was the growth in case of implementing Solution 1 in comparison with Solution 3 (Fig. 18).

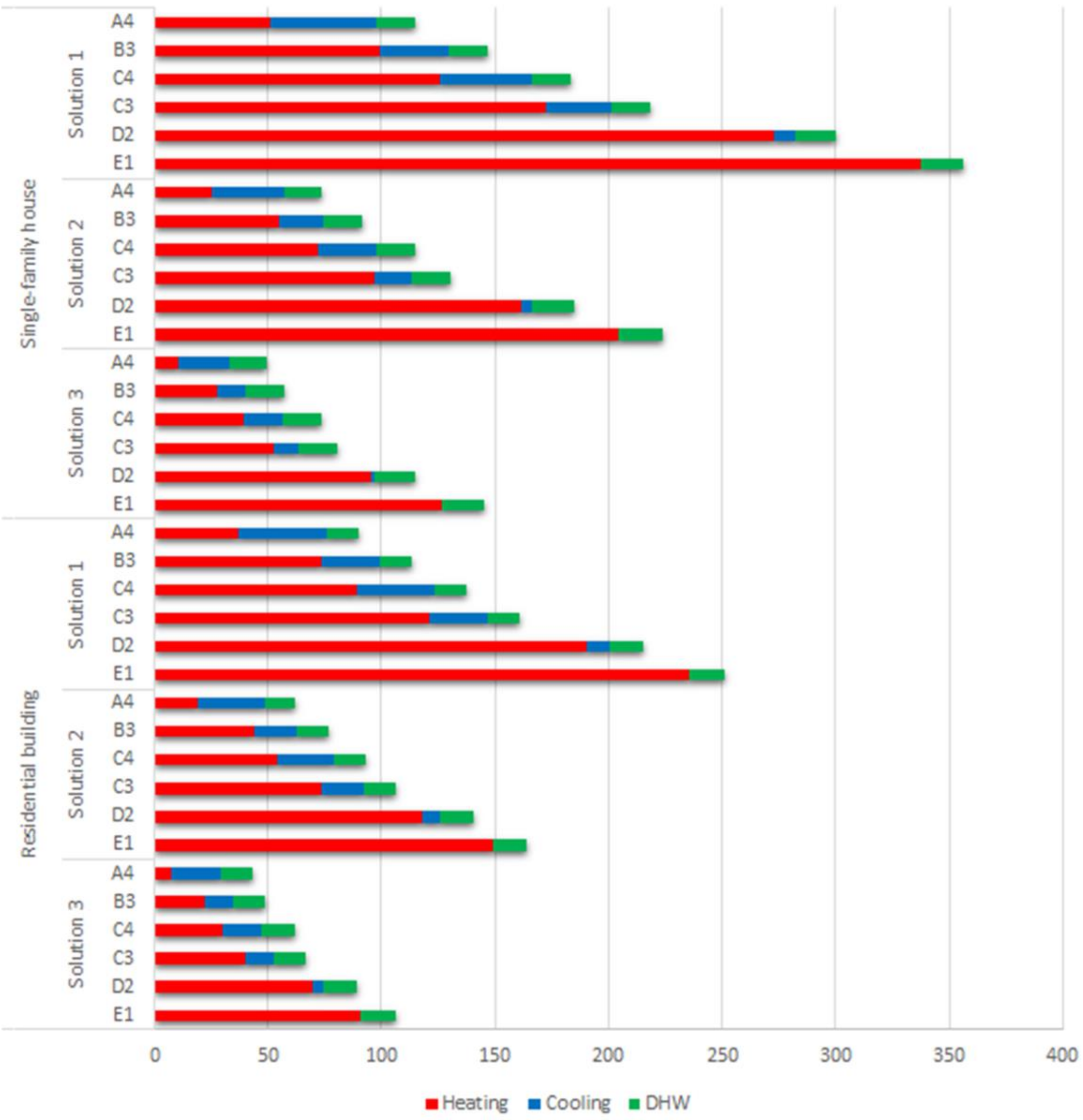

Fig. 18. Energy demand (kWh/m^2 per year).

In general, the single-family house was the building that obtained larger improvement because of having more envelope surface per m^2 and thus more surface to be improved by constructive solutions.

6.2.2. CO_2 emissions and energy rating

Taking into account that the building sector represents 40% of the energy consumption and 36% of the CO_2 emissions in Europe (Directive 2002/91/EC, Directive

2010/31/EU), the use of energy-efficient materials in the thermal envelopes of buildings leads not only to a reduction of the energy demanded, but also to a significant reduction of the environmental impact derived from this sector.

Table 25 and Fig. 19 show the CO_2 emissions generated as a consequence of the energy demanded. In this section, and due to the fact that the energy consumption for DHW production is associated with the energy produced for heating because of using the same boiler, both were considered as a whole.

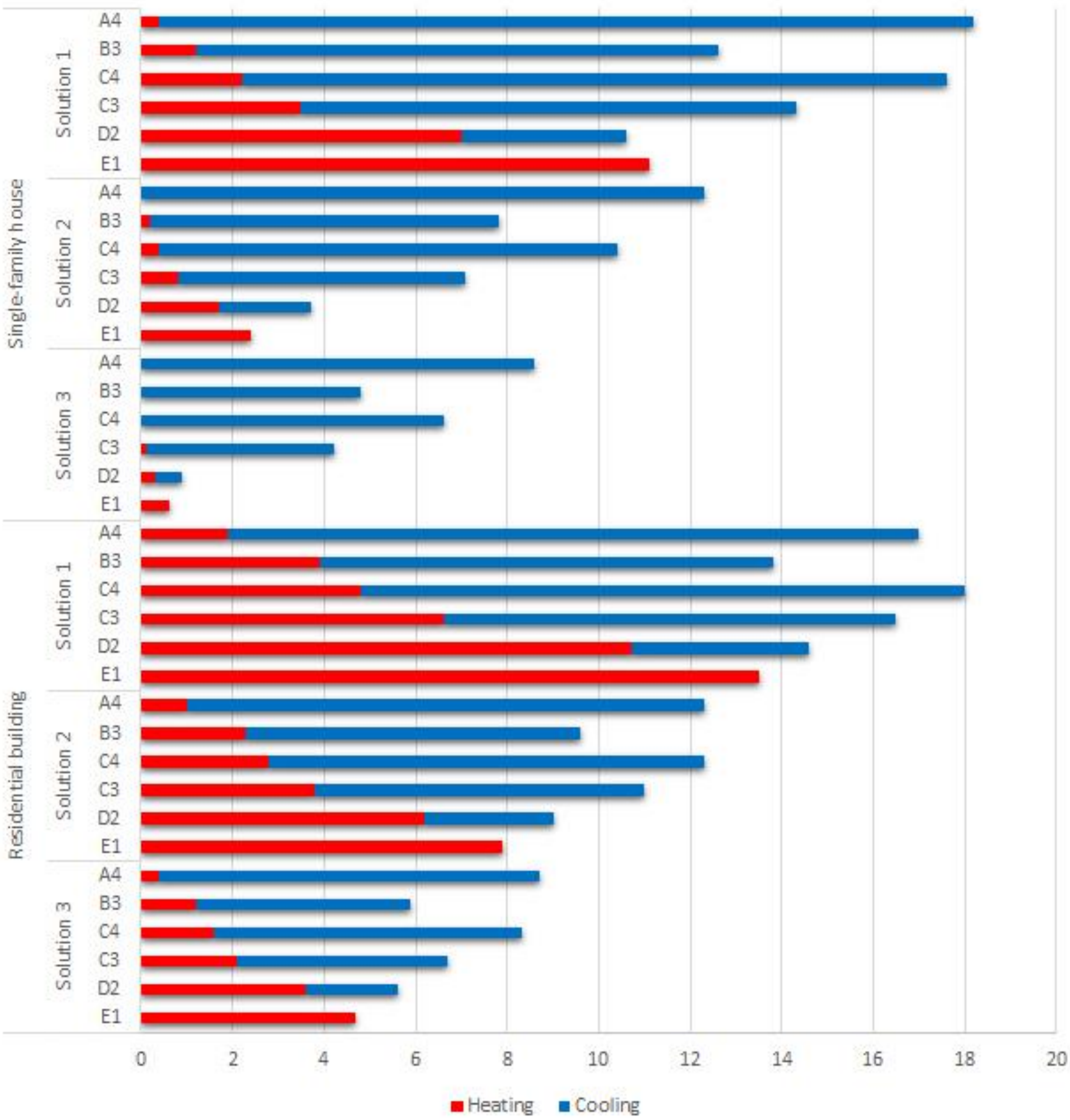

Fig. 19. CO_2 emissions ($kgCO_2/m^2$ per year).

In order to discuss the results obtained, Solution 3 was considered as the point of reference because of being the optimum constructive solution (with minimum energy demand and near-zero emissions). From this point, it was observed that the use of Solution 2 resulted in an increase of 44%-300% regarding the CO_2 emissions generated in the single-family house, whereas this increment varied between 41% and 68% when the multi-family building was considered (Fig. 19).

Table 25. Energy demand, CO_2 emissions and energy rating.

		CZ	Energy demand (kwh/m² per year)				CO_2 emissions (kg CO_2/m² per year)			
			Heating	Cooling	DHW	Total	Heating+DHW	Cooling	Total	ER
Single-family house	Solution 1	A4	51.2	46.7	16.6	114.5	0.4	17.8	18.2	D
		B3	99.6	30.0	17.1	146.7	1.2	11.4	12.7	C
		C4	126.0	40.4	17.2	183.6	2.2	15.4	17.6	C
		C3	172.6	28.4	17.1	218.1	3.5	10.8	14.3	C
		D2	272.6	9.5	18.2	300.3	7.0	3.6	10.6	A
		E1	337.4	0.0	18.8	356.2	11.1	0.0	11.1	A
	Solution 2	A4	25.1	32.2	16.6	73.9	0.0	12.3	12.4	C
		B3	54.6	19.8	17.1	91.5	0.2	7.6	7.8	B
		C4	71.6	26.1	17.2	114.9	0.4	10.0	10.4	B
		C3	96.6	16.4	17.1	130.1	0.8	6.3	7.1	A
		D2	161.3	5.1	18.2	184.6	1.7	2.0	3.6	A
		E1	204.7	0.0	18.8	223.5	2.4	0.0	2.4	A
	Solution 3	A4	10.5	22.6	16.6	49.7	0.0	8.6	8.6	C
		B3	27.3	12.5	17.1	56.9	0.0	4.8	4.8	A
		C4	39.5	17.2	17.2	73.9	0.0	6.6	6.6	A
		C3	52.4	10.9	17.1	80.4	0.1	4.1	4.2	A
		D2	95.4	1.5	18.2	115.1	0.3	0.6	0.9	A
		E1	126.2	0.0	18.8	145.0	0.6	0.0	0.6	A
Multi-family building	Solution 1	A4	36.8	39.4	13.6	89.8	1.9	15.1	17.0	E
		B3	73.6	25.9	14.0	113.5	3.9	9.9	13.8	D
		C4	88.8	34.7	14.1	137.6	4.8	13.2	18.0	D
		C3	120.8	26.0	14.0	160.8	6.6	9.9	16.5	D
		D2	190.2	10.2	14.8	215.2	10.7	3.9	14.6	C
		E1	235.6	0.0	15.3	250.9	13.5	0.0	13.5	B
	Solution 2	A4	18.9	29.7	13.6	62.2	1.0	11.3	12.3	D
		B3	43.7	19.1	14.0	76.8	2.3	7.3	9.6	C
		C4	54.2	24.9	14.1	93.2	2.8	9.5	12.3	C
		C3	73.2	18.8	14.0	106.0	3.8	7.2	11.0	C
		D2	118.2	7.3	14.8	140.3	6.2	2.8	9.0	B
		E1	148.9	0.0	15.3	164.2	7.9	0.0	7.9	A
	Solution 3	A4	7.5	21.8	13.6	42.9	0.4	8.3	8.7	C
		B3	22.1	12.3	14.0	48.4	1.2	4.7	5.9	B
		C4	29.8	17.6	14.1	61.5	1.6	6.7	8.3	B
		C3	40.0	12.2	14.0	66.2	2.1	4.6	6.7	B
		D2	69.4	5.2	14.8	89.4	3.6	2.0	5.6	A
		E1	90.6	0.0	15.3	105.9	4.7	0.0	4.7	A

CZ: Climatic zone; ER: Energy rating

The higher values of the intervals corresponded to the coldest areas (E1), while on the contrary the minimum values of increment were achieved in the warmest climate zones (Table 25). These ranges were substantially enlarged when the Solution 1 was implemented, achieving 112%-1,750% of increment in the case of the CO_2 emissions generated in the single-family house and corresponding the major percentage to the house located in the climatic zone E1.

As observed with Solution 2, the ranges of increment were also reduced for Solution 1 when the multi-family building was analyzed, being the growth of CO_2 emissions within 95%-187%.

As in the case of the energy demand, larger reductions in CO_2 emissions are achieved in the case of the single-family house because of having more envelope surface to be improved by constructive solutions.

On the other hand, and because of the existent relationship between the CO_2 emissions and the energy rating of the buildings (RD 314/2006), a higher quality of the materials used in the envelope of a building led to higher energy ratings. As shown in Table 25, the use of the Solution 3 entailed the obtaining of two positive energy rating levels in both types of buildings in comparison with the energy ratings that resulted from the use of Solution 1.

6.3. Conclusions

This study has demonstrated that an appropriate envelope design of buildings implies important advantages such as the following: (i) reduction of the total energy demand; (ii) reduction of CO_2 emissions to the atmosphere; (iii) higher energy rating.

The use of constructive solutions with high values of thermal transmittance could require from 179% to 211% of the energy demanded in the same building when a constructive solution of low U-value is implemented. The use of these high-quality solutions also reduces considerably the CO_2 emissions, achieving values of 95% of reduction in the single-family house and 65% in the multi-family building. In addition, the use of constructive solutions with high thermal resistance enhances the energy rating of the housing units in all the cases.

However, the improvement of the energy efficiency of the buildings is also dependent on the type of building considered (single-family or multi-family) and the climatic zone. Single-family houses get larger benefits from the use of high-quality materials in the envelope because of having more surface of envelope per m^2 of building surface. In addition, buildings located in warm climatic zones are those that in general terms have a lower energy demand with any of the constructive solutions studied.

CHAPTER 7.-

A PROPOSED METHOD BASED ON APPROXIMATION AND INTERPOLATION FOR DETERMINING CLIMATIC ZONES AND ITS EFFECT ENERGY DEMAND AND CO_2 EMISSIONS ON BUILDINGS[7]

[7] The results shown in this chapter were presented in: **Carpio, M.**, Jódar, J., Rodríguez, M.L., Zamorano, M., **A proposed method for determining climatic zones and its effect energy demand and CO_2 emissions on buildings** (2015) *Energy and Buildings* 87 PP. 253-264.

7.1. Introduction

Climatic zone concept is used in different scopes such as: buildings, to define energy rating (Rakoto-Joseph et al. 2009); urban ecosystems, to decide upon more suitable urban vegetation (Wilson et al. 2003); agriculture, to determine potential production (Falasca et al. 2012); civil engineering, to decide upon more suitable materials (Moradchelleh. 2011); and atmospheric pollution, to determine the amount of organic matter in the air (Feng et al. 2006). From a building perspective, as shown in Chapter 2, the climatic zone is defined as an area for which common external conditions for calculating the energy demand are defined using a few parameters (RD 314/2006).

In relation to the use of climatic zones to determine the energy rating of buildings, the EPBDs (Directive 2002/91/EC, Directive 2010/31/EU) regulates the energy rating of buildings and their respective legislative transpositions to different countries, as shown in Chapter 1. It has been transposed to the Spanish legal framework and, at this moment, Royal Decree 235/2013 contains the necessary requirements for determining buildings' energy efficiency rating, including new and existing constructions.

The energy rating of a building strongly depends on its energy demand, which is defined as the quantity of energy necessary to make a user enjoy certain comfort conditions. The rating depends on the building's architectural characteristics, its end use, and the climatic characteristics of the place where the building is located, which is defined according to the notion of *climatic zone* (RD 314/2006). Two methods to determine the climatic zone were proposed in the CTE (RD 314/2006) and the following updating documents, CTE09 (Orden VIV/984/2009) and CTE13 (Orden FOM/1635/2013). The first one used climatic registers and the second one, which is applicable when climatic data are not available, uses tabulated values that only depend on the provincial capital where a building is located. In consequence, experience has shown some illogical results; for example, municipalities with significant altitude differences could be included in the same climatic zone.

Similar methods are used by other countries in order to assign the climatic zone to a municipality: e.g. India uses a method based on degree-days, which are calculated by using three different methods (ASHRAE formula; equations; and UKMO Kehrig Schoenau-based method for different temperatures (Borah et al. 2015)); Portugal uses the degree-days system in base 20 (Decreto-Lei 80/2006), as well as Spain (RD 314/2006). Other countries such as China uses an hourly weather database (Lam et al. 2005). All countries have in common that their methods are based on statistical weather data in the last years. The number of climatic zones depends on each country; eg, India defiines 4 (Borah et al. 2015) , Portugal defines 9 (Decreto-Lei 80/2006), China defines 10 (Lam et al. 2005), Spain defines 20 (RD 314/2006), etc. The number of climatic zones depends on the thresholds, so it is difficult to make a direct comparison between the countries.

The results obtained in the previous chapters show how the climate zone where the building is located affects its energy demand and consequently the CO_2 emitted. This evidences that the use of an accurate method is an essential issue in the energy rating of buildings. Therefore the objective of this chapter is to propose a new method to determine climatic zones using the approximation and interpolation theory, so the use of this method could be extrapolated to other areas. Andalusia has been selected as the study area for the development of the method. Official climate registers from 47 municipalities in Andalusia in Southern Spain were used to develop the new method that was applied to determine a new climatic zone classification of 772 municipalities in the same region. The new classification was validated in areas with available climatic data, and it was also compared to the theoretical classifications according to the CTE methods. Finally the new classification was used to analyse its influence on buildings' theoretical CO_2 emissions, energy demand and energy rating compared to the CTE methods. CO_2 emissions, energy demand and energy rating have been calculated with CERMA, which is based on the Energy Efficiency Indicators method (ATECYR. 2011).

7.2. Materials and methods

7.2.1. Methods to determinate climatic zone

7.2.1.1. Methods established by Technical Building Code (CTE09 and CTE013)

To determine climatic zones, the CTE introduced the notion of *climatic severity* and included a WCS and a SCS (RD 314/2006). The concept of climatic severity combines degree per day and solar radiation at a location such that two locations with the same WCS demand approximately the same quantity of heating energy if they have similar characteristics. The same notion is applied in the case of SCS for the energy demand for cooling (Orden VIV/984/2009). Climatic severity is defined as the ratio between the energy demands of a building in any given location over the same building in a reference-point location. In the case of Spain, the reference point is Madrid, so the climatic severity there is the unit (1) (RD 314/2006). Eq. 5 and 6 are used to calculate climatic severity, depending on the availability of climatic data. In these equations, *CS* is the climactic severity (WCS or SCS); *DG* is the average value of winter degrees/day in base 20 for January, February, and December in the case of WCS, and for June, July, and August for SCS (they are calculated for each month in time base and then divided by 24); *Rad*, in kWh/m^2, is the average value of the global gathered radiation for January, February, and December in the case of WCS and for June, July and August for SCS; *n/N*, is the ratio between the maximum hours of sunlight, added separately for each of January, February, and December in the case of WCS and for each of June, July, and August for SCS; the values of *a, b, c, d, e* and *f* are included in Table 26.

Depending on the calculated values, WCS and SCS could be classified in five (A, B, C, D, and E) and four (1, 2, 3, and 4) different intervals, respectively, according to the values previously described in Part 1 in Table 3 (RD 314/2006). The combination of these intervals supposes a total of 20 possible different climatic zones (Table 3), although some of them could not be identified in Spain because not all climates are possible, e.g. an Antarctic climate and a Sahara desert climate (RD 314/2006).

Table 26. Values of coefficients a, b, c, d, e and f to calculate WCS and SCS.

		a	b	c	d	e	f
Winter Climate Severity (WCS)	**Equation 5**	$-8.35\cdot10^{-3}$	$3.72\cdot10^{-3}$	$-8.62\cdot10^{-6}$	$4.88\cdot10^{-5}$	$7.15\cdot10^{-7}$	$-6.81\cdot10^{-2}$
	Equation 6	$2.395\cdot10^{-3}$	-1.111	$1.885\cdot10^{-6}$	$7.026\cdot10^{-1}$	$5.709\cdot10^{-2}$	-
Summer Climate Severity (SCS)	**Equation 5**	$3.724\cdot10^{-3}$	$1.409\cdot10^{-2}$	$-1.869\cdot10^{-5}$	$-2.053\cdot10^{-6}$	$-1.389\cdot10^{-5}$	$-5.434\cdot10^{-1}$
	Equation 6	$1.090\cdot10^{-2}$	1.023	$-1.638\cdot10^{-5}$	$-5.977\cdot10^{-1}$	$-3.370\cdot10^{-1}$	-

$$CS = a \cdot \mathrm{Rad} + b \cdot \mathrm{DG} + c \cdot \mathrm{Rad} \cdot \mathrm{DG} + d \cdot (\mathrm{Rad})^2 + e \cdot (\mathrm{DG})^2 + f$$

Eq. 5. Climatic severity 1.

$$CS = a \cdot \mathrm{Rad} + b \cdot {}^{n}\!/_{N} + c \cdot \mathrm{DG}^2 + d \cdot \left({}^{n}\!/_{N}\right)^2 + e$$

Eq. 6. Climatic severity 2.

The method proposed by the CTE, according to its DB-HE (Orden VIV/984/2009) was referred in this study by the CTE09 method**,** and it includes the following two alternatives to determinate a locality's climatic zone:

- Using climatic registers. WCS and SCS are calculated from climatic registers of each locality. Climate data are obtained by a historical register of global radiation and the municipality's temperatures in summer and winter.
- Using tabulated values based on climate zone data from Spain's 52 provincial capitals and the city's altitude in the province. Altitude differences lower than 200 m or lower than the capital's result in the same climate zone classification. See Table 27 for the Andalusian capitals' altitude value thresholds included in the DB-HE (Orden VIV/984/2009).

Table 27. Climatic zone. Altitude thresholds. CTE09 method.

Capital of province	Capital	Reference altitude (m)	Unevenness between the locality and the capital of the province (m)				
			≥200 <400	≥400 <600	≥600 <800	≥800 <1000	≥1000
Almería	A4	0	B3	B3	C1	C1	D1
Cádiz	A3	0	B3	B3	C1	C1	D1
Córdoba	B4	113	C3	C2	D1	D1	E1
Granada	C3	754	D2	D1	E1	E1	E1
Huelva	B4	50	B3	C1	C1	D1	D1
Jaén	C4	436	C3	D2	D1	E1	E1
Málaga	A3	0	B3	C1	C1	D1	D1
Sevilla	B4	9	B3	C2	C1	D1	E1

The *Actualización del Documento Básico de Ahorro de Energía* (DB-HE) (Actualization of Basic Document of Energy Savings) (Orden FOM/1635/2013) has been identified in this study by the CTE13 method; comparing it to the CTE09 method, the modification only affects the determination of climatic zone using tabulated values. In this case, a lower altitude than the provincial capital value has not resulted in the same climatic zone classification. There is an adjustment period (year 2014) where it is possible use both (CTE09 and CTE13) until all tools are adjusted. Final classification depends on each province and, according to Table 28, in the case of Andalusia region (Orden FOM/1635/2013).

Table 28. Climatic zone. Altitude thresholds. CTE13 method.

Capital of province	Capital	Altitude(m)	A4	A3	A2	A1	B4	B3	B2	B1	C4	C3	C2	C1	D3	D2	D1	E1
Almería	A4	0	h<100				h<250	h<400				h<800			h≥800			
Cádiz	A3	0		h<150				h<450				h<600	h<850			h≥850		
Córdoba	B4	113					h<150				h<550				h≥550			
Granada	C3	754	h<50				h<350				h<600	h<800			h<1300			h≥1300
Huelva	B4	50	h<50				h<150	h<350				h<800			h≥800			
Jaén	C4	436					h<350				h<750				h<1250			h≥1250
Málaga	A3	0						h<300				h<700			h≥700			
Sevilla	B4	9					h<200				h<200							

h: Altitude of the locality

7.2.1.2. Approximation and interpolation method (AIM)

There are several techniques for approximating a large amount (N) of data. Approximation and interpolation employing radial basis functions (RBF) has found significant applications since the early 1980s. Hardy (Hardy. 1971), who originally presented the method for the multiquadric (MQ) radial function, introduced the RBF methodology in 1971. The method emerged from a cartography problem, where a bivariate interpolant of sparse and scattered data was needed to represent topography and to produce contours. None of the existing interpolation methods (e.g. Fourier, polynomial, bivariate splines) were satisfactory because they were either too smooth or too oscillatory.

A radial basis function (RBF) is a real-valued function whose value depends only on the distance from the *origin*, so that $\phi(x) = \phi(\|x\|)$; or, alternatively, on the distance from some other point *c*, called a *centre*, so that $\phi(x,c) = \phi(\|x-c\|)$. Any function ϕ that satisfies the property $\phi(x) = \phi(\|x\|)$ is a *radial function*. The norm is usually the *Euclidean distance*, although other *distance functions* are also possible.

The new method proposed in this study has been identified by the AIM method, and it has the objective of fitting the given data set with a radial basis expansion to within a given tolerance. To accomplish this, a specific technique named *adaptive least square*, which employs a data reduction process, starting with a good fit and successively reducing the number of knots used to reach a certain given tolerance. The main advantage of the proposed method could be arriving at a continuous classification to determine a new climatic zone instead of a step approximation. The algorithm proposed was created and run using the software MatLab Release 2012a® y 2013a® (Fasshauer. 2007, MathWorks. 2013) with a license to the University of Granada. This popular commercial software provides an interactive environment for numeric computations and graphics using an interpreted programming language that can optionally be compiled. The proposed algorithm included the following three steps:

i. Normalizing and scaling data set points. Available data set points—latitude, longitude, and altitude–were normalized between 0 and 1 and scaled for uniformity. City altitude is more important than latitude and longitude in terms of temperature, so data were weighted in that order.

ii. Approximating data set points. Data set points were approximated by four types of radial basis functions:

- Gaussian (Eq. 7): where the first term, which is used for normalising the Gaussian, is missing, because in our sum, every Gaussian has a weight, so the normalisation is not necessary.

$$\phi(r) = e^{-(\varepsilon r)^2}$$

Eq. 7. Gaussian.

- Inverse multiquadric (Eq. 8)

$$\phi(r) = \frac{1}{1 + (\varepsilon r)^2}$$

Eq. 8. Inverse multiquadric.

- Multiquadric (Eq. 9)

$$\phi(r) = \sqrt{1 + (\varepsilon r)^2}$$

Eq. 9. Multiquadric.

- Wendland function (Eq. 10)

$$\phi(r) = \max(1 - \varepsilon r)^4 \cdot (4\varepsilon r + 1)$$

Eq. 10. Wendland function.

Rippa's method was implemented in the algorithm to find the optimal value of **ε** (shape parameter) of the radial functions for trilinear interpolation.

iii. Obtaining new climatic zone classification. The output was the prediction index of a location. An estimation of the relative error for each function was computed to determine the best approximate function, and finally the new climatic zone classification could be determined for all Andalusian localities.

7.2.2. Geographical area considered for the study

This study was carried out in Andalusia in Southern Spain (Fig. 20), an area of Spain of 87 thousand km^2, which comprises 17% of Spain. It is between the latitudes 36º 0' 46'' (Tarifa, Cádiz) and 38º 35' 44'' (Santa Eufemia, Córdoba), the longitudes -7º 28' 4" (Sanlucar de Guadiana, Huelva) and -1º 44' 44" (Pulpí, Almería). Its altitude is from sea level to 3,479 m (Mulhacén, Sierra Nevada, Cordillera Penibética), with the highest altitude city at 1,532 m (Trevélez, Granada) (BCN500. 2012). These factors contribute to a region with a significant range of climates, including subtropical, temperate, and cool.

The climatic data used in this study (Table 29), WCS and SCS, consisted of a representative number of years, solar radiations, and temperatures for all days of the year in 47 of the 772 Andalusian municipalities. The data were provided by Agencia Andaluza de la Energía (Andalusian Energy Agency) (AAE. 2014) at the Consejería de Economía, Innovación, Ciencia y Empleo (Ministry of Economy, Innovation, Science and Employment) of Junta de Andalucía (Government of Andalusia).

The use of tabulated values with the CTE09 and CTE013. Table 30 had special application problems in the following areas:

- Area 1. Localities at lower altitudes than the province capital. In these cases, the same climate zone was assigned without considering other factors.
- Area 2. Localities at the highest threshold limits. In these cases, cities with minimum altitude variations were considered to be in different climate zones.
- Area 3. Localities near the borders of the provinces. In these cases, the localities' province capitals were used for reference so that cities geographically closer and with similar climates, but belonging to different provinces, could be classified in different climate zones.

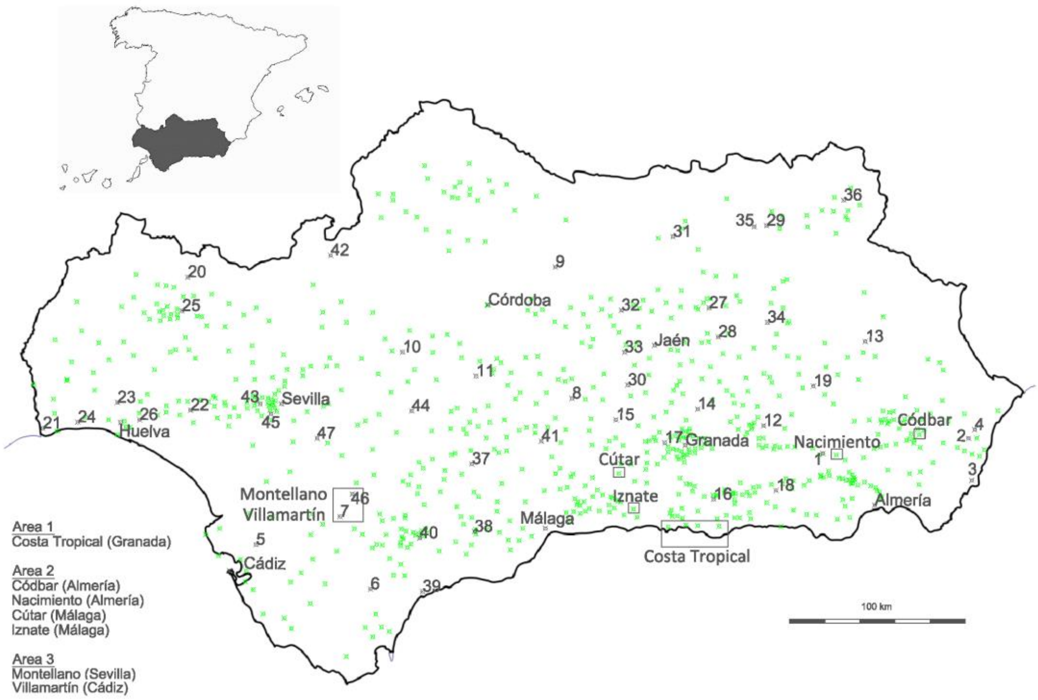

Fig. 20. Plan of the 47 reference cities and the 772 total cities of Andalusia.

According to the conflictive defined areas, and with the objective of checking new classifications of the climatic zones obtained with this method, the following 13 localities in Andalusia were selected for this study, whose characteristics and locations are included in Table 30 and in Fig. 20:

- Area 1. Albuñol, Almuñecar, Benaudalla, Jete, Molvízar, Motril, and Vélez de Benaudalla (Costa Tropical - South of Granada). All these localities were at sea level.
- Area 2. Nacimiento, Cóbdar, (Almería), Cútar, and Iznate (Málaga)
- Area 3. Montellano (Sevilla) and Villamartín (Cádiz). These localities were 57 and 69 km away away from Sevilla and Cádiz, respectively, and only 16 km apart from each other.

Table 29. 47 reference cities.

P	Id	City	Geographical data			Climate Severity		Climatic zone CTE09 method		Climatic zone CTE13 method		Climatic zoneAIM method	
			Latitude	Longitude	Altitude	WCS	SCS	W	S	W	S	W	S
Almería	1	Abla	37.1411	-2.7801	871.17	0.780	1.160	C	1	D	3	C	3
	2	Antas	37.2452	-1.9175	107.26	0.320	1.160	A	4	B	4	B	3
	3	Carboneras	36.9966	-1.8950	6.72	0.120	1.260	A	4	A	4	A	4
	4	Cuevas de Almanzora	37.2971	-1.8815	97.29	0.210	1.330	A	4	A	4	A	4
Cádiz	5	Jerez de la Frontera	36.6866	-6.1372	55.75	0.430	1.490	A	3	A	3	B	4
	6	Jimena de la Frontera	36.4340	-5.4535	131.44	0.410	1.510	A	3	A	3	B	4
	7	Villamartin	36.8613	-5.6418	167.81	0.560	1.560	A	3	B	3	B	4
Córdoba	8	Carcabuey	37.4436	-4.2734	628.29	0.780	1.420	D	1	D	3	C	4
	9	Montoro	38.0262	-4.3819	201.33	0.600	1.560	B	4	C	4	C	4
	10	Palma del Río	37.7016	-5.2838	60.92	0.450	1.640	B	4	B	4	B	4
	11	Santaella	37.5663	-4.8451	238.22	0.410	1.740	B	4	C	4	B	4
Granada	12	Guadix	37.3004	-3.1346	919.40	1.140	1.020	C	3	D	3	D	2
	13	Huescar	37.8095	-2.5397	959.98	1.150	1.010	D	2	D	3	D	3
	14	Iznalloz	37.3927	-3.5275	816.34	1.160	1.020	C	3	D	3	D	3
	15	Montefrio	37.3210	-4.0114	835.14	1.070	1.050	C	3	D	3	D	3
	16	Órgiva	36.9022	-3.4240	465.87	0.650	1.210	C	3	C	4	D	3
	17	Santa Fe	37.1894	-3.7191	582.65	1.100	0.900	C	3	C	4	D	3
	18	Ugíjar	36.9608	-3.0548	547.52	0.760	1.110	C	3	C	4	D	3
	19	Zújar	37.5402	-2.8428	771.52	1.230	1.010	C	3	C	3	D	3
Huelva	20	Aracena	37.8942	-6.5612	674.00	0.830	1.270	C	1	C	3	C	4
	21	Ayamonte	37.2147	-7.4098	3.16	0.310	0.900	B	4	A	4	B	2
	22	Bollullos	37.3362	-6.5358	116.02	0.430	1.700	B	4	B	4	B	4
	23	Gibraleón	37.3750	-6.9701	29.22	0.360	1.600	B	4	A	4	B	4
	24	Lepe	37.2543	-7.2033	24.54	0.350	1.130	B	4	A	4	B	3
	25	Minas de Río Tinto	37.6939	-6.5918	417.64	0.600	1.510	B	3	C	3	B	4
	26	Moguer	37.2747	-6.8366	53.91	0.330	1.290	B	4	B	4	B	4
Jaén	27	Baeza	37.9934	-3.4692	759.48	0.740	1.820	C	3	D	3	C	4
	28	Bedmar y Garcíez	37.8227	-3.4118	645.47	0.690	1.590	C	3	C	4	C	4
	29	Castellar	38.2562	-3.1319	755.20	0.980	1.410	C	3	D	3	D	4
	30	Castillo de Locubín	37.5283	-3.9437	702.94	0.930	1.440	C	3	C	4	C	4
	31	Guarroman	38.1815	-3.6865	348.13	0.760	1.650	C	4	B	4	C	4
	32	Lahiguera	37.9705	-3.9892	372.68	0.660	1.820	C	4	B	4	C	4
	33	Martos	37.7228	-3.9663	739.37	0.960	1.160	C	3	C	4	D	3
	34	Peal del Becerro	37.9133	-3.1217	548.82	0.930	1.550	C	4	C	4	C	4
	35	Santisteban del Puerto	38.2475	-3.2064	706.27	0.810	1.600	C	3	C	4	C	4
	36	Torres de Albanchez	38.4145	-2.6771	830.67	1.050	1.200	C	3	D	3	D	3
Málaga	37	Campillos	37.0454	-4.8615	458.55	0.720	1.250	C	1	C	3	C	3
	38	Casarabonela	36.7852	-4.8422	469.91	0.380	1.700	C	1	C	3	B	4
	39	Estepona	36.4248	-5.1449	9.66	0.190	1.190	A	3	B	3	A	3
	40	Ronda	36.7420	-5.1664	721.03	0.920	0.890	C	1	D	3	C	2
	41	Villanueva de Algaidas	37.1863	-4.4508	542.55	0.960	1.190	C	1	C	3	D	3
Sevilla	42	Alanís	38.0375	-5.7153	674.50	0.780	1.140	C	1	C	4	C	3
	43	Espartinas	37.3800	-6.1236	129.53	0.530	1.240	B	4	B	4	B	3
	44	Lantejuela, La	37.3535	-5.2230	152.55	0.510	1.720	B	4	B	4	B	4
	45	Puebla del Río, La	36.9956	-5.5709	270.64	0.460	1.450	B	4	B	4	B	3
	46	Montellano	37.2675	-6.0626	21.87	0.440	1.120	B	3	C	4	B	4
	47	Utrera	37.1814	-5.7815	49.07	0.530	1.270	B	4	B	4	B	4

Latitude and longitude in decimal degrees. Altitude in meters. P: Province; W:Winter; S:Summer

Table 30. Studied areas.

Studied Area			Geographical data			Climate Severity		Climatic zone					
								CTE09		CTE13		AIM	
Area	**Province**	**City**	**Latitude**	**Longitude**	**Altitude**	**WCS**	**SCS**	**W**	**S**	**W**	**S**	**W**	**S**
1	Granada	Albuñol	36.79125	-3.203485	247	0.262	1.402	C	3	B	4	A	4
	Granada	Almuñécar	36.73454	-3.690736	24	0.205	1.367	C	3	A	4	A	4
	Granada	Jete	36.79732	-3.668151	134	0.264	1.483	C	3	B	4	A	4
	Granada	Molvízar	36.78689	-3.607518	239	0.298	1.477	C	3	B	4	A	4
	Granada	Motril	36.74467	-3.516718	41	0.197	1.376	C	3	A	4	A	4
	Granada	Salobreña	36.74626	-3.587108	21	0.197	1.363	C	3	A	4	A	4
	Granada	Vélez de Benaudalla	36.83195	-3.516209	171	0.272	1.478	C	3	B	4	A	4
2	Almería	Cóbdar	37.26199	-2.210223	607	0.833	1.008	C	1	C	3	C	3
	Almería	Nacimiento	37.10497	-2.647740	597	0.822	1.035	B	3	C	3	C	3
	Málaga	Cútar	36.83069	-4.228007	298	0.384	1.563	B	3	B	3	B	4
	Málaga	Iznate	36.77612	-4.183560	305	0.353	1.571	B	3	C	3	B	4
3	Sevilla	Montellano	36.99564	-5.570882	271	0.460	1.450	B	3	C	4	B	4
	Cádiz	Villamartín	36.86132	-5.641834	168	0.560	1.560	A	3	B	3	B	4

Latitude and longitude in decimal degrees. Altitude in meters. W:Winter; S:Summer

7.2.3. Thermal simulation

Energy demands, CO_2 emissions, and energy ratings of a housing type were calculated using the methods considered in this study to determine and to compare the effects of the climatic zone classifications.

7.2.3.1. Simulation software used

Theoretical thermal simulations were performed with the software CERMA to determine buildings' energy demands, CO_2 emissions, and energy ratings (ATECYR. 2011). This software is a validated tool for rating energy by The Housing Ministry of Spain (Article 3 of Royal Decree 235/2013). CERMA is based on the Energy Efficiency Indicators method. The estimation of the energy necessary to comply with the demands of a building under normal conditions of occupancy and functioning is known as the Energy Efficiency Rating. By comparing a number of indicators of the mean energy use in model buildings of reference, a real building can be qualified and certified on an energy scale established for this purpose. The EEI in residential buildings are: (i) EEI heating demand;

(ii) EEI cooling demand; (iii) EEI of heating emissions; (iv) EEI of cooling emissions; (v) EEI of emissions for DHW; and (vi) EEI of total emissions.

The blueprints and measurements of the constructions were processed by means of AutoCAD LT® (Autodesk. 2012) with license to the University of Granada.

7.2.3.2. Characteristics of the building studied

A single-family housing type was selected to do thermal simulations (Fig. 21); it consisted of three floors and had a total usable area of 254.60 m^2: ground floor (135.70 m^2), first floor (88.12 m^2), and second floor (30.78 m^2). The most important materials in the thermal enclosure and the thermal transmittance limit (U) used were: roof (0.48 W/m^2K), uninhabitable area roof (0.75 W/m^2K), external wall (0.54 W/m^2K), ground floor (0.65W/m^2K), wood door (2.20 W/m^2K), garage door (3.20 W/m^2K), and windows (2.47 W/m^2K). The windows have the following areas and orientations: north 6.00 m^2; west 2.80 m^2; south 7.60 m^2 and east 2.10 m^2. Furthermore, the garage door and the wood door are south-facing, with an area of 6.60 m^2 and 3.20 m^2 respectively. The main façade faced south in all cases. A comfortable indoor temperature, between 17 °C and 20 °C in winter, and between 24 °C and 26 °C in summer, was selected.

In relation to the heating and the DHW systems, a biomass fuel boiler was selected due to the increased use in Andalusia, as currently biomass is the source that most contributes to Andalusian energy infrastructures of renewable energies, including 78.7% of the renewable energy consumption and 6.3% of the total primary energy consumption (García-Maraver et al. 2012), and the quantity of biomass available in the area —land surface of 8,759,531.18 ha. ≈40% forest and ≈60% farmland (EC). The thermal load selected for the boiler was set to 24 kW, with a thermal efficiency of 90% and an outlet water temperature of 50 °C for DHW and 80 °C for heating. The flow rate of DHW was 229 litres/day. The house had an accumulator with a capacity of 200 litres. The water temperature varied between 60 °C and 80 °C, with the global heat transfer coefficient (U×A) being 1 W/K.

Fig. 21. Plan of the single-family house.

7.3. Results and discussion

7.3.1. Climatic zoning classification

The results of the application of the CTE09 (Orden VIV/984/2009), CTE013 (Orden FOM/1635/2013), and AIM methods for the 772 localities of Andalusia are included in Tables 30 to 33, and they are described and discussed below.

7.3.1.1. CTE09 method

After the application of the CTE09 method, the WCS most common in the region was C (45.9%) followed by B (29.8%), D (15.7%), and A (8.6%); The E classification did not appear in the studied area. However, the most common SCS classification in the region was 3 (40.8%) followed by 1 and 4 with similar percentage (26.3 and 25.4 % respectively); the 2 classification was below the norm, with only 7.5% of the municipalities. Finally, the combination of WCS and SCS classifications resulted in 10 of the 20 possible climatic zones in Andalusia (Table 31); as result, the most common climatic zone in this region was C3 (22%) followed by other combinations, as shown in Table 31.

Climactic zones were particularly studied in specific localities that did not have available climatic data, and they were identified in areas with special application problems. The results are summarized in Table 30 and discussed below.

- Area 1. This region includes seven cities that are located in the Costa Tropical. It is at sea level and is characterized by a Subtropical Climate with an average annual temperatures around 20 °C, a minimum of 14 °C, and a maximum of 33 °C (Chen and Chen. 2013). The capital of the province, Granada, has an altitude of 754 m and is characterized by a Mediterranean Climate, cold winters or a Continental-Mediterranean Climate, extreme temperatures (differences between day and night could be greater than 20 degrees), long and very cold winters (temperatures lower than -10 °C) and hot summers (temperatures higher than 40 °C) (Chen and Chen. 2013). The climate zone of Granada was included in CTE, considering the climate data available. It resulted in a zone C3, which was the same classification that resulted after the application of CTE09 for the seven cities in this area despite the significant climate differences between Granada and the coastal cities studied.

- Area 2. This area included four localities at the limits of the highest thresholds in two different provinces, Almería and Málaga: Cóbdar (C1) and Nacimiento (B3) in Almería province, and Cútar (B3) and Izanate (B3) in Málaga province. All four municipalities here showed several climatic zones within themselves (Table 30), but all of them had a Continental-Mediterranean Climate (Chen and Chen. 2013), the same real climate but with variations in WCS and SCS.
- Area 3. This case included two nearby cities belonging to two different provinces, Sevilla and Cádiz. Both cities are characterized by the typical Mediterranean Climate, with dry and hot summers, average temperatures around 22 °C, and wet and rainy winters with mild temperatures (Chen and Chen. 2013). The application of the CTE09 method resulted in different classifications for WSC for both municipalities and thus different climatic zones, although they have the same climatic characteristics. The results for Montellano, located south of Sevilla, put this city in the B3 climatic zone, and Villamartín, located north of Cadiz, was included in the A3 climatic zone. In this case, the differences between the climatic zones of both cities were not strongly different and only affected WCS; however, these results could mean differences in determining the heating energy consumption during the winter, in spite of the similarities in the climatic characteristics in both cities.

The results showed that the CTE09 method is not consistent with reality in the case of the three areas with special application problems. In consequence, it was possible to conclude that CTE09 is not a suitable method for determining climatic zones.

Table 31. Combination of climate zone in winter and in summer. Percentage of locations in Andalusia.

CZ	CTE09					CTE13					AIM				
	1	**2**	**3**	**4**	**Σ**	**1**	**2**	**3**	**4**	**Σ**	**1**	**2**	**3**	**4**	**Σ**
A	-	-	6.0%	2.6%	8.6%	-	-	3.1%	3.6%	6.7%	-	-	1.7%	6%	7.7%
B	-	0	12.8%	1.7%	29.8%	-	0	9.1%	16.7%	25.8%	-	0.4%	6.7%	26.3%	33.4%
C	16.2%	1.9%	22.0%	5.8%	45.9%	-	0.7%	23.8%	17.1%	41.6%	-	2.3%	17%	19.9%	39.2%
D	10.1%	5.6%	-	-	15.7%	-	0.1%	25.3%	-	25.4%	-	1.2%	17.6%	0.9%	19.7%
E	-	-	-	-	-	0.5%	-	-	-	0.5%	-	-	-	-	-
Σ	26.3%	7.5%	40.8%	25.4%	100%	0.5%	0.8%	61.3%	37.4%	100%	0	3.9%	43%	53.1%	100%

7.3.1.2. CTE13 method

The application of the CTE13 method showed that the most common WCS in Andalusia was C (41.6%) followed by B and D (25.8 and 25.4% respectively), A (6.7%), and E (0.5%). In the case of SCS, the most common classification was 3 (61.3%) followed by 4 (37.4%) and finally 1 and 2, with similar percentages (0.5 and 0.8%, respectively). Finally, the most common climatic zone was D3 (25.3%), followed by other combinations shown in Table 31.

In the following section the municipalities of conflict areas were studied with the CTE13 method:

- Area 1. The application of CTE 13 to the cities in Area 1 resulted in the A4 (Almuñecar, Motril, and Salobreña) and the B4 (Albuñol, Jete, Molvízar, and Vélez de Benaudalla) climatic zones. In this case, the classifications of these municipalities' climatic zone was completely different from Granada's capital classification (C3), and they came closer to their real Subtropical Climate (Chen and Chen. 2013). The results also considered slight differences between the cities located just at sea level (Almuñecar, Motril and Salobreña) and those located near the sea but with an altitude between 134 and 247 (Table 30).
- Area 2. The CTE13 method in Area 2 changed the threshold limits, as shown in Table 28. Using the CTE09 (Table 27) method, all cities had a Continental-

Mediterranean Climate (Chen and Chen. 2013). This situation caused the climatic zones of the bordering cities to change. In CTE13 in Almería province, Cóbdar and Nacimiento had the same climate zone, C3, because the new limit was 800 meters (Table 28). In contrast, in Málaga province, Cútar and Iznate, with CTE13, obtained different climatic zones, B3 and C3 respectively, because the new limit between climatic zones was 300 meters (Table 28).

- Area 3. For Montellano, located south of Sevilla, the results placed the city as a C4 climatic zone; and Villamartín, located north of Cádiz, had a B3 climatic zone. So the differences of WCS and the SCS were observed, and all cities had a Mediterranean Climate (Chen and Chen. 2013).

The results obtained have shown that the new tabulated values proposed by the CTE13 method improved the procedures for determining the climatic zones of cities located in provinces with a capital with a higher altitude than the other municipalities (Area 1). However, in the rest of the areas with special application problems (Areas 2 and 3), the method was still not consistent with reality, showing different climatic zones to nearby municipalities characterized by the same climate as the CTE09 method. This is due to the use of the capital as the reference point to determine the climatic zone for the rest of the localities.

7.3.1.3. AIM method

For the AIM method, the altitude, latitude, and longitude data of 47 data set points (Table 29) were normalized and scaled for uniformity, while city altitude was weighted. Consequently, data set points were approximated by the following radial basis functions: (i) Gaussian, (ii) inverse multiquadric, (iii) multiquaddric, and (iv) Wendland to get a quantitative measure of the degree of approximation provided by each approximant; Fig. 22 and 23 show approximation functions for WCS and SCS. Finally an estimation of the relative error was computed to determine the best approximant function. Table 32 summarizes the maximum error and the relative mean square error (RMS) for them, depending on the season, concluding that the function that resulted in the best approximation was the inverse multiquadric function, so it was used to determine WCS and SCS for all the Andalusian municipalities (Table 31).

Table 32. Errors for the studied functions. AIM method.

	Summer		Winter	
	Max. Error	**RMS Error**	**Max. Error**	**RMS Error**
Gauss (ep=20)	1.088019e-14	4.511634e-16	7.438494e-15	3.575953e-16
Multiquadric	1.088019e-14	4.511634e-16	1.054712e-14	6.166019e-16
Inverse mult.	**5.773160e-15**	**2.390121e-16**	**6.661338e-16**	**3.924787e-17**
Wendand (C2)	9.863221e-13	5.422403e-14	2.543521e-13	1.554525e-14

The application of the AIM method results placed C as the most common WCS in Andalusia (39.2%), followed by B (33.4%), D (19.7%), and A (7.7%); The E classification did not appear in the studied area. The most common SCS classification in the region was 4 (53.1%), followed by 3 (43%), and 2 (3.9%); The 1 classification did not appear in the studied area. Finally, as result of combining the WCS and SCS classifications, the most common climatic zone in the region was B4 (26.3%), followed by the other combinations shown in Table 31.

The results in conflict areas were also compared, and they obtained the following:

- Area 1. In the case of Area 1, The AIM method gave the closest classification to the reality of the Subtropical Climate (Chen and Chen. 2013) that characterizes municipalities included in this area, by considering the cities below the provincial capital with a suitable climate zone.

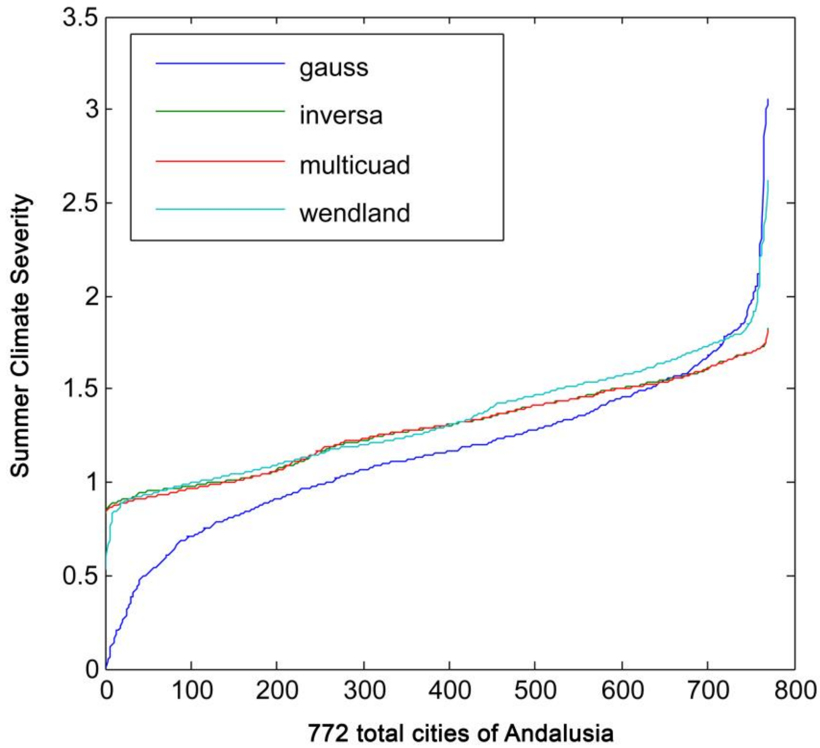

Fig. 22. Approximation functions for Summer Climate Severity.

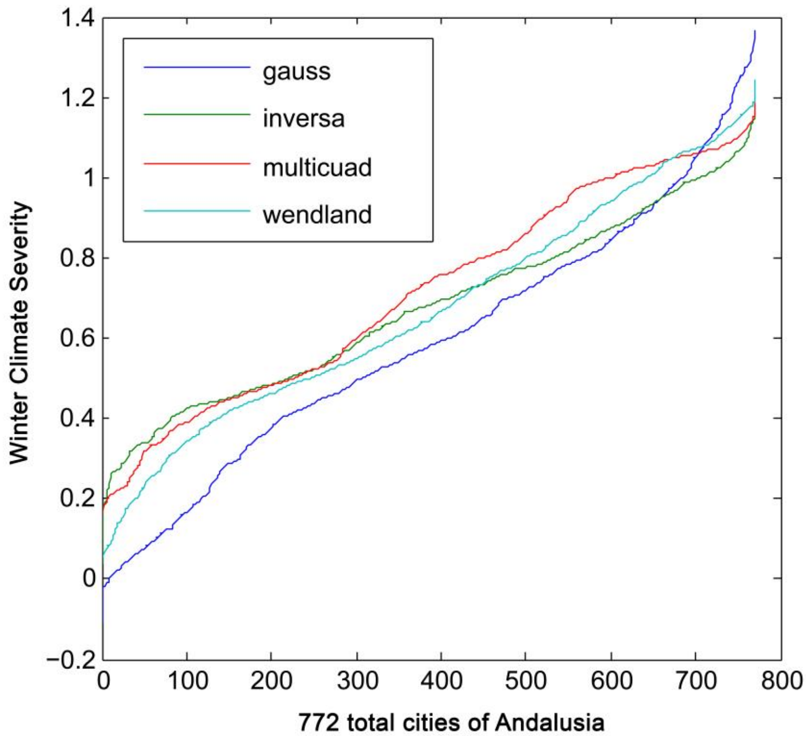

Fig. 23. Approximation functions for Winter Climate Severity.

- Area 2. The application of the CTE09 and the CTE13 methods provided different results for Area 2, depending on the value of the threshold elevation. With the implementation of the AIM method, these thresholds disappeared, and the results were closer to reality, with a Continental-Mediterranean Climate (Chen and Chen. 2013). These results indicate the AIM method as the most appropriate because the threshold limits were eliminated, thus giving a more progressive classification.
- Area 3. The AIM method removed the restriction to referencing a municipality to the capital of its province, as CTE09 and CTE13 methods required. The results obtained for Area 3 with the AIM method reference only other nearby municipalities with actual climate data, thus bringing the results closer to Area 3's actual Mediterranean Climate (Chen and Chen. 2013).

The results have shown that the new proposed method, AIM, improved the procedures for determining climatic areas that had special application problems in representing reality. Just as noted above, the AIM method covers the CTE methods' deficiencies. Regarding the cities below their provincial capitals, threshold limits are eliminated, and the results reference instead only nearby municipalities. Although the best method was carried out with real climate data, in the cities without data the proposed method (AIM) resulted to be the more accurate because it is based in nearby cities with real climate data. This method has interpolated the altitude, latitude and longitude, and was validated with the climate of the 47 municipalities with climate data, as well as with the 8 capitals of province.

7.3.1.4. Comparison of methods

Table 31 shows the percentages of global climactic zones and WCS and SCS climatic zones, respectively, obtained by the CTE09, CTE13, and AIM methods. The applied methods have resulted in different climatic zones for the studied Andalusian municipalities, showing significant variations in the percentages of each climate zone. On the one hand, comparison of climate areas obtained applying the CTE09 and the AIM methods showed an increase in A by 1%, C by 7%, 1 by 26%, and 2 by 3%, as well as a decrease in B by 4%, D by 4 %, 3 by 4%, and 2 by 28%; E remained unchanged, only in CTE13 but with a minimum variation. On the other hand, comparing the CTE13 and AIM methods showed an increase in C by 2%, D by 6%, E by 1%, and 1 by 1%, and a decrease of A by 1%, B by 8%, 2 by 3%, and 4 by 16%. In consequence, the CTE13 and AIM methods had higher coincidence rates than the CTE09 method.

The analysis of the results also showed similar tendencies in the distribution of Winter Climatic Zones regardless of the method applied, with slight differences in percentages between them; however, significant differences were detected in Summer Climatic Zones, resulting in the warmest climatic zone 4 as the most frequent (Fig. 24). The percentage of municipalities included in the hottest SCS classification (number 4) was higher in the case of AIM method and, in consequence, the percentage in the coldest classification (number 1) was lower. This increase was due to the fact that the new method took into account the latitude, altitude and longitude conditions of the cities but not the difference of altitude between the municipalities or the altitude of the capital of province. In consequence, many coastal cities were included in a warmer climatic zone than the real one.

With each method, the following were observed: With the CTE09 method, the most common climatic area was C3. This classification is related to a climate characterised by dry and hot summers, mild winters and irregular rainfall, according to the typical climate of the region, a Mediterranean Climate (Junta de Andalucía. 2014). With the CTE13 method, the most common was D3, a climate zone similar to C3, D3 fits in a Continental-Mediterranean Climate, with extreme temperatures and cold winters (Chen and Chen. 2013). Finally, with the AIM method, the most common was B4, which is characterized by a Continental-Mediterranean Climate, becoming in some cases a Dry Mediterranean Climate, with warmer winter temperatures and less rainfall than the Continental Mediterranean (Chen and Chen. 2013); this climatic zone is the one that best identifies the Andalusian climate as characterised by its many hours of sunshine per year (Junta de Andalucía. 2014).

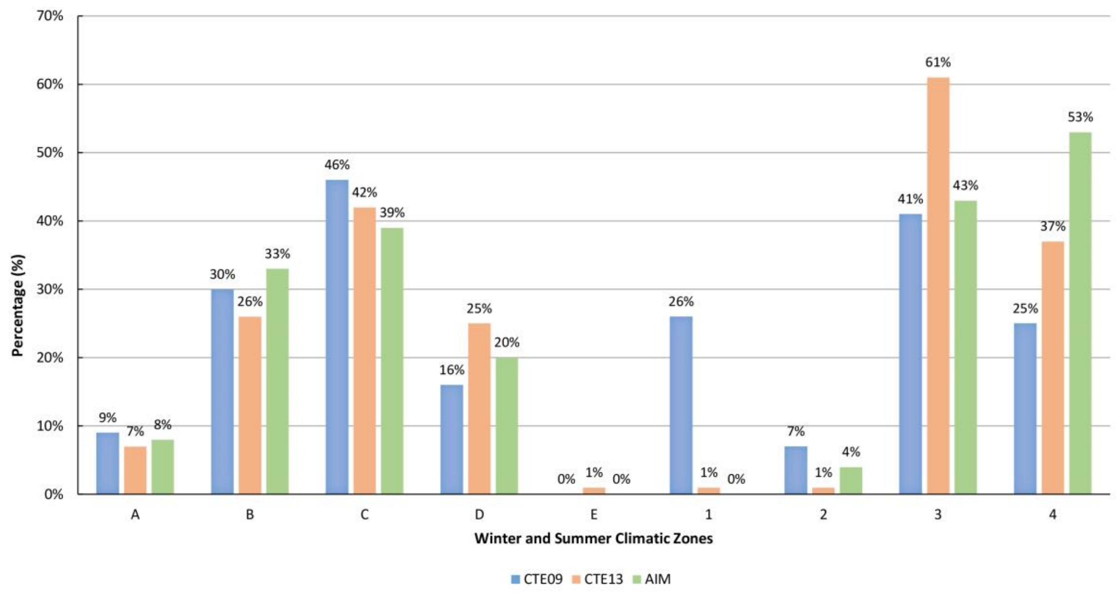

Fig. 24. Tendency of the distribution of WCZ and SCZ with CTE09, CTE13 and AIM method.

7.3.2. Energy demand, CO_2 emissions

The use of an inappropriate climatic zone affects the previous calculations in a building's thermal performance, resulting in erroneous estimations of its energy demands (Carpio et al. 2013); furthermore, a misallocation of climate zone has also affected the theoretical calculations of CO_2 emissions (Ruiz and Romero. 2011). As a consequence, energy demands and CO_2 emissions for areas with special application problems and for housing types have been determined with different methods to analyse the effect of the climate zone classification.

Fig. 25 shows that the CTE09 method supposed an increase (280.13%) of heating demand in coastal cities and a decrease (70.26%) in cooling, compared to the AIM method. Fig. 26 shows that these results have also implied an increase of CO_2 emissions (285.71%) in heating and a reduction (60.34%) for cooling, comparing the CTE09 to the AIM method.

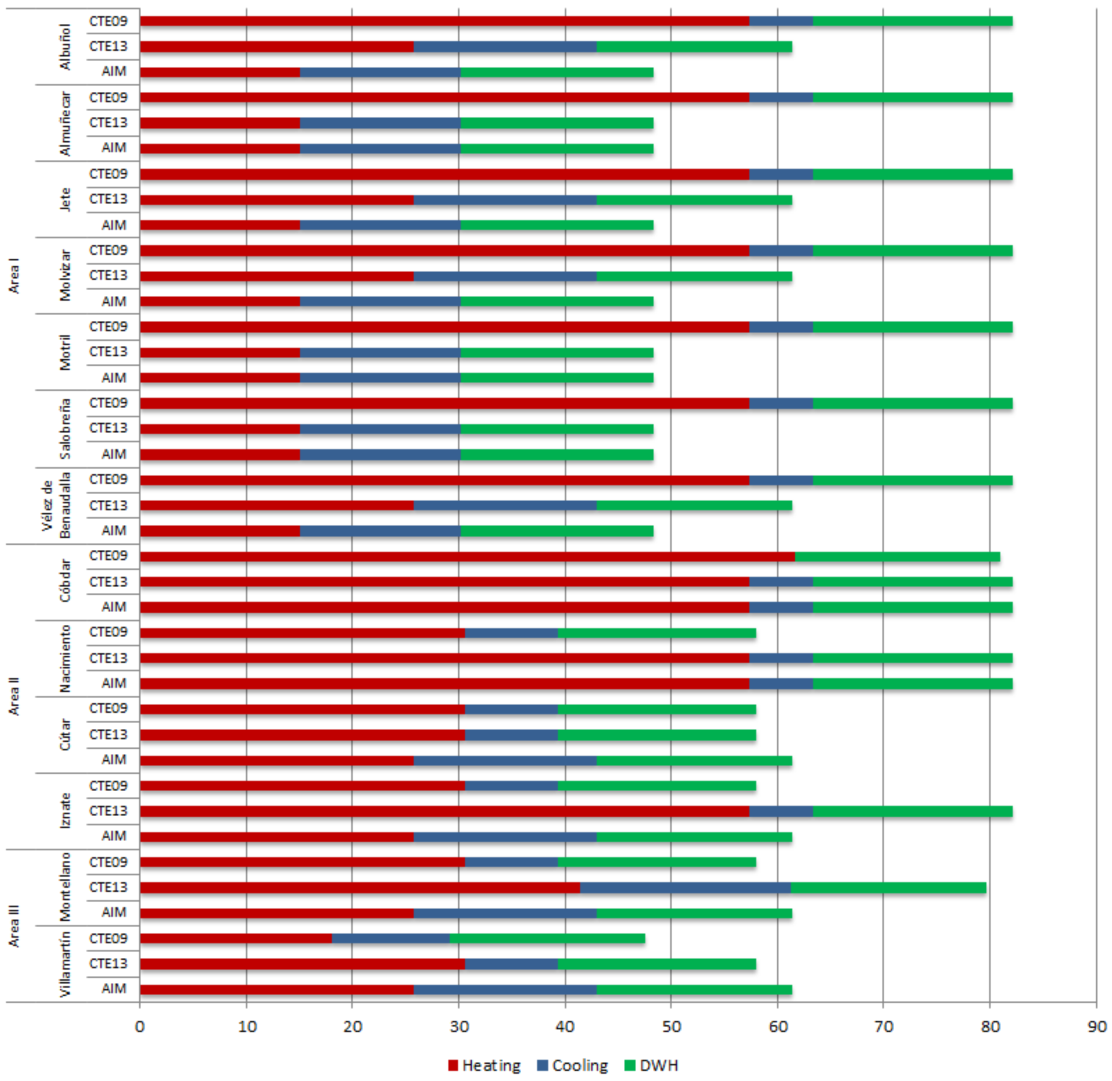

Fig. 25. Energy demand (kWh/m² per year).

Finally, for all the studied areas, the DHW resulted in zero CO_2 emissions, independently of the considered area because it was associated with heating. The influence of the climatic zone was minimal because the demand appeared to depend largely upon the area of the living quarters.

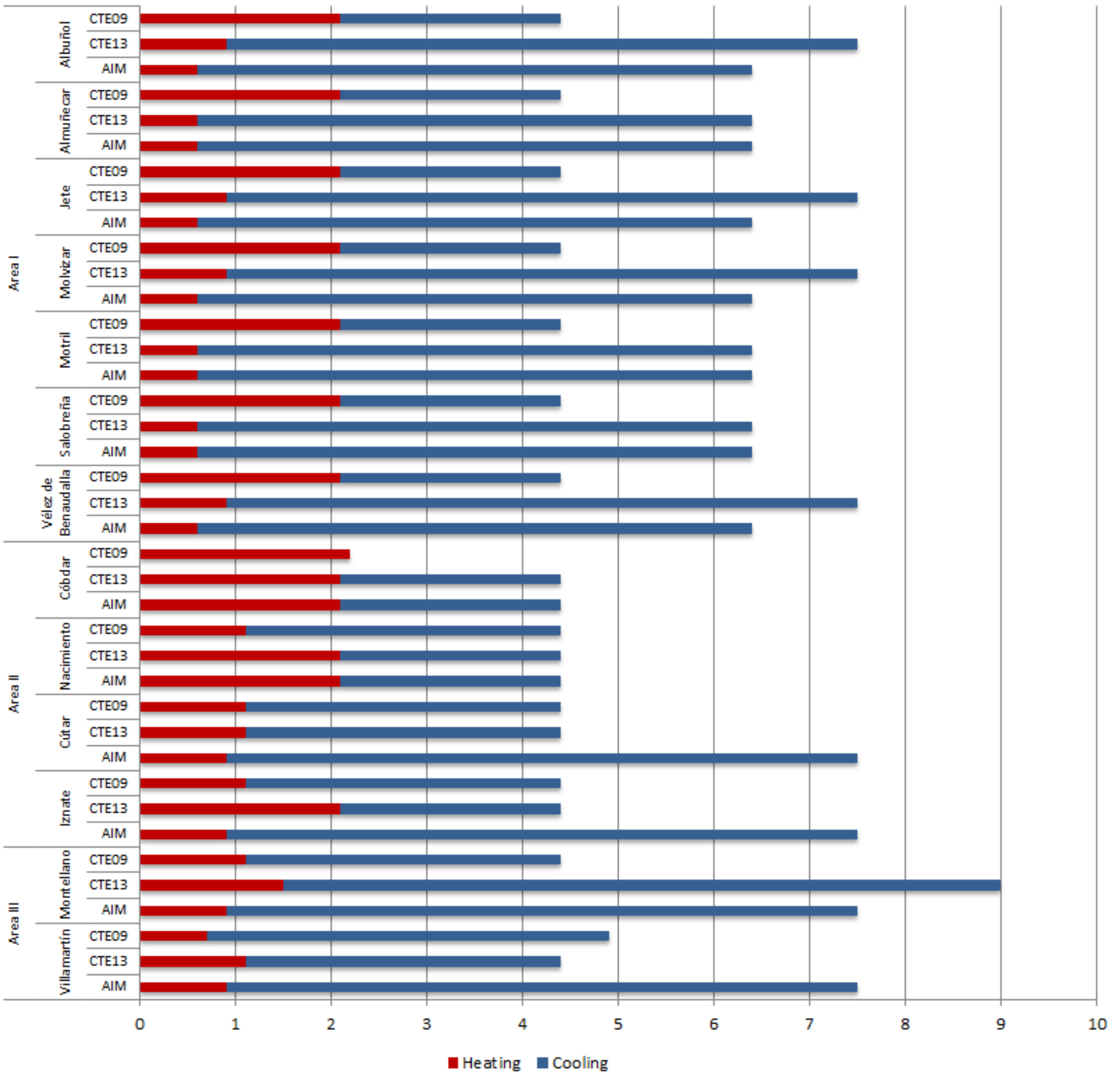

Fig. 26. CO_2 emissions (kg CO_2/m^2 per year).

7.3.3. Energy rating

The energy ratings of housing types were determined in areas with special application problems using different methods to analyse the effects of the climate zone classification, but no significant differences were detected (Table 33). In the case of cities located in a coastal area (Area 1), the CTE13 and the AIM methods obtained the same classification (B) while CTE09 obtained a better classification (A) because of the better ratio of demand with respect to emissions. However, CTE09 had an erroneous climate zone. In the case of cities located at the limits of the highest thresholds (Area 2) no differences were detected; finally no coincidences were found between energy rating values in localities in different provinces but near between them (Area 3).

Table 33. Energy ratings.

Studied Area			**Energy rating**		
Area	**Province**	**City**	**CTE09**	**CTE13**	**AIM**
1	Granada	Albuñol	A	B	B
	Granada	Almuñécar	A	B	B
	Granada	Jete	A	B	B
	Granada	Molvízar	A	B	B
	Granada	Motril	A	B	B
	Granada	Salobreña	A	B	B
	Granada	Vélez de Benaudalla	A	B	B
2	Almería	Cóbdar	A	A	A
	Almería	Nacimiento	A	A	A
	Málaga	Cútar	A	A	A
	Málaga	Iznate	A	A	A
3	Sevilla	Montellano	A	B	A
	Cádiz	Villamartín	B	A	A

The results could be explained by the use of renewable energy (biomass) instead of gasoil or natural gas (Carpio et al. 2013). This choice usually reaches four classes on a scale of seven levels (Carpio et al. 2013). Furthermore, a biomass boiler is considered to be better than a conventional boiler in economic (Chau et al. 2009) and environmental terms (Dion et al. 2011).

7.4. Conclusions

The results of the application of three different methods of determining climatic zones for the calculation of buildings' energy efficiency showed that both methodologies proposed by the CTE present important disadvantages since the results did not always reflect the real climate of the cities. However the new proposed AIM method showed a climatic zone classification more in accordance with the real climatic characteristics of Andalusian cities.

Unsuitable climatic zone classifications have resulted in energy demands as well as CO_2 emissions not consistent with areas' real climatic characteristics (maximum increases of 280.13% and 285.71% respectively according to the method used have been observed) Although these differences have not resulted in significant differences in energy rating, in the case of using renewable fuels instead of fossil fuels, the differences could imply a previous bad building design because the precision in correctly assigning a climatic zone to a dwelling is essential to design it with correct energy efficiency (Carpio et al. 2013), such as installing thermal insulation or other related building materials (Ruiz and Romero. 2011).

Therefore, the proposed approximation and interpolation method is a suitable way to determine climatic zone in areas without available climate data. The use of latitude, altitude, and longitude data is enough to calculate a good approximation of a climatic zone, so the use of this method could be extrapolated to other areas.

CONCLUSIONES

Las aportaciones más importantes que se pueden deducir de este trabajo se han clasificado en cinco secciones de acuerdo a los objetivos de la tesis:

i. El análisis del marco legal relativo a la eficiencia energética de la edificación en Europa y su transposición en España.
ii. La evaluación de la capacidad de potencia instalada en los edificios de un área representativa de España, teniendo en cuenta los diferentes sistemas de calefacción, refrigeración y ACS.
iii. La determinación de las ventajas ambientales y económicas del uso de la biomasa en los edificios residenciales en comparación con las fuentes de energía convencionales.
iv. La evaluación de la influencia del diseño de la envolvente térmica de los edificios en la demanda energética, las emisiones de CO_2 y la calificación energética.
v. La propuesta de un método más riguroso para determinar zonas climáticas utilizando la teoría de la aproximación y la interpolación.

En relación con el análisis comparativo de las distintas transposiciones del marco europeo relativo a la eficiencia energética en la edificación y su transposición en España, se concluye lo siguiente:

- La transposición del marco europeo para cada país ha creado una serie de normas con el mismo origen pero no homogéneo entre sí. En consecuencia, no es posible comparar la eficiencia energética de dos edificios idénticos en diferentes países, ni siquiera teniendo las mismas condiciones climáticas, debido a que las escalas energéticas son diferentes, así como los métodos de cálculo.
- En el caso particular de España, referente a los documentos reconocidos para el cálculo de la edificiencia energética, CEX es el documento más ampliamente utilizado por expertos en la realización de una certificación

energética, seguido por CE3, CALENER VYP y CERMA. La aplicación de los cuatro documentos a un caso de estudio tipo ofrece resultados divergentes, con ≈26% de desviación de las emisiones de CO_2 y un nivel sobre siete en la escala de certificación energética.

- En estos métodos de cálculo y en los documentos reconocidos, el combustible utilizado en los sistemas térmicos, los materiales, soluciones constructivas utilizadas y la zona climática del edificio son fundamentales para la calificación energética final.

En cuanto a la evaluación de la capacidad de potencia instalada en los edificios en un área representativa de España, se han llegado a las siguientes conclusiones:

- En el área de estudio (provincia de Granada) hay un claro predominio de los combustibles fósiles sobre las energías renovables, en particular el gas natural (≈49%); sin embargo, cuando se analiza la calefacción, la fuente predominante de energía es gasoil (≈40%), seguido de gas natural (≈34%). En electricidad de refrigeración se utiliza más ampliamente (≈63%).
- En todos los casos el uso de energías renovables representa un pequeño porcentaje, con independencia del sistema analizado en la provincia de Granada. No obstante la biomasa es la fuente renovable más utilizada, representando un 4,31%, mientras que la energía solar sólo supone el 0,19%.

Referente a la determinación de las ventajas ambientales y económicas del uso de la biomasa en los edificios residenciales en comparación con las fuentes de energía convencionales, se deducen las siguientes conclusiones:

- El uso de la biomasa, en lugar de los combustibles fósiles, supone una importante reducción de las emisiones de CO_2 en todos los casos (hasta el 95% en sustitución de gasoil por biomasa), así como la mejora en la calificación energética de la vivienda; el uso de este biocombustible puede suponer una mejora de hasta cuatro niveles sobre siete en la escala de calificación energética.

- En el caso particular de la provincia de Granada, la sustitución del 20% de las calderas instaladas actualmente por calderas de biomasa, de acuerdo con los objetivos del programa 20-20-20, supondría una reducción de aproximadamente el 16% de las emisiones de CO_2 y el 13% en coste económico.
- Desde el punto de vista económico, el uso de pellets de madera puede dar lugar a un ahorro de hasta el 70%, y aproximadamente el 88% cuando se utilizan astillas de madera o huesos de aceituna en comparación con gasoil.
- En lo que respecta a la demanda energética de una vivienda, la zona climática es claramente un factor determinante. Las ciudades más frías en la península ibérica pueden requerir diez veces más energía que las más cálidas para satisfacer la demanda de calefacción. Del mismo modo, para una demanda conjunta de calefacción, ACS y refrigeración, el consumo sería tres veces mayor en una ciudad fría.

Con respecto a la evaluación de la influencia del diseño de la envolvente de los edificios en la demanda energética, las emisiones de CO_2 y la calificación energética, se concluye lo siguiente:

- El uso de soluciones constructivas con altos valores de transmitancia térmica podría requerir de 179% a 211% de la energía demandada en el mismo edificio cuando se implementa una solución constructiva de bajo valor de transmitancia térmica.
- El uso de soluciones de alta calidad también reduce considerablemente las emisiones de CO_2, alcanzando valores de 65% a 95% de reducción. Además, el uso de soluciones constructivas con alta resistencia térmica mejora el grado de la energía de las viviendas en todos los casos.
- La mejora de la eficiencia energética de los edificios también depende del tipo de edificio considerado y la zona climática. Las viviendas unifamiliares obtienen mayores beneficios que los edificios, con la utilización de

materiales de alta calidad en la envolvente térmica, por tener más superficie exterior en la envolvente por m^2 de superficie del edificio.

Por último, en relación con el método propuesto, basado en la aproximación y la interpolación, para determinar zonas climáticas y su efecto sobre la demanda energética y emisiones de CO_2 de los edificios, se ha podido concluir que:

- En España, la aplicación de las metodologías propuestas por el CTE (CTE09 y CTE13) para la determinación de la zona climática no siempre ha reflejado el verdadero clima de las ciudades, mostrando variaciones de hasta un 285%. Estos resultados dan lugar a errores en el cálculo de la demanda energética, así como de las emisiones de CO_2, lo que implica inadecuado diseño en la fase de proyecto del edifico, así como la instalación de aislamiento térmico o materiales inadecuados.
- El nuevo método de aproximación e interpolación propuesta ha permitido obtener una clasificación de las zonas climáticas más acorde con las características climáticas reales de las ciudades.
- El uso del método de aproximación e interpolación propuesto podría extrapolarse a cualquier otra área, debido a la utilización de la latitud, la altitud y la longitud de datos es suficiente para calcular una buena aproximación de una zona climática.

CONCLUSIONS

The most important contributions that can be deduced from this work can be classified in five sections according to the objectives of the thesis:

i. The comparative analysis of the different transpositions of the EPBD within the European appointed countries and the current documents recognized.
ii. The evaluation of the installed power capacity in buildings in a representative area of Spain, considering the different systems for heating, cooling and DHW.
iii. The determination of the environmental and economic advantages of using biomass in residential buildings as opposed to conventional energy sources.
iv. The evaluation of the influence of the envelope design of buildings in the energy demand, CO_2 emissions and energy rating.
v. The propose of a more rigorous method to determine climatic zones using the approximation and interpolation theory.

In relation to the comparative analysis of the different transpositions of the European framework and the current documents recognized in Spain, it has been concluded that:

- The transposition of the European framework to each country has created a series of regulations with the same origin but not homogeneous among themselves. In consequence it is not possible to compare the energy efficiency of two identical buildings in different States, even having the same climatic conditions, because the energy scales are different, as well as the calculation methods.
- In the particular case of Spain, CEX is the most widely used recognized document by experts when processing an energy certification, followed by CE3, CALENER VYP and CERMA. The application of the four documents to

a case study type provides divergent results, with ≈26% of deviation in CO_2 emissions and a level of seven of the energy certification scale.

- In these calculation methods and in the recognized documents, the fuel used in thermal systems, the materials and construction solutions used and the climate zone of the building are critical for the final energy rating.

Regarding the evaluation of the installed power capacity in buildings in a representative area of Spain, it has been concluded that:

- In the area studied (province of Granada) there is a clear predominance of fossil fuels over renewable energies, in particular natural gas (≈49%); however when heating is analyzed, the predominant source of energy is gasoil (≈40%), following by natural gas (≈34%). In cooling electricity is used most extensively (≈63%).
- In all cases the use of renewable energies accounts for small percentages, irrespective of the system analysed in the province of Granada. Altogether biomass represent 4.31%, while solar power only accounts for 0.19%.

Concerning the determination of the environmental and economic advantages of using biomass in residential buildings as opposed to conventional energy sources, the following conclusions were deduced:

- The use of biomass, instead of fossil fuels, brings about an important reduction of the CO_2 emissions in all cases (up to 95% replacing gasoil by biomass), and improvements up to four points of seven on the scale of residential energy rating is possible.
- In the particular case of the province of Granada, the replacement of 20% of boilers currently installed to biomass boilers according to the objectives of 20-20-20 programme, leading to a reduction of approximately 16% in CO_2 emissions and 13 % in economic cost.

- The use of wood pellets can lead to economic savings of up to 70%, and approximately 88% when wood chips or olive pits are used in comparison with gasoil.
- In regard to the energy demands of a residence, the climatic zone is clearly a determinant factor. The coldest cities on the Iberian Peninsula may require ten times more energy than the warmest ones, to satisfy heating demand. Likewise, for a joint demand of heating, DHW and cooling, consumption would be three times higher in a cold city.

With regards to the evaluation of the influence of the envelope design of buildings in the energy demand, CO_2 emissions and energy rating, it has been concluded that:

- The use of constructive solutions with high values of thermal transmittance could require from 179% to 211% of the energy demanded in the same building when a constructive solution of low U-value is implemented.
- The use of high-quality solutions also reduces considerably the CO_2 emissions, achieving values from 65% to 95% of reduction. In addition, the use of constructive solutions with high thermal resistance enhances the energy rating of the housing units in all the cases.
- The improvement of the energy efficiency of the buildings is also dependent on the type of building considered and the climatic zone. Single-family houses get larger benefits that buildings from the use of high-quality materials in the envelope because of having more surface of envelope per m^2 of building surface.

Finally, in relation to the proposed method based on approximation and interpolation for determining climatic zones and its effect on energy demand and CO_2 emissions from buildings, it was possible to conclude that:

- In Spain, the methodologies proposed by the CTE (CTE09 and CTE13) present important disadvantages since the results did not always reflect the real climate of the cities. However the new proposed approximation and interpolation method showed a climatic zone classification more in accordance with the real climatic characteristics of cities.

- Unsuitable climatic zone classifications have resulted in energy demands as well as CO_2 emissions not consistent with areas' real climatic characteristics with variations up to 285%. These differences imply a previous bad building design, such as installing thermal insulation or other related building materials. The use of the proposed approximation and interpolation method could be extrapolated to anywhere, due to the use of latitude, altitude, and longitude data is enough to calculate a good approximation of a climatic zone.

LÍNEAS FUTURAS DE INVESTIGACIÓN

Del desarrollo del presente estudio se han derivado algunos aspectos los cuales necesitan ser estudiados en profundidad, por lo que se proponen como líneas futuras de investigación:

- Desarrollar una transposición homogénea de la EPBD en los diferentes países de la Unión Europea.
- Armonizar todos los documentos reconocidos en España con el fin de garantizar unos resultados más homogéneos.
- Analizar el rendimiento de las calderas de biomasa ubicadas en edificios no residenciales.
- Diseñar soluciones constructivas y configuraciones adaptadas a los estándares actuales para la eficiencia energética.

FUTURE LINES OF RESEARCH

From the study developed in this work, there have been observed some aspects that need a more detailed analysis. Therefore, they are proposed below as future lines of research:

- Proposal a homogeneous transposition of the EPBD in the different countries of the European Union.
- Harmonize all the recognized documents in Spain in order to ensure more homogenous results than the ones reflected here.
- Analyze the performance of biomass boilers located in non-residential buildings.
- Design constructive solutions and configurations adapted to the current standards for energy efficiency

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ANNEXES

ANNEX 1.- RESULTS FROM THE AIM

Id.	Province	City	Latitude	Longitude	Altitude	Climate Severity		Climatic zone CTE09 method		Climatic zone CTE13 method		Climatic zone AIM method	
						WCS	SCS	Winter	Summer	Winter	Summer	Winter	Summer
1	**Almería**	**Abla***	**37.14114**	**-2.780104**	**871.17**	**0.780**	**1.160**	**C**	**1**	**D**	**3**	**C**	**3**
2	Almería	Abrucena	37.13305	-2.797098	976.94	0.840	1.113	C	1	D	3	C	3
3	Almería	Adra	36.74807	-3.022522	10.98	0.144	1.304	A	4	A	4	A	4
4	Almería	Albánchez	37.28710	-2.181163	481.31	0.675	1.046	B	3	C	3	C	3
5	Almería	Alboloduy	37.03319	-2.621750	388.43	0.463	1.176	B	3	B	3	B	3
6	Almería	Albox	37.38979	-2.147483	426.43	0.618	1.078	B	3	C	3	C	3
7	Almería	Alcolea	36.97449	-2.961038	744.70	0.727	1.110	C	1	C	3	C	3
8	Almería	Alcóntar	37.33585	-2.596944	955.13	1.023	1.040	C	1	D	3	D	3
9	Almería	Alcudia de Monteagud	37.23598	-2.266174	1018.35	0.812	1.067	D	1	D	3	C	3
10	Almería	Alhabia	36.98930	-2.587667	288.06	0.289	1.265	B	3	B	3	A	4
11	Almería	Alhama de Almería	36.95742	-2.570075	523.20	0.598	1.147	B	3	C	3	B	3
12	Almería	Alicún	36.96630	-2.601994	420.49	0.471	1.178	B	3	C	3	B	3
13	Almería	Almería	36.84016	-2.467922	27.01	0.122	1.292	A	4	A	4	A	4
14	Almería	Almócita	37.00236	-2.790071	831.13	0.633	1.181	C	1	D	3	C	3
15	Almería	Alsodux	37.00200	-2.594579	312.04	0.324	1.244	B	3	B	3	B	3
16	**Almería**	**Antas***	**37.24516**	**-1.917543**	**107.26**	**0.320**	**1.160**	**A**	**4**	**B**	**4**	**B**	**3**
17	Almería	Arboleas	37.35025	-2.074867	288.08	0.272	1.201	B	3	B	3	A	3
18	Almería	Armuña de Almanzora	37.34969	-2.411396	625.53	0.958	1.002	C	1	C	3	D	3
19	Almería	Bacares	37.26083	-2.454761	1202.63	0.819	0.964	D	1	D	3	C	3
20	Almería	Bayárcal	37.03116	-2.996469	1271.17	0.786	0.925	D	1	D	3	C	3
21	Almería	Bayarque	37.33091	-2.435660	816.22	0.992	1.018	C	1	D	3	D	3
22	Almería	Bédar	37.18964	-1.981898	391.56	0.409	1.087	B	3	B	3	B	3

Id.	Province	City	Latitude	Longitude	Altitude	Climate Severity		Climatic zone CTE09 method		Climatic zone CTE13 method		Climatic zone AIM method	
						WCS	SCS	Winter	Summer	Winter	Summer	Winter	Summer
23	Almería	Beires	37.01200	-2.790928	919.23	0.655	1.186	C	1	D	3	C	3
24	Almería	Benahadux	36.92587	-2.455683	113.97	0.151	1.338	A	4	B	4	A	4
25	Almería	Benitagla	37.23124	-2.239107	945.09	0.792	1.099	C	1	D	3	C	3
26	Almería	Benizalón	37.21175	-2.241685	933.75	0.766	1.112	C	1	D	3	C	3
27	Almería	Bentarique	36.98652	-2.619420	319.80	0.333	1.243	B	3	B	3	B	3
28	Almería	Berja	36.84644	-2.949425	340.79	0.347	1.303	B	3	B	3	B	4
29	Almería	Canjáyar	37.00973	-2.739681	607.97	0.763	1.078	C	1	C	3	C	3
30	Almería	Cantoria	37.35259	-2.193626	388.66	0.526	1.101	B	3	B	3	B	3
31	**Almería**	**Carboneras***	**36.99659**	**-1.895012**	**6.72**	**0.120**	**1.260**	**A**	**4**	**A**	**4**	**A**	**4**
32	Almería	Castro de Filabres	37.18464	-2.439524	943.71	0.785	1.127	C	1	D	3	C	3
33	Almería	Chercos	37.26633	-2.257897	789.68	0.871	1.038	C	1	C	3	C	3
34	Almería	Chirivel	37.59560	-2.264839	1039.71	1.024	0.955	D	1	D	3	D	3
35	Almería	Cóbdar	37.26199	-2.210223	607.00	0.833	1.008	C	1	C	3	C	3
36	**Almería**	**Cuevas del Almanzora***	**37.29709**	**-1.881476**	**97.29**	**0.210**	**1.330**	**A**	**4**	**A**	**4**	**A**	**4**
37	Almería	Dalías	36.82121	-2.870697	415.96	0.415	1.262	B	3	C	3	B	4
38	Almería	Ejido (El)	36.77506	-2.812738	80.00	0.144	1.334	A	4	A	4	A	4
39	Almería	Enix	36.87704	-2.602107	720.63	0.569	1.164	C	1	C	3	B	3
40	Almería	Felix	36.86892	-2.657921	822.43	0.508	1.204	C	1	D	3	B	3
41	Almería	Fiñana	37.17101	-2.840678	950.42	0.890	1.113	C	1	D	3	C	3
42	Almería	Fines	37.35888	-2.262964	448.70	0.672	1.072	B	3	C	3	C	3
43	Almería	Fondón	36.97942	-2.858356	858.47	0.623	1.190	C	1	D	3	C	3
44	Almería	Gádor	36.95393	-2.492936	169.00	0.178	1.334	A	4	B	4	A	4

Id.	Province	City	Latitude	Longitude	Altitude	Climate Severity		Climatic zone CTE09 method		Climatic zone CTE13 method		Climatic zone AIM method	
						WCS	SCS	Winter	Summer	Winter	Summer	Winter	Summer
45	Almería	Gallardos (Los)	37.16948	-1.940099	113.99	0.169	1.318	A	4	B	4	A	4
46	Almería	Garrucha	37.17925	-1.821901	2.57	0.174	1.292	A	4	A	4	A	4
47	Almería	Gérgal	37.12070	-2.538305	750.50	0.776	1.082	C	1	C	3	C	3
48	Almería	Huécija	36.96788	-2.611436	410.04	0.458	1.184	B	3	C	3	B	3
49	Almería	Huércal-Overa	37.39063	-1.943684	284.61	0.322	1.147	B	3	B	3	B	3
50	Almería	Huércal de Almería	36.88415	-2.435978	72.53	0.133	1.320	A	4	A	4	A	4
51	Almería	Illar	36.98504	-2.639302	428.12	0.504	1.168	B	3	C	3	B	3
52	Almería	Instinción	36.99316	-2.659945	434.57	0.525	1.162	B	3	C	3	B	3
53	Almería	Laroya	37.29667	-2.329601	854.09	0.902	1.057	C	1	D	3	C	3
54	Almería	Láujar de Andarax	36.99384	-2.889220	910.99	0.660	1.181	C	1	D	3	C	3
55	Almería	Líjar	37.29527	-2.219928	593.50	0.847	1.007	B	3	C	3	C	3
56	Almería	Lubrín	37.21585	-2.067055	521.52	0.665	1.037	B	3	C	3	C	3
57	Almería	Lucainena de las Torres	37.04179	-2.200706	533.88	0.585	1.095	B	3	C	3	B	3
58	Almería	Lúcar	37.39965	-2.427074	901.75	1.048	1.015	C	1	D	3	D	3
59	Almería	Macael	37.33229	-2.304892	538.73	0.824	1.025	B	3	C	3	C	3
60	Almería	María	37.71110	-2.165795	1196.44	0.903	0.915	D	1	D	3	C	3
61	Almería	Mojácar	37.13995	-1.851328	165.06	0.158	1.263	A	4	B	4	A	4
62	Almería	Mojonera (La)	36.75254	-2.688159	41.25	0.121	1.292	A	4	A	4	A	4
63	Almería	Nacimiento	37.10497	-2.647740	596.90	0.822	1.035	B	3	C	3	C	3
64	Almería	Níjar	36.96576	-2.206510	353.12	0.294	1.179	B	3	B	3	A	3
65	Almería	Ohanes	37.03723	-2.745168	953.43	0.697	1.164	C	1	D	3	C	3
66	Almería	Olula de Castro	37.17611	-2.476297	1054.84	0.811	1.061	D	1	D	3	C	3

Id.	Province	City	Latitude	Longitude	Altitude	Climate Severity		Climatic zone CTE09 method		Climatic zone CTE13 method		Climatic zone AIM method	
						WCS	SCS	Winter	Summer	Winter	Summer	Winter	Summer
67	Almería	Olula del Río	37.35212	-2.298121	486.60	0.749	1.052	B	3	C	3	C	3
68	Almería	Oria	37.48503	-2.295018	1038.98	0.992	0.974	D	1	D	3	D	3
69	Almería	Padules	36.99884	-2.773482	745.10	0.704	1.118	C	1	C	3	C	3
70	Almería	Partaloa	37.40604	-2.226434	548.59	0.859	1.030	B	3	C	3	C	3
71	Almería	Paterna del Río	37.02088	-2.953087	1201.81	0.784	0.967	D	1	D	3	C	3
72	Almería	Pechina	36.91667	-2.440625	107.51	0.146	1.334	A	4	B	4	A	4
73	Almería	Pulpí	37.41183	-1.745502	194.99	0.259	1.220	A	4	B	4	A	3
74	Almería	Purchena	37.34855	-2.361550	541.00	0.850	1.028	B	3	C	3	C	3
75	Almería	Rágol	36.99564	-2.680989	404.83	0.482	1.181	B	3	C	3	B	3
76	Almería	Rioja	36.94406	-2.462424	133.21	0.161	1.340	A	4	B	4	A	4
77	Almería	Roquetas de Mar	36.76427	-2.614935	11.85	0.115	1.271	A	4	A	4	A	4
78	Almería	Santa Cruz de Marchena	37.01720	-2.603768	328.97	0.355	1.228	B	3	B	3	B	3
79	Almería	Santa Fe de Mondújar	36.97506	-2.530279	210.60	0.209	1.318	B	3	B	4	A	4
80	Almería	Senés	37.20457	-2.347544	1007.39	0.803	1.084	D	1	D	3	C	3
81	Almería	Serón	37.34361	-2.508077	800.14	1.033	1.002	C	1	D	3	D	3
82	Almería	Sierro	37.32348	-2.398526	721.07	0.989	0.991	C	1	C	3	D	3
83	Almería	Somontín	37.39139	-2.389127	816.81	1.054	0.991	C	1	D	3	D	3
84	Almería	Sorbas	37.09841	-2.126351	391.58	0.394	1.117	B	3	B	3	B	3
85	Almería	Suflí	37.33820	-2.389523	636.85	0.955	0.998	C	1	C	3	D	3
86	Almería	Tabernas	37.04945	-2.392681	405.96	0.451	1.143	B	3	C	3	B	3
87	Almería	Taberno	37.46729	-2.076205	702.80	1.004	0.987	C	1	C	3	D	3
88	Almería	Tahal	37.22803	-2.284970	1008.58	0.809	1.075	D	1	D	3	C	3

Id.	Province	City	Latitude	Longitude	Altitude	Climate Severity		Climatic zone CTE09 method		Climatic zone CTE13 method		Climatic zone AIM method	
						WCS	SCS	Winter	Summer	Winter	Summer	Winter	Summer
89	Almería	Terque	36.98359	-2.597233	282.44	0.282	1.272	B	3	B	3	A	4
90	Almería	Tíjola	37.34551	-2.439434	685.38	1.004	0.991	C	1	C	3	D	3
91	Almería	Tres Villas (Las)	37.13334	-2.700000	693.09	0.867	1.033	C	1	C	3	C	3
92	Almería	Turre	37.15225	-1.894899	49.41	0.163	1.316	A	4	A	4	A	4
93	Almería	Turrillas	37.03019	-2.264096	840.34	0.558	1.180	C	1	D	3	B	3
94	Almería	Uleila del Campo	37.18548	-2.203801	629.61	0.783	1.024	C	1	C	3	C	3
95	Almería	Urrácal	37.39732	-2.365070	744.76	1.056	0.978	C	1	C	3	D	3
96	Almería	Velefique	37.19375	-2.403687	937.57	0.785	1.124	C	1	D	3	C	3
97	Almería	Vélez-Blanco	37.69095	-2.095682	1072.43	0.975	0.944	D	1	D	3	D	3
98	Almería	Vélez-Rubio	37.64802	-2.074232	842.29	1.099	0.998	C	1	D	3	D	3
99	Almería	Vera	37.24686	-1.868238	102.07	0.191	1.322	A	4	B	4	A	4
100	Almería	Viator	36.88963	-2.426541	74.79	0.134	1.321	A	4	A	4	A	4
101	Almería	Vícar	36.83145	-2.642515	276.26	0.229	1.299	B	3	B	3	A	4
102	Almería	Zurgena	37.34265	-2.039607	248.16	0.272	1.201	B	3	B	4	A	3
103	Cádiz	Alcalá de los Gazules	36.46045	-5.723718	158.40	0.453	1.565	A	3	B	3	B	4
104	Cádiz	Alcalá del Valle	36.90491	-5.173237	623.34	0.817	1.155	C	1	C	2	C	3
105	Cádiz	Algar	36.65533	-5.657418	213.08	0.489	1.609	B	3	B	3	B	4
106	Cádiz	Algeciras	36.12978	-5.447698	22.41	0.159	1.112	A	3	A	3	A	3
107	Cádiz	Algodonales	36.88092	-5.405773	370.12	0.411	1.504	B	3	B	3	B	4
108	Cádiz	Arcos de la Frontera	36.75078	-5.812395	139.21	0.542	1.587	A	3	A	3	B	4
109	Cádiz	Barbate	36.19282	-5.918903	15.97	0.213	1.152	A	3	A	3	A	3
110	Cádiz	Barrios (Los)	36.18539	-5.492747	25.34	0.181	1.146	A	3	A	3	A	3

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111	Cádiz	Benalup-Casas Viejas	36.34284	-5.809400	75.25	0.334	1.373	A	3	A	3	B	4
112	Cádiz	Benaocaz	36.69952	-5.421263	792.07	0.950	0.780	C	1	C	2	C	2
113	Cádiz	Bornos	36.81459	-5.743362	153.59	0.559	1.570	A	3	B	3	B	4
114	Cádiz	Bosque (El)	36.75752	-5.506988	273.19	0.427	1.582	B	3	B	3	B	4
115	Cádiz	Cádiz	36.52969	-6.292657	15.42	0.326	1.324	A	3	A	3	B	4
116	Cádiz	Castellar de la Frontera	36.28621	-5.419937	30.78	0.208	1.200	A	3	A	3	A	3
117	Cádiz	Chiclana de la Frontera	36.41915	-6.149412	13.25	0.292	1.284	A	3	A	3	A	4
118	Cádiz	Chipiona	36.74080	-6.435870	11.72	0.354	1.233	A	3	A	3	B	3
119	Cádiz	Conil de la Frontera	36.27675	-6.088436	33.71	0.270	1.239	A	3	A	3	A	3
120	Cádiz	Espera	36.87319	-5.806213	147.47	0.564	1.535	A	3	A	3	B	4
121	Cádiz	Gastor (El)	36.85509	-5.323623	600.30	0.733	1.223	C	1	C	2	C	3
122	Cádiz	Grazalema	36.75837	-5.366071	830.53	0.976	0.755	C	1	C	2	D	2
123	**Cádiz**	**Jerez de la Frontera***	**36.68656**	**-6.137173**	**55.75**	**0.430**	**1.490**	**A**	**3**	**A**	**3**	**B**	**4**
124	**Cádiz**	**Jimena de la Frontera***	**36.43404**	**-5.453479**	**131.44**	**0.410**	**1.510**	**A**	**3**	**A**	**3**	**B**	**4**
125	Cádiz	Línea de la Concepción (La)	36.16118	-5.348256	10.40	0.142	1.095	A	3	A	3	A	3
126	Cádiz	Medina-Sidonia	36.46768	-5.927894	246.04	0.429	1.578	B	3	B	3	B	4
127	Cádiz	Olvera	36.93525	-5.267688	606.73	0.795	1.181	C	1	C	2	C	3
128	Cádiz	Paterna de Rivera	36.52333	-5.866053	125.97	0.464	1.568	A	3	A	3	B	4
129	Cádiz	Prado del Rey	36.78968	-5.555545	423.15	0.387	1.559	B	3	B	3	B	4
130	Cádiz	Puerto de Santa María (El)	36.59695	-6.227526	14.76	0.347	1.359	A	3	A	3	B	4
131	Cádiz	Puerto Real	36.52912	-6.191895	11.79	0.324	1.336	A	3	A	3	B	4
132	Cádiz	Puerto Serrano	36.92159	-5.545621	162.27	0.564	1.553	A	3	B	3	B	4

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133	Cádiz	Rota	36.61699	-6.358202	14.29	0.343	1.318	A	3	A	3	B	4
134	Cádiz	San Fernando	36.46572	-6.196626	21.14	0.317	1.327	A	3	A	3	B	4
135	Cádiz	San José del Valle	36.60554	-5.798952	142.06	0.501	1.602	A	3	A	3	B	4
136	Cádiz	San Roque	36.20975	-5.384572	106.11	0.269	1.313	A	3	A	3	A	4
137	Cádiz	Sanlúcar de Barrameda	36.77882	-6.354198	11.00	0.368	1.240	A	3	A	3	B	3
138	Cádiz	Setenil de las Bodegas	36.86406	-5.181413	555.05	0.640	1.367	B	3	C	3	C	4
139	Cádiz	Tarifa	36.01271	-5.602954	14.66	0.140	1.056	A	3	A	3	A	3
140	Cádiz	Torre Alháquime	36.91553	-5.234736	471.36	0.536	1.438	B	3	C	3	B	4
141	Cádiz	Trebujena	36.86951	-6.176695	72.17	0.473	1.380	A	3	A	3	B	4
142	Cádiz	Ubrique	36.67771	-5.446557	326.72	0.352	1.636	B	3	B	3	B	4
143	Cádiz	Vejer de la Frontera	36.25331	-5.962856	178.68	0.375	1.446	A	3	B	3	B	4
144	Cádiz	Villaluenga del Rosario	36.69587	-5.388137	874.97	0.953	0.735	C	1	D	2	D	2
145	**Cádiz**	**Villamartín***	**36.86132**	**-5.641834**	**167.81**	**0.560**	**1.560**	**A**	**3**	**B**	**3**	**B**	**4**
146	Cádiz	Zahara	36.84053	-5.390547	507.40	0.517	1.462	B	3	C	3	B	4
147	Córdoba	Adamuz	38.02736	-4.524873	245.24	0.591	1.609	B	4	C	4	B	4
148	Córdoba	Aguilar de la Frontera	37.51503	-4.656057	374.60	0.577	1.537	C	3	C	4	B	4
149	Córdoba	Alcaracejos	38.38823	-4.967684	611.31	0.659	1.394	D	1	D	3	C	4
150	Córdoba	Almedinilla	37.43900	-4.091205	643.68	0.835	1.426	D	1	D	3	C	4
151	Córdoba	Almodóvar del Río	37.80959	-5.019958	119.84	0.461	1.668	B	4	B	4	B	4
152	Córdoba	Añora	38.41099	-4.897461	629.97	0.670	1.385	D	1	D	3	C	4
153	Córdoba	Baena	37.61441	-4.326089	432.86	0.647	1.565	C	3	C	4	C	4
154	Córdoba	Belalcázar	38.57843	-5.167119	492.91	0.637	1.430	C	3	C	4	C	4

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155	Córdoba	Belmez	38.27234	-5.208753	530.04	0.621	1.451	D	1	C	4	C	4
156	Córdoba	Benamejí	37.26732	-4.540418	458.93	0.830	1.250	C	3	C	4	C	3
157	Córdoba	Blázquez (Los)	38.40650	-5.438988	594.36	0.671	1.341	D	1	D	3	C	4
158	Córdoba	Bujalance	37.89657	-4.383588	345.51	0.569	1.770	C	3	C	4	B	4
159	Córdoba	Cabra	37.47437	-4.425931	503.62	0.746	1.392	C	3	C	4	C	4
160	Córdoba	Cañete de las Torres	37.86741	-4.318819	320.61	0.562	1.760	C	3	C	4	B	4
161	**Córdoba**	**Carcabuey***	**37.44359**	**-4.273436**	**628.29**	**0.780**	**1.420**	**D**	**1**	**D**	**3**	**C**	**4**
162	Córdoba	Cardeña	38.27047	-4.323730	747.52	0.755	1.425	D	1	D	3	C	4
163	Córdoba	Carlota (La)	37.67361	-4.932553	215.46	0.419	1.714	B	4	C	4	B	4
164	Córdoba	Carpio (El)	37.94054	-4.498775	180.55	0.547	1.599	B	4	C	4	B	4
165	Córdoba	Castro del Río	37.68864	-4.481579	229.53	0.445	1.744	B	4	C	4	B	4
166	Córdoba	Conquista	38.40844	-4.500968	597.37	0.641	1.500	D	1	D	3	C	4
167	Córdoba	Córdoba	37.88473	-4.779152	131.91	0.492	1.634	B	4	B	4	B	4
168	Córdoba	Doña Mencía	37.55457	-4.357603	598.44	0.694	1.457	D	1	D	3	C	4
169	Córdoba	Dos Torres	38.44524	-4.894932	589.48	0.651	1.421	D	1	D	3	C	4
170	Córdoba	Encinas Reales	37.27488	-4.489717	446.92	0.814	1.264	C	3	C	4	C	4
171	Córdoba	Espejo	37.68211	-4.552363	391.46	0.565	1.640	C	3	C	4	B	4
172	Córdoba	Espiel	38.18865	-5.018202	548.57	0.614	1.472	D	1	C	4	C	4
173	Córdoba	Fernán-Núñez	37.67226	-4.723994	310.79	0.472	1.679	B	4	C	4	B	4
174	Córdoba	Fuente-Tójar	37.51163	-4.148019	589.32	0.749	1.436	D	1	D	3	C	4
175	Córdoba	Fuente la Lancha	38.42257	-5.048906	560.00	0.640	1.428	D	1	D	3	C	4
176	Córdoba	Fuente Obejuna	38.26675	-5.419834	622.75	0.690	1.293	D	1	D	3	C	4

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177	Córdoba	Fuente Palmera	37.70319	-5.103904	160.08	0.440	1.686	B	4	C	4	B	4
178	Córdoba	Granjuela (La)	38.37110	-5.351436	554.32	0.643	1.397	D	1	D	3	C	4
179	Córdoba	Guadalcázar	37.75755	-4.944630	161.67	0.446	1.694	B	4	C	4	B	4
180	Córdoba	Guijo (El)	38.49629	-4.782716	565.62	0.646	1.444	D	1	D	3	C	4
181	Córdoba	Hinojosa del Duque	38.50099	-5.148333	551.71	0.646	1.408	D	1	D	3	C	4
182	Córdoba	Hornachuelos	37.83084	-5.242984	177.46	0.469	1.627	B	4	C	4	B	4
183	Córdoba	Iznájar	37.25726	-4.308423	519.91	0.945	1.192	D	1	C	4	C	3
184	Córdoba	Lucena	37.40873	-4.485598	494.18	0.786	1.340	C	3	C	4	C	4
185	Córdoba	Luque	37.55932	-4.276523	662.41	0.775	1.448	D	1	D	3	C	4
186	Córdoba	Montalbán de Córdoba	37.58292	-4.749699	277.86	0.436	1.699	B	4	C	4	B	4
187	Córdoba	Montemayor	37.64862	-4.698889	386.19	0.552	1.604	C	3	C	4	B	4
188	Córdoba	Montilla	37.58963	-4.638313	385.78	0.570	1.575	C	3	C	4	B	4
189	**Córdoba**	**Montoro***	**38.02617**	**-4.381874**	**201.33**	**0.600**	**1.560**	**B**	**4**	**C**	**4**	**B**	**4**
190	Córdoba	Monturque	37.47332	-4.581713	377.00	0.602	1.509	C	3	C	4	C	4
191	Córdoba	Moriles	37.43526	-4.608767	379.15	0.617	1.476	C	3	C	4	C	4
192	Córdoba	Nueva Carteya	37.58566	-4.467291	444.77	0.647	1.524	C	3	C	4	C	4
193	Córdoba	Obejo	38.13433	-4.800506	692.87	0.713	1.317	D	1	D	3	C	4
194	Córdoba	Palenciana	37.24920	-4.583651	396.52	0.710	1.322	C	3	C	4	C	4
195	**Córdoba**	**Palma del Río***	**37.70163**	**-5.283767**	**60.92**	**0.450**	**1.640**	**B**	**4**	**B**	**4**	**B**	**4**
196	Córdoba	Pedro Abad	37.96708	-4.457226	163.28	0.557	1.575	B	4	C	4	B	4
197	Córdoba	Pedroche	38.42873	-4.763438	623.13	0.662	1.416	D	1	D	3	C	4
198	Córdoba	Peñarroya-Pueblonuevo	38.30304	-5.272851	541.69	0.630	1.426	D	1	C	4	C	4

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199	Córdoba	Posadas	37.80041	-5.107038	88.41	0.457	1.664	B	4	B	4	B	4
200	Córdoba	Pozoblanco	38.37742	-4.848376	652.38	0.680	1.375	D	1	D	3	C	4
201	Córdoba	Priego de Córdoba	37.43890	-4.194839	657.66	0.824	1.436	D	1	D	3	C	4
202	Córdoba	Puente Genil	37.39051	-4.770465	219.07	0.439	1.792	B	4	C	4	B	4
203	Córdoba	Rambla (La)	37.60816	-4.741319	331.65	0.493	1.637	C	3	C	4	B	4
204	Córdoba	Rute	37.32587	-4.371301	632.54	0.867	1.301	D	1	D	3	C	4
205	Córdoba	San Sebastián de los Ballesteros	37.65493	-4.824157	306.46	0.461	1.664	B	4	C	4	B	4
206	Córdoba	Santa Eufemia	38.59544	-4.902765	547.03	0.653	1.411	D	1	C	4	C	4
207	**Córdoba**	**Santaella***	**37.56627**	**-4.845094**	**238.22**	**0.410**	**1.740**	**B**	**4**	**C**	**4**	**B**	**4**
208	Córdoba	Torrecampo	38.47510	-4.679456	576.43	0.646	1.459	D	1	D	3	C	4
209	Córdoba	Valenzuela	37.77508	-4.219841	341.02	0.568	1.750	C	3	C	4	B	4
210	Córdoba	Valsequillo	38.40498	-5.351680	578.05	0.658	1.369	D	1	D	3	C	4
211	Córdoba	Victoria (La)	37.88327	-4.784959	122.82	0.490	1.635	B	4	B	4	B	4
212	Córdoba	Villa del Río	37.98227	-4.290878	164.00	0.576	1.559	B	4	C	4	B	4
213	Córdoba	Villafranca de Córdoba	37.96193	-4.545728	143.05	0.541	1.578	B	4	B	4	B	4
214	Córdoba	Villaharta	38.13951	-4.903052	578.87	0.620	1.458	D	1	D	3	C	4
215	Córdoba	Villanueva de Córdoba	38.32279	-4.628341	728.59	0.744	1.344	D	1	D	3	C	4
216	Córdoba	Villanueva del Duque	38.39297	-5.000132	583.85	0.646	1.417	D	1	D	3	C	4
217	Córdoba	Villanueva del Rey	38.19965	-5.151443	556.63	0.626	1.431	D	1	D	3	C	4
218	Córdoba	Villaralto	38.45571	-4.984371	586.78	0.653	1.406	D	1	D	3	C	4
219	Córdoba	Villaviciosa de Córdoba	38.07598	-5.014214	699.25	0.749	1.220	D	1	D	3	C	3
220	Córdoba	Viso (El)	38.48270	-4.955392	578.68	0.651	1.413	D	1	D	3	C	4

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221	Córdoba	Zuheros	37.54314	-4.316415	652.79	0.755	1.452	D	1	D	3	C	4
222	Granada	Agrón	37.03058	-3.829724	1057.49	0.949	0.927	D	2	D	3	C	3
223	Granada	Alamedilla	37.58174	-3.244309	867.96	1.269	0.995	C	3	D	3	D	3
224	Granada	Albolote	37.23085	-3.657415	650.21	1.072	1.021	C	3	C	3	D	3
225	Granada	Albondón	36.82729	-3.210813	894.42	0.621	1.142	C	3	D	3	C	3
226	Granada	Albuñán	37.22719	-3.133893	1115.98	0.974	0.956	D	2	D	3	D	3
227	Granada	Albuñol	36.79125	-3.203485	247.21	0.262	1.402	C	3	B	4	A	4
228	Granada	Albuñuelas	36.92820	-3.631472	728.18	0.850	1.054	C	3	C	3	C	3
229	Granada	Aldeire	37.16264	-3.072488	1274.02	0.856	0.897	D	1	D	3	C	2
230	Granada	Alfacar	37.23657	-3.570654	915.65	1.100	1.000	C	3	D	3	D	3
231	Granada	Algarinejo	37.32492	-4.158846	596.21	0.924	1.229	C	3	C	4	C	3
232	Granada	Alhama de Granada	37.00252	-3.988389	890.95	0.920	0.992	C	3	D	3	C	3
233	Granada	Alhendín	37.10760	-3.645584	736.65	0.973	1.050	C	3	C	3	D	3
234	Granada	Alicún de Ortega	37.60968	-3.137986	692.78	1.024	1.259	C	3	C	3	D	4
235	Granada	Almegíjar	36.90245	-3.299801	811.47	0.705	1.122	C	3	D	3	C	3
236	Granada	Almuñécar	36.73454	-3.690736	24.02	0.205	1.367	C	3	A	4	A	4
237	Granada	Alpujarra de la Sierra	36.98150	-3.157129	1238.54	0.793	0.930	D	1	D	3	C	3
238	Granada	Alquife	37.17983	-3.116288	1202.95	0.899	0.922	D	1	D	3	C	3
239	Granada	Arenas del Rey	36.95771	-3.894323	870.34	0.874	1.015	C	3	D	3	C	3
240	Granada	Armilla	37.14010	-3.617981	671.62	1.044	0.990	C	3	C	3	D	3
241	Granada	Atarfe	37.22290	-3.687416	604.92	1.096	0.937	C	3	C	3	D	3
242	Granada	Baza	37.49065	-2.774473	850.30	1.234	0.969	C	3	D	3	D	3

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243	Granada	Beas de Granada	37.21916	-3.481737	1068.34	1.046	0.942	D	2	D	3	D	3
244	Granada	Beas de Guadix	37.27940	-3.205976	955.70	1.129	1.013	D	2	D	3	D	3
245	Granada	Benalúa	37.35030	-3.169040	858.69	1.171	0.992	C	3	D	3	D	3
246	Granada	Benalúa de las Villas	37.42758	-3.683473	848.78	1.182	0.989	C	3	D	3	D	3
247	Granada	Benamaurel	37.60913	-2.699214	719.23	1.138	1.108	C	3	C	3	D	3
248	Granada	Bérchules	36.97672	-3.190379	1330.12	0.783	0.885	D	1	E	1	C	2
249	Granada	Bubión	36.94883	-3.356741	1298.58	0.801	0.882	D	1	D	3	C	2
250	Granada	Busquístar	36.93771	-3.294846	1160.20	0.799	0.962	D	1	D	3	C	3
251	Granada	Cacín	37.05995	-3.916890	702.00	0.983	1.036	C	3	C	3	D	3
252	Granada	Cádiar	36.94673	-3.180546	926.39	0.713	1.133	C	3	D	3	C	3
253	Granada	Cájar	37.13422	-3.570618	730.57	0.988	1.048	C	3	C	3	D	3
254	Granada	Calahorra (La)	37.18137	-3.064513	1198.75	0.893	0.929	D	1	D	3	C	3
255	Granada	Calicasas	37.27329	-3.618200	764.55	1.050	1.102	C	3	C	3	D	3
256	Granada	Campotéjar	37.48131	-3.616497	925.54	1.248	0.933	C	3	D	3	D	3
257	Granada	Cáñar	36.92661	-3.428235	1026.40	0.803	1.028	D	2	D	3	C	3
258	Granada	Caniles	37.43626	-2.722401	914.92	1.170	0.991	C	3	D	3	D	3
259	Granada	Capileira	36.96122	-3.358654	1444.89	0.782	0.828	D	1	E	1	C	2
260	Granada	Carataunas	36.92287	-3.408202	761.69	0.778	1.087	C	3	C	3	C	3
261	Granada	Cástaras	36.93169	-3.253733	1021.06	0.768	1.061	D	2	D	3	C	3
262	Granada	Castilléjar	37.71470	-2.642967	770.95	1.146	1.164	C	3	C	3	D	3
263	Granada	Castril	37.79573	-2.779088	904.82	1.188	1.095	C	3	D	3	D	3
264	Granada	Cenes de la Vega	37.15931	-3.537524	746.42	0.992	1.059	C	3	C	3	D	3

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265	Granada	Chauchina	37.20142	-3.772540	552.42	1.077	0.936	C	3	C	4	D	3
266	Granada	Chimeneas	37.13137	-3.823198	699.71	1.013	1.049	C	3	C	3	D	3
267	Granada	Churriana de la Vega	37.14777	-3.645950	657.35	1.060	0.973	C	3	C	3	D	3
268	Granada	Cijuela	37.19989	-3.810801	539.73	1.060	0.963	C	3	C	4	D	3
269	Granada	Cogollos de Guadix	37.22443	-3.161336	1142.02	0.961	0.939	D	2	D	3	D	3
270	Granada	Cogollos de la Vega	37.27486	-3.572908	997.72	1.133	0.952	D	2	D	3	D	3
271	Granada	Colomera	37.37206	-3.713820	855.02	1.154	0.993	C	3	D	3	D	3
272	Granada	Cortes de Baza	37.65493	-2.769917	707.98	1.087	1.188	C	3	C	3	D	3
273	Granada	Cortes y Graena	37.30363	-3.218777	976.44	1.147	0.994	D	2	D	3	D	3
274	Granada	Cuevas del Campo	37.60847	-2.931033	832.76	1.258	1.028	C	3	D	3	D	3
275	Granada	Cúllar	37.58368	-2.576282	895.67	1.206	0.983	C	3	D	3	D	3
276	Granada	Cúllar Vega	37.15327	-3.670436	643.17	1.074	0.954	C	3	C	3	D	3
277	Granada	Darro	37.35002	-3.292531	1115.74	1.066	0.914	D	2	D	3	D	3
278	Granada	Dehesas de Guadix	37.58868	-3.102278	684.30	1.034	1.237	C	3	C	3	D	3
279	Granada	Deifontes	37.32524	-3.594484	744.61	1.067	1.146	C	3	C	3	D	3
280	Granada	Diezma	37.32085	-3.331664	1227.45	0.978	0.867	D	1	D	3	D	2
281	Granada	Dílar	37.07499	-3.601624	878.01	0.918	1.055	C	3	D	3	C	3
282	Granada	Dólar	37.18004	-2.989589	1204.45	0.877	0.934	D	1	D	3	C	3
283	Granada	Dúdar	37.18567	-3.484442	812.03	0.993	1.056	C	3	D	3	D	3
284	Granada	Dúrcal	36.98793	-3.566160	786.65	0.847	1.069	C	3	C	3	C	3
285	Granada	Escúzar	37.06251	-3.761499	873.65	0.929	1.034	C	3	D	3	C	3
286	Granada	Ferreira	37.17229	-3.036083	1267.67	0.857	0.902	D	1	D	3	C	3

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287	Granada	Fonelas	37.41344	-3.173344	785.62	1.187	1.010	C	3	C	3	D	3
288	Granada	Freila	37.52869	-2.906795	824.42	1.262	0.980	C	3	D	3	D	3
289	Granada	Fuente Vaqueros	37.21957	-3.783053	545.49	1.065	0.958	C	3	C	4	D	3
290	Granada	Gabias (Las)	37.13500	-3.698333	703.11	1.014	1.038	C	3	C	3	D	3
291	Granada	Galera	37.74289	-2.551193	837.25	1.178	1.105	C	3	D	3	D	3
292	Granada	Gobernador	37.47737	-3.320455	1039.05	1.190	0.921	D	2	D	3	D	3
293	Granada	Gójar	37.10443	-3.606203	791.87	0.938	1.063	C	3	C	3	C	3
294	Granada	Gor	37.36952	-2.969444	1241.51	0.935	0.889	D	1	D	3	C	2
295	Granada	Gorafe	37.47902	-3.044275	847.66	1.258	0.967	C	3	D	3	D	3
296	Granada	Granada	37.17649	-3.597929	697.49	1.034	1.039	C	3	C	3	D	3
297	Granada	Guadahortuna	37.55655	-3.400713	968.34	1.258	0.936	D	2	D	3	D	3
298	**Granada**	**Guadix***	**37.30040**	**-3.134583**	**919.40**	**1.140**	**1.020**	**C**	**3**	**D**	**3**	**D**	**3**
299	Granada	Guajares (Los)	36.84568	-3.611650	475.61	0.617	1.273	C	3	C	4	C	4
300	Granada	Gualchos	36.74357	-3.389869	335.95	0.327	1.408	C	3	B	4	B	4
301	Granada	Güejar Sierra	37.15992	-3.438619	1098.16	0.984	0.943	D	2	D	3	D	3
302	Granada	Güevéjar	37.25698	-3.597678	876.23	1.096	1.008	C	3	D	3	D	3
303	Granada	Huélago	37.41980	-3.260146	914.93	1.252	0.961	C	3	D	3	D	3
304	Granada	Huéneja	37.17693	-2.948596	1155.85	0.888	0.964	D	1	D	3	C	3
305	**Granada**	**Huéscar***	**37.80949**	**-2.539663**	**959.98**	**1.150**	**1.010**	**D**	**2**	**D**	**3**	**D**	**3**
306	Granada	Huétor de Santillán	37.21823	-3.517399	1019.82	1.075	0.964	D	2	D	3	D	3
307	Granada	Huétor Tájar	37.19463	-4.047139	489.00	0.956	1.115	C	3	C	4	D	3
308	Granada	Huétor Vega	37.15238	-3.575904	739.99	0.993	1.058	C	3	C	3	D	3

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309	Granada	Illora	37.28843	-3.879782	775.87	1.032	1.140	C	3	C	3	D	3
310	Granada	Itrabo	36.79948	-3.638711	384.31	0.432	1.406	C	3	C	4	B	4
311	**Granada**	**Iznalloz***	**37.39270**	**-3.527549**	**816.34**	**1.160**	**1.020**	**C**	**3**	**D**	**3**	**D**	**3**
312	Granada	Jayena	36.94883	-3.822807	911.84	0.863	1.013	C	3	D	3	C	3
313	Granada	Jerez del Marquesado	37.18385	-3.159872	1237.27	0.893	0.900	D	1	D	3	C	2
314	Granada	Jete	36.79732	-3.668151	134.28	0.264	1.483	C	3	B	4	A	4
315	Granada	Jun	37.22064	-3.594430	763.61	1.023	1.081	C	3	C	3	D	3
316	Granada	Juviles	36.94825	-3.225788	1258.52	0.785	0.916	D	1	D	3	C	3
317	Granada	Láchar	37.19508	-3.834064	559.71	1.079	0.945	C	3	C	4	D	3
318	Granada	Lanjarón	36.91806	-3.480488	662.31	0.852	1.050	C	3	C	3	C	3
319	Granada	Lanteira	37.16890	-3.138551	1279.62	0.867	0.887	D	1	D	3	C	2
320	Granada	Lecrín	36.94770	-3.550382	705.31	0.869	1.044	C	3	C	3	C	3
321	Granada	Lentegí	36.83430	-3.674449	638.01	0.789	1.113	C	3	C	3	C	3
322	Granada	Lobras	36.92786	-3.212306	917.72	0.702	1.132	C	3	D	3	C	3
323	Granada	Loja	37.16884	-4.151471	456.73	0.876	1.181	C	3	C	4	C	3
324	Granada	Lugros	37.23069	-3.240909	1241.42	0.924	0.883	D	1	D	3	C	2
325	Granada	Lújar	36.78755	-3.401651	509.90	0.583	1.267	C	3	C	4	B	4
326	Granada	Malahá (La)	37.10146	-3.722502	709.62	0.994	1.035	C	3	C	3	D	3
327	Granada	Maracena	37.20568	-3.636805	649.40	1.076	0.991	C	3	C	3	D	3
328	Granada	Marchal	37.29620	-3.202323	926.45	1.148	1.013	C	3	D	3	D	3
329	Granada	Moclín	37.34158	-3.786422	1061.08	1.136	0.885	D	2	D	3	D	2
330	Granada	Molvízar	36.78689	-3.607518	239.25	0.298	1.477	C	3	B	4	A	4

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331	Granada	Monachil	37.13209	-3.539469	811.25	0.950	1.063	C	3	D	3	C	3
332	**Granada**	**Montefrío***	**37.32097**	**-4.011364**	**835.14**	**1.070**	**1.050**	**C**	**3**	**D**	**3**	**D**	**3**
333	Granada	Montejícar	37.57196	-3.504700	1145.29	1.119	0.859	D	2	D	3	D	2
334	Granada	Montillana	37.50127	-3.672423	1019.38	1.214	0.896	D	2	D	3	D	2
335	Granada	Moraleda de Zafayona	37.16977	-3.965147	621.86	1.062	1.008	C	3	C	3	D	3
336	Granada	Morelábor	37.43111	-3.310278	1023.95	1.191	0.933	D	2	D	3	D	3
337	Granada	Motril	36.74467	-3.516718	41.48	0.197	1.376	C	3	A	4	A	4
338	Granada	Murtas	36.88737	-3.108971	1134.92	0.731	1.009	D	2	D	3	C	3
339	Granada	Nevada	37.00000	-3.016667	792.31	0.720	1.132	C	3	C	3	C	3
340	Granada	Nigüelas	36.97741	-3.539319	927.88	0.835	1.060	C	3	D	3	C	3
341	Granada	Nívar	37.25794	-3.577918	1038.03	1.099	0.937	D	2	D	3	D	3
342	Granada	Ogíjares	37.11991	-3.607937	721.77	0.989	1.041	C	3	C	3	D	3
343	Granada	Orce	37.72141	-2.479451	932.25	1.168	1.001	C	3	D	3	D	3
344	**Granada**	**Órgiva***	**36.90224**	**-3.423990**	**465.87**	**0.650**	**1.210**	**C**	**3**	**C**	**4**	**C**	**3**
345	Granada	Otívar	36.81491	-3.681497	266.52	0.334	1.482	C	3	B	4	B	4
346	Granada	Otura	37.09431	-3.635073	783.02	0.937	1.061	C	3	C	3	C	3
347	Granada	Padul	37.02432	-3.626719	757.93	0.901	1.053	C	3	C	3	C	3
348	Granada	Pampaneira	36.94004	-3.361339	1054.91	0.806	1.019	D	2	D	3	C	3
349	Granada	Pedro Martínez	37.50168	-3.230659	1036.34	1.191	0.926	D	2	D	3	D	3
350	Granada	Peligros	37.23122	-3.629415	687.53	1.051	1.074	C	3	C	3	D	3
351	Granada	Peza (La)	37.27560	-3.284761	996.59	1.117	0.989	D	2	D	3	D	3
352	Granada	Píñar	37.44337	-3.439418	912.62	1.256	0.947	C	3	D	3	D	3

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353	Granada	Pinar (El)	37.44337	-3.439418	912.62	1.256	0.947	C	3	D	3	D	3
354	Granada	Pinos Genil	37.16339	-3.502635	777.88	0.979	1.062	C	3	C	3	D	3
355	Granada	Pinos Puente	37.25146	-3.750995	575.29	1.078	0.961	C	3	C	4	D	3
356	Granada	Polícar	37.25764	-3.232102	1146.40	0.988	0.923	D	2	D	3	D	3
357	Granada	Polopos	36.79553	-3.297135	783.93	0.639	1.135	C	3	C	3	C	3
358	Granada	Pórtugos	36.94241	-3.310386	1312.61	0.789	0.883	D	1	E	1	C	2
359	Granada	Puebla de Don Fadrique	37.95790	-2.435080	1160.90	0.973	0.923	D	1	D	3	D	3
360	Granada	Pulianas	37.22264	-3.608163	728.16	1.032	1.090	C	3	C	3	D	3
361	Granada	Purullena	37.31759	-3.190274	908.00	1.165	1.006	C	3	D	3	D	3
362	Granada	Quéntar	37.19201	-3.468192	855.64	1.012	1.046	C	3	D	3	D	3
363	Granada	Rubite	36.80884	-3.348044	778.73	0.664	1.125	C	3	C	3	C	3
364	Granada	Salar	37.14882	-4.067732	545.42	1.035	1.042	C	3	C	4	D	3
365	Granada	Salobreña	36.74626	-3.587108	20.96	0.197	1.363	C	3	A	4	A	4
366	Granada	Santa Cruz del Comercio	37.06024	-3.976717	737.32	0.962	1.051	C	3	C	3	D	3
367	**Granada**	**Santa Fe***	**37.18936**	**-3.719076**	**582.65**	**1.100**	**0.900**	**C**	**3**	**C**	**4**	**D**	**2**
368	Granada	Soportújar	36.92839	-3.405133	944.02	0.767	1.083	C	3	D	3	C	3
369	Granada	Sorvilán	36.79442	-3.267524	770.00	0.637	1.138	C	3	C	3	C	3
370	Granada	Taha (La)	36.93333	-3.316667	1100.91	0.799	0.996	D	2	D	3	C	3
371	Granada	Torre-Cardela	37.50457	-3.356015	1219.53	1.038	0.849	D	1	D	3	D	2
372	Granada	Torvizcón	36.87788	-3.298552	667.79	0.768	1.093	C	3	C	3	C	3
373	Granada	Trevélez	37.00245	-3.266871	1542.32	0.765	0.808	D	1	E	1	C	2
374	Granada	Turón	36.86357	-3.057771	698.52	0.682	1.128	C	3	C	3	C	3

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375	**Granada**	**Ugíjar***	**36.96075**	**-3.054754**	**547.52**	**0.760**	**1.110**	**C**	**3**	**C**	**4**	**C**	**3**
376	Granada	Valderrubio	37.25146	-3.750995	575.29	1.078	0.961	C	3	C	4	D	3
377	Granada	Valle (El)	37.28611	-3.008889	1245.15	0.909	0.897	D	1	D	3	C	2
378	Granada	Valle del Zalabí	37.28611	-3.008889	1245.15	0.909	0.897	D	1	D	3	C	2
379	Granada	Válor	36.99589	-3.083123	901.99	0.716	1.156	C	3	D	3	C	3
380	Granada	Vegas del Genil	37.16667	-3.700000	615.00	1.095	0.916	C	3	C	3	D	3
381	Granada	Vélez de Benaudalla	36.83195	-3.516209	170.52	0.272	1.478	C	3	B	4	A	4
382	Granada	Ventas de Huelma	37.06853	-3.822133	858.72	0.936	1.032	C	3	D	3	C	3
383	Granada	Villamena	36.99035	-3.588935	762.76	0.867	1.059	C	3	C	3	C	3
384	Granada	Villanueva de las Torres	37.55663	-3.090193	645.94	1.006	1.229	C	3	C	3	D	3
385	Granada	Villanueva Mesía	37.21420	-4.011248	493.51	0.966	1.105	C	3	C	4	D	3
386	Granada	Víznar	37.23108	-3.553835	1074.32	1.057	0.927	D	2	D	3	D	3
387	Granada	Zafarraya	36.97551	-4.144421	896.44	0.925	0.960	C	3	D	3	C	3
388	Granada	Zagra	37.25303	-4.168132	680.06	0.962	1.212	C	3	C	3	D	3
389	Granada	Zubia (La)	37.12061	-3.584668	744.77	0.971	1.053	C	3	C	3	D	3
390	**Granada**	**Zújar***	**37.54015**	**-2.842817**	**771.52**	**1.230**	**1.010**	**C**	**3**	**C**	**3**	**D**	**3**
391	Huelva	Alájar	37.87439	-6.666078	578.18	0.735	1.380	C	1	C	3	C	4
392	Huelva	Aljaraque	37.27111	-7.021585	36.70	0.343	1.233	B	4	A	4	B	3
393	Huelva	Almendro (El)	37.50693	-7.270019	235.16	0.494	1.917	B	4	B	3	B	4
394	Huelva	Almonaster la Real	37.87181	-6.787901	581.58	0.738	1.390	C	1	C	3	C	4
395	Huelva	Almonte	37.26254	-6.517240	77.07	0.378	1.359	B	4	B	4	B	4
396	Huelva	Alosno	37.54936	-7.115428	183.97	0.479	2.023	B	4	B	3	B	4

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397	**Huelva**	**Aracena***	**37.89417**	**-6.561207**	**674.00**	**0.830**	**1.270**	**C**	**1**	**C**	**3**	**C**	**4**
398	Huelva	Aroche	37.94426	-6.954265	407.16	0.603	1.613	B	3	C	3	C	4
399	Huelva	Arroyomolinos de León	38.02604	-6.421104	599.79	0.744	1.334	C	1	C	3	C	4
400	**Huelva**	**Ayamonte***	**37.21466**	**-7.409819**	**3.16**	**0.310**	**0.900**	**B**	**4**	**A**	**4**	**B**	**2**
401	Huelva	Beas	37.42592	-6.792988	120.98	0.425	1.959	B	4	B	4	B	4
402	Huelva	Berrocal	38.00000	-6.883333	465.08	0.638	1.536	C	1	C	3	C	4
403	**Huelva**	**Bollullos Par del Condado***	**37.33615**	**-6.535758**	**116.02**	**0.430**	**1.700**	**B**	**4**	**B**	**4**	**B**	**4**
404	Huelva	Bonares	37.32190	-6.680697	82.24	0.366	1.584	B	4	B	4	B	4
405	Huelva	Cabezas Rubias	37.72650	-7.087451	222.55	0.514	1.933	B	4	B	3	B	4
406	Huelva	Cala	37.97217	-6.316490	594.07	0.739	1.325	C	1	C	3	C	4
407	Huelva	Calañas	37.65482	-6.878683	297.42	0.541	1.744	B	3	B	3	B	4
408	Huelva	Campillo (El)	37.69332	-6.630814	434.68	0.612	1.495	B	3	C	3	C	4
409	Huelva	Campofrío	37.76776	-6.573099	518.70	0.677	1.409	C	1	C	3	C	4
410	Huelva	Cañaveral de León	38.01454	-6.527808	545.94	0.696	1.406	C	1	C	3	C	4
411	Huelva	Cartaya	37.28314	-7.154979	24.17	0.355	1.237	B	4	A	4	B	3
412	Huelva	Castaño del Robledo	37.89510	-6.703943	739.81	0.874	1.192	C	1	C	3	C	3
413	Huelva	Cerro de Andévalo (El)	37.73519	-6.938734	301.12	0.546	1.757	B	3	B	3	B	4
414	Huelva	Chucena	37.36157	-6.393946	148.22	0.493	1.585	B	4	B	4	B	4
415	Huelva	Corteconcepción	37.89585	-6.505878	581.74	0.736	1.359	C	1	C	3	C	4
416	Huelva	Cortegana	37.90937	-6.820616	686.31	0.833	1.286	C	1	C	3	C	4
417	Huelva	Cortelazor	37.93554	-6.624768	624.83	0.780	1.336	C	1	C	3	C	4
418	Huelva	Cumbres de Enmedio	38.07224	-6.692877	592.32	0.736	1.379	C	1	C	3	C	4

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419	Huelva	Cumbres de San Bartolomé	38.07691	-6.743336	579.47	0.724	1.399	C	1	C	3	C	4
420	Huelva	Cumbres Mayores	38.06370	-6.647074	694.77	0.825	1.254	C	1	C	3	C	4
421	Huelva	Encinasola	38.13522	-6.872141	430.96	0.618	1.578	B	3	C	3	C	4
422	Huelva	Escacena del Campo	37.41033	-6.389561	172.00	0.512	1.588	B	4	B	3	B	4
423	Huelva	Fuenteheridos	37.90327	-6.660661	711.65	0.857	1.232	C	1	C	3	C	3
424	Huelva	Galaroza	37.92757	-6.709221	562.20	0.718	1.406	C	1	C	3	C	4
425	**Huelva**	**Gibraleón***	**37.37495**	**-6.970141**	**29.22**	**0.360**	**1.600**	**B**	**4**	**A**	**4**	**B**	**4**
426	Huelva	Granada de Río-Tinto (La)	37.23156	-6.918230	0.00	0.315	0.993	B	4	A	4	B	3
427	Huelva	Granado (El)	37.26469	-6.926992	18.33	0.327	1.141	B	4	A	4	B	3
428	Huelva	Higuera de la Sierra	37.83819	-6.447579	627.31	0.785	1.299	C	1	C	3	C	4
429	Huelva	Hinojales	38.00843	-6.589147	615.30	0.764	1.342	C	1	C	3	C	4
430	Huelva	Hinojos	37.29273	-6.376253	83.67	0.423	1.374	B	4	B	4	B	4
431	Huelva	Huelva	37.25710	-6.949555	20.74	0.328	1.124	B	4	A	4	B	3
432	Huelva	Isla Cristina	37.19943	-7.325246	6.34	0.313	0.882	B	4	A	4	B	2
433	Huelva	Jabugo	37.91671	-6.729078	658.24	0.812	1.313	C	1	C	3	C	4
434	**Huelva**	**Lepe***	**37.25432**	**-7.203348**	**24.54**	**0.350**	**1.130**	**B**	**4**	**A**	**4**	**B**	**3**
435	Huelva	Linares de la Sierra	37.88009	-6.621002	490.77	0.654	1.464	C	1	C	3	C	4
436	Huelva	Lucena del Puerto	37.30394	-6.730086	83.69	0.358	1.550	B	4	B	4	B	4
437	Huelva	Manzanilla	37.38773	-6.429422	163.73	0.500	1.635	B	4	B	3	B	4
438	Huelva	Marines (Los)	37.90303	-6.623320	723.58	0.866	1.208	C	1	C	3	C	3
439	**Huelva**	**Minas de Riotinto***	**37.69391**	**-6.591848**	**417.64**	**0.600**	**1.510**	**B**	**3**	**C**	**3**	**B**	**4**
440	**Huelva**	**Moguer***	**37.27469**	**-6.836591**	**53.91**	**0.330**	**1.290**	**B**	**4**	**B**	**4**	**B**	**4**

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						WCS	SCS	Winter	Summer	Winter	Summer	Winter	Summer
441	Huelva	Nava (La)	37.96342	-6.745746	424.02	0.610	1.564	B	3	C	3	C	4
442	Huelva	Nerva	37.69511	-6.550632	336.93	0.556	1.602	B	3	B	3	B	4
443	Huelva	Niebla	37.36010	-6.679200	42.89	0.349	1.497	B	4	A	4	B	4
444	Huelva	Palma del Condado (La)	37.38784	-6.553400	96.01	0.417	1.713	B	4	B	4	B	4
445	Huelva	Palos de la Frontera	37.22820	-6.893426	29.09	0.320	1.056	B	4	A	4	B	3
446	Huelva	Paterna del Campo	37.42096	-6.401431	184.36	0.515	1.601	B	4	B	3	B	4
447	Huelva	Paymogo	37.74063	-7.345994	180.55	0.495	2.024	B	4	B	3	B	4
448	Huelva	Puebla de Guzmán	37.61144	-7.245831	212.82	0.497	1.982	B	4	B	3	B	4
449	Huelva	Puerto Moral	37.89208	-6.478770	519.95	0.675	1.418	C	1	C	3	C	4
450	Huelva	Punta Umbría	37.18248	-6.967148	7.50	0.310	0.887	B	4	A	4	B	2
451	Huelva	Rociana del Condado	37.30781	-6.598672	97.40	0.390	1.609	B	4	B	4	B	4
452	Huelva	Rosal de la Frontera	37.96780	-7.220527	221.48	0.527	1.908	B	4	B	3	B	4
453	Huelva	San Bartolomé de la Torre	37.44596	-7.106683	131.23	0.431	2.012	B	4	B	4	B	4
454	Huelva	San Juan del Puerto	37.31416	-6.840784	8.00	0.329	1.275	B	4	A	4	B	4
455	Huelva	San Silvestre de Guzmán	37.38840	-7.350305	152.81	0.433	1.878	B	4	B	3	B	4
456	Huelva	Sanlúcar de Guadiana	37.47318	-7.467861	15.39	0.390	1.703	B	4	A	4	B	4
457	Huelva	Santa Ana la Real	37.86396	-6.724445	637.69	0.796	1.328	C	1	C	3	C	4
458	Huelva	Santa Bárbara de Casa	37.79655	-7.188633	310.59	0.553	1.790	B	3	B	3	B	4
459	Huelva	Santa Olalla del Cala	37.90651	-6.229617	518.62	0.664	1.397	C	1	C	3	C	4
460	Huelva	Trigueros	37.38319	-6.833752	78.59	0.374	1.774	B	4	B	4	B	4
461	Huelva	Valdelarco	37.95044	-6.683222	619.30	0.774	1.350	C	1	C	3	C	4
462	Huelva	Valverde del Camino	37.57339	-6.753376	282.48	0.532	1.723	B	3	B	3	B	4

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463	Huelva	Villablanca	37.30373	-7.341905	95.64	0.392	1.558	B	4	B	4	B	4
464	Huelva	Villalba del Alcor	37.39729	-6.476595	161.81	0.493	1.694	B	4	B	3	B	4
465	Huelva	Villanueva de las Cruces	37.62762	-7.024521	119.63	0.460	2.073	B	4	B	4	B	4
466	Huelva	Villanueva de los Castillejos	37.50046	-7.272443	225.00	0.488	1.934	B	4	B	3	B	4
467	Huelva	Villarrasa	37.38945	-6.606914	66.98	0.381	1.638	B	4	B	4	B	4
468	Huelva	Zalamea la Real	37.67891	-6.660578	409.55	0.596	1.528	B	3	C	3	B	4
469	Huelva	Zufre	37.83384	-6.338613	441.53	0.609	1.479	B	3	C	3	C	4
470	Jaén	Albanchez de Mágina	37.79165	-3.468285	838.45	1.091	1.259	D	2	D	3	D	4
471	Jaén	Alcalá la Real	37.46358	-3.925078	929.47	1.202	0.918	D	2	D	3	D	3
472	Jaén	Alcaudete	37.59106	-4.086735	660.81	0.792	1.469	C	3	C	4	C	4
473	Jaén	Aldeaquemada	38.41182	-3.371774	700.27	0.821	1.462	C	3	C	4	C	4
474	Jaén	Andújar	38.03675	-4.054391	215.33	0.634	1.571	C	4	B	4	C	4
475	Jaén	Arjona	37.93648	-4.054891	436.59	0.660	1.787	C	4	B	4	C	4
476	Jaén	Arjonilla	37.97355	-4.107027	348.89	0.632	1.803	C	4	B	4	C	4
477	Jaén	Arquillos	38.18201	-3.430886	382.30	0.810	1.627	C	4	B	4	C	4
478	Jaén	Arroyo del Ojanco	38.32092	-2.894979	540.23	0.840	1.520	C	4	C	4	C	4
479	**Jaén**	**Baeza***	**37.99343**	**-3.469237**	**759.48**	**0.740**	**1.820**	**C**	**3**	**D**	**3**	**C**	**4**
480	Jaén	Bailén	38.09588	-3.774859	351.00	0.730	1.724	C	4	B	4	C	4
481	Jaén	Baños de la Encina	38.17133	-3.774258	419.49	0.746	1.720	C	4	B	4	C	4
482	Jaén	Beas de Segura	38.25238	-2.889883	581.13	0.835	1.563	C	4	C	4	C	4
483	**Jaén**	**Bedmar y Garcíez***	**37.82271**	**-3.411761**	**645.47**	**0.690**	**1.590**	**C**	**3**	**C**	**4**	**C**	**4**
484	Jaén	Begíjar	37.98452	-3.534830	556.93	0.750	1.694	C	4	C	4	C	4

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485	Jaén	Bélmez de la Moraleda	37.72390	-3.382220	863.73	1.186	1.124	D	2	D	3	D	3
486	Jaén	Benatae	38.35257	-2.650866	854.92	1.066	1.199	D	2	D	3	D	3
487	Jaén	Cabra del Santo Cristo	37.70535	-3.286108	946.85	1.234	1.005	D	2	D	3	D	3
488	Jaén	Cambil	37.67691	-3.565627	766.17	1.061	1.210	C	3	D	3	D	3
489	Jaén	Campillo de Arenas	37.55593	-3.635789	873.84	1.234	0.969	D	2	D	3	D	3
490	Jaén	Canena	38.04868	-3.482172	522.58	0.802	1.697	C	4	C	4	C	4
491	Jaén	Carboneros	38.22952	-3.631522	403.33	0.776	1.656	C	4	B	4	C	4
492	Jaén	Cárcheles	37.65330	-3.635799	797.90	1.133	1.113	C	3	D	3	D	3
493	Jaén	Carolina (La)	38.27468	-3.615412	598.45	0.656	1.706	C	4	C	4	C	4
494	**Jaén**	**Castellar***	**38.25621**	**-3.131925**	**755.20**	**0.980**	**1.410**	**C**	**3**	**D**	**3**	**D**	**4**
495	**Jaén**	**Castillo de Locubín***	**37.52826**	**-3.943678**	**702.94**	**0.930**	**1.440**	**C**	**3**	**C**	**4**	**C**	**4**
496	Jaén	Cazalilla	37.98460	-3.882231	299.45	0.660	1.720	C	4	B	4	C	4
497	Jaén	Cazorla	37.91055	-3.002167	804.00	0.997	1.489	C	3	D	3	D	4
498	Jaén	Chiclana de Segura	38.31147	-3.042188	849.22	1.095	1.234	D	2	D	3	D	3
499	Jaén	Chilluévar	38.00106	-3.031099	731.59	0.817	1.699	C	3	C	4	C	4
500	Jaén	Escañuela	37.87872	-4.033281	319.12	0.608	1.770	C	4	B	4	C	4
501	Jaén	Espelúy	38.03308	-3.861802	279.36	0.673	1.665	C	4	B	4	C	4
502	Jaén	Frailes	37.48515	-3.838214	965.38	1.220	0.904	D	2	D	3	D	3
503	Jaén	Fuensanta de Martos	37.64784	-3.906000	739.03	1.001	1.206	C	3	C	4	D	3
504	Jaén	Fuerte del Rey	37.87396	-3.884589	436.63	0.702	1.752	C	4	B	4	C	4
505	Jaén	Génave	38.43014	-2.732766	828.01	1.049	1.199	C	3	D	3	D	3
506	Jaén	Guardia de Jaén (La)	37.74164	-3.692717	617.78	0.702	1.528	C	4	C	4	C	4

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507	**Jaén**	**Guarromán***	**38.18151**	**-3.686501**	**348.13**	**0.760**	**1.650**	**C**	**4**	**B**	**4**	**C**	**4**
508	Jaén	Higuera de Calatrava	37.79690	-4.154945	327.07	0.572	1.758	C	4	B	4	B	4
509	Jaén	Hinojares	37.71555	-2.999204	662.65	0.922	1.368	C	3	C	4	C	4
510	Jaén	Hornos	38.21679	-2.720247	856.19	1.096	1.237	D	2	D	3	D	3
511	Jaén	Huelma	37.64524	-3.455428	957.86	1.246	0.960	D	2	D	3	D	3
512	Jaén	Huesa	37.76411	-3.078167	633.47	0.852	1.452	C	4	C	4	C	4
513	Jaén	Ibros	38.02261	-3.502375	595.42	0.681	1.736	C	4	C	4	C	4
514	Jaén	Iruela (La)	37.92038	-2.993985	940.51	1.148	1.132	D	2	D	3	D	3
515	Jaén	Iznatoraf	38.15744	-3.032914	1037.59	1.065	1.040	D	1	D	3	D	3
516	Jaén	Jabalquinto	38.01932	-3.724704	487.92	0.751	1.735	C	4	C	4	C	4
517	Jaén	Jaén	37.76574	-3.789518	576.39	0.692	1.566	C	4	C	4	C	4
518	Jaén	Jamilena	37.74709	-3.912299	754.03	0.974	1.160	C	3	D	3	D	3
519	Jaén	Jimena	37.84158	-3.476529	610.77	0.695	1.606	C	4	C	4	C	4
520	Jaén	Jódar	37.84398	-3.352545	650.84	0.691	1.614	C	3	C	4	C	4
521	**Jaén**	**Lahiguera***	**37.97049**	**-3.989164**	**372.68**	**0.660**	**1.820**	**C**	**4**	**B**	**4**	**C**	**4**
522	Jaén	Larva	37.75892	-3.200150	736.21	0.940	1.419	C	3	C	4	C	4
523	Jaén	Linares	38.09362	-3.635844	410.83	0.775	1.730	C	4	B	4	C	4
524	Jaén	Lopera	37.94367	-4.214694	272.20	0.593	1.697	C	4	B	4	B	4
525	Jaén	Lupión	37.99656	-3.546936	500.90	0.808	1.696	C	4	C	4	C	4
526	Jaén	Mancha Real	37.78617	-3.612393	759.83	0.926	1.362	C	3	D	3	C	4
527	Jaén	Marmolejo	38.04433	-4.170608	244.33	0.634	1.610	C	4	B	4	C	4
528	**Jaén**	**Martos***	**37.72278**	**-3.966259**	**739.37**	**0.960**	**1.160**	**C**	**3**	**C**	**4**	**D**	**3**

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529	Jaén	Mengíbar	37.96833	-3.808806	322.40	0.675	1.748	C	4	B	4	C	4
530	Jaén	Montizón	38.34243	-3.103404	644.21	0.776	1.564	C	3	C	4	C	4
531	Jaén	Navas de San Juan	38.18464	-3.315369	660.08	0.677	1.759	C	3	C	4	C	4
532	Jaén	Noalejo	37.52939	-3.653675	1090.68	1.165	0.869	D	1	D	3	D	2
533	Jaén	Orcera	38.31738	-2.664912	758.69	1.043	1.265	C	3	D	3	D	4
534	**Jaén**	**Peal de Becerro***	**37.91332**	**-3.121655**	**548.82**	**0.930**	**1.550**	**C**	**4**	**C**	**4**	**C**	**4**
535	Jaén	Pegalajar	37.73797	-3.651098	795.40	1.061	1.200	C	3	D	3	D	3
536	Jaén	Porcuna	37.87086	-4.184721	468.45	0.636	1.721	C	4	C	4	C	4
537	Jaén	Pozo Alcón	37.70512	-2.934360	866.22	1.224	1.090	D	2	D	3	D	3
538	Jaén	Puente de Génave	38.35323	-2.804408	546.52	0.844	1.481	C	4	C	4	C	4
539	Jaén	Puerta de Segura (La)	38.34861	-2.737147	584.88	0.848	1.468	C	4	C	4	C	4
540	Jaén	Quesada	37.84510	-3.067591	679.36	0.801	1.566	C	3	C	4	C	4
541	Jaén	Rus	38.04807	-3.462054	589.62	0.701	1.737	C	4	C	4	C	4
542	Jaén	Sabiote	38.06915	-3.306595	829.25	0.970	1.539	C	3	D	3	D	4
543	Jaén	Santa Elena	38.33911	-3.539236	744.13	0.861	1.465	C	3	C	4	C	4
544	Jaén	Santiago de Calatrava	37.75299	-4.169107	391.08	0.613	1.721	C	4	B	4	C	4
545	Jaén	Santiago-Pontones	38.10000	-2.550000	1229.57	0.938	0.903	D	1	D	3	C	3
546	**Jaén**	**Santisteban del Puerto***	**38.24746**	**-3.206428**	**706.27**	**0.810**	**1.600**	**C**	**3**	**C**	**4**	**C**	**4**
547	Jaén	Santo Tomé	38.02818	-3.101844	450.98	0.921	1.578	C	4	C	4	C	4
548	Jaén	Segura de la Sierra	38.29776	-2.651513	1110.40	0.968	0.989	D	1	D	3	D	3
549	Jaén	Siles	38.38734	-2.581310	831.98	1.050	1.201	C	3	D	3	D	3
550	Jaén	Sorihuela del Guadalimar	38.23954	-3.054152	630.35	0.767	1.639	C	4	C	4	C	4

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551	Jaén	Torre del Campo	37.77657	-3.895521	627.65	0.667	1.523	C	4	C	4	C	4
552	Jaén	Torreblascopedro	37.99618	-3.638916	329.47	0.718	1.714	C	4	B	4	C	4
553	Jaén	Torredonjimeno	37.76543	-3.959263	585.91	0.660	1.558	C	4	C	4	C	4
554	Jaén	Torreperogil	38.03450	-3.287597	757.69	0.784	1.794	C	3	D	3	C	4
555	Jaén	Torres	37.78608	-3.510031	885.69	1.155	1.145	D	2	D	3	D	3
556	**Jaén**	**Torres de Albánchez***	**38.41451**	**-2.677051**	**830.67**	**1.050**	**1.200**	**C**	**3**	**D**	**3**	**D**	**3**
557	Jaén	Úbeda	38.00809	-3.368519	737.46	0.707	1.848	C	3	C	4	C	4
558	Jaén	Valdepeñas de Jaén	37.59034	-3.819645	921.38	1.224	0.935	D	2	D	3	D	3
559	Jaén	Vilches	38.20467	-3.507662	546.20	0.729	1.707	C	4	C	4	C	4
560	Jaén	Villacarrillo	38.11541	-3.087194	793.01	0.979	1.526	C	3	D	3	D	4
561	Jaén	Villanueva de la Reina	38.00499	-3.919512	220.49	0.633	1.591	C	4	B	4	C	4
562	Jaén	Villanueva del Arzobispo	38.16934	-3.010099	673.13	0.786	1.654	C	3	C	4	C	4
563	Jaén	Villardompardo	37.83969	-4.001286	443.15	0.674	1.735	C	4	B	4	C	4
564	Jaén	Villares (Los)	37.68932	-3.818570	636.13	0.735	1.488	C	3	C	4	C	4
565	Jaén	Villarrodrigo	38.48793	-2.636272	870.65	1.004	1.178	D	2	D	3	D	3
566	Jaén	Villatorres	37.93130	-3.692753	302.40	0.670	1.705	C	4	B	4	C	4
567	Málaga	Alameda	37.20783	-4.658073	431.06	0.775	1.245	C	1	C	3	C	3
568	Málaga	Alcaucín	36.90263	-4.114147	506.84	0.728	1.290	C	1	C	3	C	4
569	Málaga	Alfarnate	36.99511	-4.260656	890.33	0.948	0.944	D	1	D	3	C	3
570	Málaga	Alfarnatejo	36.97935	-4.272528	853.53	0.938	0.960	D	1	D	3	C	3
571	Málaga	Algarrobo	36.77216	-4.039314	76.23	0.282	1.474	A	3	B	3	A	4
572	Málaga	Algatocín	36.57289	-5.276559	711.45	0.800	0.961	C	1	D	3	C	3

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573	Málaga	Alhaurín de la Torre	36.66836	-4.552967	55.92	0.298	1.416	A	3	B	3	A	4
574	Málaga	Alhaurín el Grande	36.64186	-4.691447	262.00	0.328	1.633	B	3	B	3	B	4
575	Málaga	Almáchar	36.80859	-4.217409	251.38	0.362	1.576	B	3	B	3	B	4
576	Málaga	Almargen	37.00392	-5.021193	511.26	0.724	1.288	C	1	C	3	C	4
577	Málaga	Almogía	36.82528	-4.540719	369.32	0.390	1.601	B	3	C	3	B	4
578	Málaga	Álora	36.82264	-4.706715	217.74	0.416	1.617	B	3	B	3	B	4
579	Málaga	Alozaina	36.72768	-4.856460	367.51	0.299	1.706	B	3	C	3	A	4
580	Málaga	Alpandeire	36.63317	-5.202244	691.16	0.807	0.997	C	1	C	3	C	3
581	Málaga	Antequera	37.01938	-4.562885	519.31	0.835	1.249	C	1	C	3	C	3
582	Málaga	Árchez	36.83739	-3.990186	434.62	0.528	1.424	C	1	C	3	B	4
583	Málaga	Archidona	37.09481	-4.387545	711.65	0.970	1.085	C	1	D	3	D	3
584	Málaga	Ardales	36.87798	-4.846642	408.75	0.440	1.558	C	1	C	3	B	4
585	Málaga	Arenas	36.81469	-4.043716	395.60	0.447	1.492	B	3	C	3	B	4
586	Málaga	Arriate	36.79936	-5.140064	596.15	0.689	1.286	C	1	C	3	C	4
587	Málaga	Atajate	36.63999	-5.245177	743.50	0.887	0.866	C	1	D	3	C	2
588	Málaga	Benadalid	36.60577	-5.268939	694.84	0.797	0.991	C	1	C	3	C	3
589	Málaga	Benahavís	36.52446	-5.046305	169.08	0.393	1.554	A	3	B	3	B	4
590	Málaga	Benalauría	36.59402	-5.261163	680.53	0.761	1.039	C	1	C	3	C	3
591	Málaga	Benalmádena	36.59523	-4.573368	246.07	0.308	1.607	B	3	B	3	B	4
592	Málaga	Benamargosa	36.83208	-4.192390	107.37	0.338	1.551	A	3	B	3	B	4
593	Málaga	Benamocarra	36.79120	-4.159968	129.85	0.327	1.541	A	3	B	3	B	4
594	Málaga	Benaoján	36.71874	-5.253150	565.65	0.550	1.418	C	1	C	3	B	4

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595	Málaga	Benarrabá	36.55169	-5.276832	536.67	0.398	1.538	C	1	C	3	B	4
596	Málaga	Borge (El)	36.81446	-4.234890	253.30	0.366	1.578	B	3	B	3	B	4
597	Málaga	Burgo (El)	36.78993	-4.946407	578.50	0.637	1.375	C	1	C	3	C	4
598	**Málaga**	**Campillos***	**37.04541**	**-4.861525**	**458.55**	**0.720**	**1.250**	**C**	**1**	**C**	**3**	**C**	**3**
599	Málaga	Canillas de Aceituno	36.87345	-4.082042	653.66	0.867	1.092	C	1	C	3	C	3
600	Málaga	Canillas de Albaida	36.84607	-3.987585	579.26	0.775	1.200	C	1	C	3	C	3
601	Málaga	Cañete la Real	36.95146	-5.024308	750.48	0.983	0.911	C	1	D	3	D	3
602	Málaga	Carratraca	36.85158	-4.818239	527.61	0.584	1.482	C	1	C	3	B	4
603	Málaga	Cartajima	36.64540	-5.153931	835.13	0.917	0.783	D	1	D	3	C	2
604	Málaga	Cártama	36.71131	-4.630741	103.49	0.364	1.514	A	3	B	3	B	4
605	Málaga	Casabermeja	36.89404	-4.428977	543.28	0.735	1.330	C	1	C	3	C	4
606	**Málaga**	**Casarabonela***	**36.78524**	**-4.842167**	**469.91**	**0.380**	**1.700**	**C**	**1**	**C**	**3**	**B**	**4**
607	Málaga	Casares	36.44333	-5.273519	395.24	0.255	1.690	B	3	C	3	A	4
608	Málaga	Coín	36.65871	-4.760344	212.39	0.374	1.603	B	3	B	3	B	4
609	Málaga	Colmenar	36.90502	-4.335212	674.26	0.907	1.071	C	1	C	3	C	3
610	Málaga	Comares	36.84872	-4.247061	691.99	0.871	1.061	C	1	C	3	C	3
611	Málaga	Cómpeta	36.83300	-3.974872	631.62	0.809	1.134	C	1	C	3	C	3
612	Málaga	Cortes de la Frontera	36.61691	-5.342681	623.01	0.646	1.221	C	1	C	3	C	3
613	Málaga	Cuevas Bajas	37.23587	-4.489641	316.25	0.561	1.509	B	3	C	3	B	4
614	Málaga	Cuevas de San Marcos	37.26963	-4.414079	407.23	0.745	1.315	C	1	C	3	C	4
615	Málaga	Cuevas del Becerro	36.87637	-5.045729	727.99	0.965	0.911	C	1	D	3	D	3
616	Málaga	Cútar	36.83069	-4.228007	297.53	0.384	1.563	B	3	B	3	B	4

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617	**Málaga**	**Estepona***	**36.42477**	**-5.144903**	**9.66**	**0.190**	**1.190**	**A**	**3**	**B**	**3**	**A**	**3**
618	Málaga	Faraján	36.61620	-5.189152	632.20	0.662	1.207	C	1	C	3	C	3
619	Málaga	Frigiliana	36.79252	-3.898076	326.03	0.372	1.503	B	3	C	3	B	4
620	Málaga	Fuengirola	36.53901	-4.624353	9.70	0.198	1.250	A	3	B	3	A	3
621	Málaga	Fuente de Piedra	37.13463	-4.729656	444.61	0.779	1.216	C	1	C	3	C	3
622	Málaga	Gaucín	36.51830	-5.317524	609.40	0.555	1.294	C	1	C	3	B	4
623	Málaga	Genalguacil	36.54427	-5.235879	508.33	0.336	1.622	C	1	C	3	B	4
624	Málaga	Guaro	36.65645	-4.833355	347.66	0.276	1.716	B	3	C	3	A	4
625	Málaga	Humilladero	37.11469	-4.703457	447.00	0.778	1.218	C	1	C	3	C	3
626	Málaga	Igualeja	36.63033	-5.122461	692.65	0.804	1.003	C	1	C	3	C	3
627	Málaga	Istán	36.58216	-4.949401	295.79	0.308	1.673	B	3	B	3	B	4
628	Málaga	Iznate	36.77612	-4.183560	305.81	0.353	1.571	B	3	C	3	B	4
629	Málaga	Jimera de Líbar	36.65202	-5.273455	548.84	0.468	1.495	C	1	C	3	B	4
630	Málaga	Jubrique	36.56432	-5.215247	556.01	0.440	1.491	C	1	C	3	B	4
631	Málaga	Júzcar	36.62506	-5.170815	622.42	0.641	1.244	C	1	C	3	C	3
632	Málaga	Macharaviaya	36.76239	-4.213979	232.85	0.340	1.574	B	3	B	3	B	4
633	Málaga	Málaga	36.71965	-4.420019	20.77	0.276	1.392	A	3	B	3	A	4
634	Málaga	Manilva	36.37706	-5.249271	135.04	0.355	1.459	A	3	B	3	B	4
635	Málaga	Marbella	36.50994	-4.886352	23.82	0.222	1.261	A	3	B	3	A	4
636	Málaga	Mijas	36.59570	-4.637619	421.16	0.229	1.767	C	1	C	3	A	4
637	Málaga	Moclinejo	36.77120	-4.254001	443.12	0.424	1.575	C	1	C	3	B	4
638	Málaga	Mollina	37.12564	-4.657106	476.19	0.841	1.201	C	1	C	3	C	3

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639	Málaga	Monda	36.63018	-4.831124	359.95	0.258	1.734	B	3	C	3	A	4
640	Málaga	Montejaque	36.73365	-5.251382	696.32	0.881	0.946	C	1	C	3	C	3
641	Málaga	Nerja	36.74503	-3.876649	25.00	0.228	1.388	A	3	B	3	A	4
642	Málaga	Ojén	36.56424	-4.856492	314.17	0.277	1.689	B	3	C	3	A	4
643	Málaga	Parauta	36.65533	-5.129627	819.96	0.920	0.793	D	1	D	3	C	2
644	Málaga	Periana	36.92694	-4.187304	570.69	0.856	1.182	C	1	C	3	C	3
645	Málaga	Pizarra	36.76717	-4.707456	88.96	0.391	1.532	A	3	B	3	B	4
646	Málaga	Pujerra	36.61270	-5.149421	781.43	0.888	0.833	C	1	D	3	C	2
647	Málaga	Rincón de la Victoria	36.71566	-4.275504	3.76	0.246	1.359	A	3	B	3	A	4
648	Málaga	Riogordo	36.91491	-4.293622	390.23	0.524	1.458	B	3	C	3	B	4
649	**Málaga**	**Ronda***	**36.74196**	**-5.166412**	**721.03**	**0.920**	**0.890**	**C**	**1**	**D**	**3**	**C**	**2**
650	Málaga	Salares	36.85496	-4.024393	585.05	0.793	1.189	C	1	C	3	C	3
651	Málaga	Sayalonga	36.79799	-4.011899	364.62	0.403	1.511	B	3	C	3	B	4
652	Málaga	Sedella	36.86289	-4.033070	697.34	0.863	1.058	C	1	C	3	C	3
653	Málaga	Sierra de Yeguas	37.12461	-4.868739	451.51	0.764	1.207	C	1	C	3	C	3
654	Málaga	Teba	36.98348	-4.920274	541.61	0.763	1.288	C	1	C	3	C	4
655	Málaga	Tolox	36.68674	-4.904676	305.95	0.326	1.668	B	3	C	3	B	4
656	Málaga	Torremolinos	36.62179	-4.500273	52.34	0.266	1.377	A	3	B	3	A	4
657	Málaga	Torrox	36.75845	-3.952617	146.88	0.292	1.511	A	3	B	3	A	4
658	Málaga	Totalán	36.76529	-4.297044	285.32	0.347	1.591	B	3	B	3	B	4
659	Málaga	Valle de Abdalajís	36.93133	-4.682709	345.65	0.464	1.514	B	3	C	3	B	4
660	Málaga	Vélez-Málaga	36.77864	-4.100675	55.93	0.282	1.461	A	3	B	3	A	4

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661	**Málaga**	**Villanueva de Algaidas***	**37.18628**	**-4.450837**	**542.55**	**0.960**	**1.190**	**C**	**1**	**C**	**3**	**D**	**3**
662	Málaga	Villanueva de la Concepción	37.01938	-4.562885	519.31	0.835	1.249	C	1	C	3	C	3
663	Málaga	Villanueva de Tapia	37.18035	-4.335978	659.88	0.970	1.154	C	1	C	3	D	3
664	Málaga	Villanueva del Rosario	36.99622	-4.364309	694.95	0.957	1.053	C	1	C	3	D	3
665	Málaga	Villanueva del Trabuco	37.02825	-4.338388	685.79	0.967	1.066	C	1	C	3	D	3
666	Málaga	Viñuela	36.86280	-4.141331	166.82	0.358	1.585	A	3	B	3	B	4
667	Málaga	Yunquera	36.73168	-4.920869	675.09	0.827	1.053	C	1	C	3	C	3
668	Sevilla	Aguadulce	37.25283	-4.991125	269.42	0.492	1.595	B	3	C	4	B	4
669	**Sevilla**	**Alanís***	**38.03748**	**-5.715293**	**674.50**	**0.780**	**1.140**	**C**	**1**	**C**	**4**	**C**	**3**
670	Sevilla	Albaida del Aljarafe	37.42702	-6.165926	165.99	0.536	1.344	B	4	B	4	B	4
671	Sevilla	Alcalá de Guadaíra	37.33833	-5.844032	55.90	0.512	1.204	B	4	B	4	B	3
672	Sevilla	Alcalá del Río	37.51827	-5.978236	27.89	0.452	1.374	B	4	B	4	B	4
673	Sevilla	Alcolea del Río	37.61416	-5.671293	31.59	0.457	1.490	B	4	B	4	B	4
674	Sevilla	Algaba (La)	37.46177	-6.013736	11.91	0.436	1.313	B	4	B	4	B	4
675	Sevilla	Algámitas	37.01501	-5.149775	426.41	0.592	1.325	C	2	C	4	B	4
676	Sevilla	Almadén de la Plata	37.87345	-6.079766	454.20	0.606	1.454	C	2	C	4	C	4
677	Sevilla	Almensilla	37.30904	-6.113987	46.31	0.453	1.170	B	4	B	4	B	3
678	Sevilla	Arahal	37.26410	-5.542829	119.19	0.567	1.434	B	4	B	4	B	4
679	Sevilla	Aznalcázar	37.30518	-6.248415	66.95	0.440	1.251	B	4	B	4	B	4
680	Sevilla	Aznalcóllar	37.52354	-6.269565	142.94	0.512	1.503	B	4	B	4	B	4
681	Sevilla	Badolatosa	37.30871	-4.672858	223.32	0.457	1.768	B	3	C	4	B	4
682	Sevilla	Benacazón	37.35343	-6.199005	122.71	0.512	1.308	B	4	B	4	B	4

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683	Sevilla	Bollullos de la Mitación	37.34011	-6.138757	89.17	0.493	1.235	B	4	B	4	B	3
684	Sevilla	Bormujos	37.37101	-6.070961	100.39	0.517	1.201	B	4	B	4	B	3
685	Sevilla	Brenes	37.55057	-5.873065	20.46	0.451	1.408	B	4	B	4	B	4
686	Sevilla	Burguillos	37.58725	-5.967274	82.90	0.488	1.423	B	4	B	4	B	4
687	Sevilla	Cabezas de San Juan (Las)	36.98133	-5.940864	66.07	0.516	1.353	B	4	B	4	B	4
688	Sevilla	Camas	37.40087	-6.032911	10.97	0.433	1.238	B	4	B	4	B	3
689	Sevilla	Campana (La)	37.56945	-5.425768	138.42	0.481	1.555	B	4	B	4	B	4
690	Sevilla	Cañada Rosal	37.59894	-5.210358	157.57	0.448	1.674	B	4	B	4	B	4
691	Sevilla	Cantillana	37.60867	-5.825826	31.12	0.456	1.469	B	4	B	4	B	4
692	Sevilla	Carmona	37.47102	-5.642328	217.98	0.507	1.430	B	3	C	4	B	4
693	Sevilla	Carrión de los Céspedes	37.36847	-6.328958	101.18	0.465	1.454	B	4	B	4	B	4
694	Sevilla	Casariche	37.29389	-4.759532	307.18	0.528	1.545	B	3	C	4	B	4
695	Sevilla	Castilblanco de los Arroyos	37.67459	-5.989300	328.96	0.531	1.500	B	3	C	4	B	4
696	Sevilla	Castilleja de Guzmán	37.40865	-6.057408	132.07	0.538	1.209	B	4	B	4	B	3
697	Sevilla	Castilleja de la Cuesta	37.38644	-6.051838	99.50	0.519	1.198	B	4	B	4	B	3
698	Sevilla	Castilleja del Campo	37.38591	-6.334450	117.34	0.483	1.491	B	4	B	4	B	4
699	Sevilla	Castillo de las Guardas (El)	37.69160	-6.314299	344.42	0.552	1.541	B	3	C	4	B	4
700	Sevilla	Cazalla de la Sierra	37.92960	-5.760799	589.12	0.701	1.282	C	2	C	4	C	4
701	Sevilla	Constantina	37.87227	-5.619115	562.73	0.666	1.326	C	2	C	4	C	4
702	Sevilla	Coria del Río	37.28506	-6.051814	12.71	0.432	1.124	B	4	B	4	B	3
703	Sevilla	Coripe	36.97023	-5.441308	322.90	0.442	1.442	B	3	C	4	B	4
704	Sevilla	Coronil (El)	37.08228	-5.633467	135.00	0.577	1.468	B	4	B	4	B	4

Id.	Province	City	Latitude	Longitude	Altitude	Climate Severity		Climatic zone CTE09 method		Climatic zone CTE13 method		Climatic zone AIM method	
						WCS	SCS	Winter	Summer	Winter	Summer	Winter	Summer
705	Sevilla	Corrales (Los)	37.09732	-4.982910	387.23	0.613	1.313	B	3	C	4	C	4
706	Sevilla	Cuervo de Sevilla (El)	36.85136	-6.041625	59.25	0.479	1.415	B	4	B	4	B	4
707	Sevilla	Dos Hermanas	37.28318	-5.922242	47.76	0.497	1.175	B	4	B	4	B	3
708	Sevilla	Écija	37.54093	-5.079953	109.00	0.455	1.733	B	4	B	4	B	4
709	**Sevilla**	**Espartinas***	**37.37997**	**-6.123577**	**129.53**	**0.530**	**1.240**	**B**	**4**	**B**	**4**	**B**	**3**
710	Sevilla	Estepa	37.29147	-4.878506	536.46	0.831	1.257	C	2	C	4	C	4
711	Sevilla	Fuentes de Andalucía	37.46221	-5.348385	181.65	0.486	1.608	B	4	B	4	B	4
712	Sevilla	Garrobo (El)	37.62539	-6.172421	269.61	0.525	1.531	B	3	C	4	B	4
713	Sevilla	Gelves	37.33677	-6.025333	9.09	0.433	1.168	B	4	B	4	B	3
714	Sevilla	Gerena	37.52553	-6.157654	91.19	0.489	1.420	B	4	B	4	B	4
715	Sevilla	Gilena	37.25134	-4.913494	466.00	0.786	1.230	C	2	C	4	C	3
716	Sevilla	Gines	37.38713	-6.078264	122.60	0.532	1.206	B	4	B	4	B	3
717	Sevilla	Guadalcanal	38.09198	-5.821165	666.41	0.772	1.164	C	1	C	4	C	3
718	Sevilla	Guillena	37.53902	-6.052268	23.12	0.442	1.420	B	4	B	4	B	4
719	Sevilla	Herrera	37.36176	-4.850014	251.00	0.460	1.705	B	3	C	4	B	4
720	Sevilla	Huévar del Aljarafe	37.35599	-6.276590	72.44	0.444	1.333	B	4	B	4	B	4
721	Sevilla	Isla Mayor	37.13356	-6.162807	4.00	0.405	1.049	B	4	B	4	B	3
722	**Sevilla**	**Lantejuela (La)***	**37.35353**	**-5.222986**	**152.55**	**0.510**	**1.720**	**B**	**4**	**B**	**4**	**B**	**4**
723	Sevilla	Lebrija	36.91951	-6.078367	36.06	0.455	1.292	B	4	B	4	B	4
724	Sevilla	Lora de Estepa	37.26869	-4.827815	447.56	0.769	1.253	C	2	C	4	C	4
725	Sevilla	Lora del Río	37.65923	-5.526284	42.95	0.455	1.557	B	4	B	4	B	4
726	Sevilla	Luisiana (La)	37.52613	-5.248721	170.00	0.461	1.665	B	4	B	4	B	4

Id.	Province	City	Latitude	Longitude	Altitude	Climate Severity		Climatic zone CTE09 method		Climatic zone CTE13 method		Climatic zone AIM method	
						WCS	SCS	Winter	Summer	Winter	Summer	Winter	Summer
727	Sevilla	Madroño (El)	37.64548	-6.511699	357.12	0.563	1.558	B	3	C	4	B	4
728	Sevilla	Mairena del Alcor	37.37316	-5.747595	131.11	0.555	1.247	B	4	B	4	B	3
729	Sevilla	Mairena del Aljarafe	37.34449	-6.065354	67.95	0.487	1.195	B	4	B	4	B	3
730	Sevilla	Marchena	37.32972	-5.416465	132.54	0.544	1.546	B	4	B	4	B	4
731	Sevilla	Marinaleda	37.37473	-4.953792	211.57	0.454	1.776	B	3	C	4	B	4
732	Sevilla	Martín de la Jara	37.10655	-4.962173	403.10	0.650	1.280	B	3	C	4	C	4
733	Sevilla	Molares (Los)	37.15531	-5.719529	78.48	0.562	1.347	B	4	B	4	B	4
734	**Sevilla**	**Montellano***	**36.99564**	**-5.570882**	**270.64**	**0.460**	**1.450**	**B**	**3**	**C**	**4**	**B**	**4**
735	Sevilla	Morón de la Frontera	37.12230	-5.451869	231.43	0.504	1.496	B	3	C	4	B	4
736	Sevilla	Navas de la Concepción (Las)	37.93347	-5.464808	433.03	0.564	1.514	C	2	C	4	B	4
737	Sevilla	Olivares	37.41868	-6.155926	173.88	0.538	1.345	B	4	B	4	B	4
738	Sevilla	Osuna	37.23697	-5.102748	291.49	0.506	1.513	B	3	C	4	B	4
739	Sevilla	Palacios y Villafranca (Los)	37.15859	-5.924166	8.85	0.461	1.156	B	4	B	4	B	3
740	Sevilla	Palomares del Río	37.32256	-6.057716	38.78	0.457	1.167	B	4	B	4	B	3
741	Sevilla	Paradas	37.28981	-5.497219	124.33	0.560	1.470	B	4	B	4	B	4
742	Sevilla	Pedrera	37.22301	-4.896754	456.65	0.782	1.221	C	2	C	4	C	3
743	Sevilla	Pedroso (El)	37.84222	-5.763515	413.62	0.564	1.487	C	2	C	4	B	4
744	Sevilla	Peñaflor	37.70726	-5.346412	56.94	0.451	1.625	B	4	B	4	B	4
745	Sevilla	Pilas	37.30167	-6.302449	69.79	0.429	1.286	B	4	B	4	B	4
746	Sevilla	Pruna	36.97364	-5.222943	546.84	0.720	1.279	C	2	C	4	C	4
747	Sevilla	Puebla de Cazalla (La)	37.22441	-5.312270	173.47	0.534	1.627	B	4	B	4	B	4
748	Sevilla	Puebla de los Infantes (La)	37.77852	-5.388995	235.63	0.467	1.594	B	3	C	4	B	4

Id.	Province	City	Latitude	Longitude	Altitude	Climate Severity		Climatic zone CTE09 method		Climatic zone CTE13 method		Climatic zone AIM method	
						WCS	SCS	Winter	Summer	Winter	Summer	Winter	Summer
749	**Sevilla**	**Puebla del Río (La)***	**37.26748**	**-6.062557**	**21.87**	**0.440**	**1.120**	**B**	**4**	**B**	**4**	**B**	**3**
750	Sevilla	Real de la Jara (El)	37.95061	-6.155900	462.96	0.616	1.459	C	2	C	4	C	4
751	Sevilla	Rinconada (La)	37.48780	-5.979309	12.00	0.440	1.342	B	4	B	4	B	4
752	Sevilla	Roda de Andalucía (La)	37.20099	-4.779276	403.13	0.703	1.283	B	3	C	4	C	4
753	Sevilla	Ronquillo (El)	37.72555	-6.176963	337.52	0.544	1.533	B	3	C	4	B	4
754	Sevilla	Rubio (El)	37.35570	-4.988925	207.18	0.463	1.773	B	4	C	4	B	4
755	Sevilla	Salteras	37.41824	-6.111633	153.26	0.539	1.274	B	4	B	4	B	4
756	Sevilla	San Juan de Aznalfarache	37.35838	-6.035451	52.55	0.476	1.195	B	4	B	4	B	3
757	Sevilla	San Nicolás del Puerto	37.99353	-5.653036	588.41	0.688	1.288	C	2	C	4	C	4
758	Sevilla	Sanlúcar la Mayor	37.38578	-6.201977	135.90	0.522	1.326	B	4	B	4	B	4
759	Sevilla	Santiponce	37.43869	-6.038414	16.95	0.438	1.286	B	4	B	4	B	4
760	Sevilla	Saucejo (El)	37.07005	-5.096187	533.45	0.793	1.225	C	2	C	4	C	3
761	Sevilla	Sevilla	37.38264	-5.996295	8.27	0.436	1.217	B	4	B	4	B	3
762	Sevilla	Tocina	37.60978	-5.733069	29.87	0.456	1.477	B	4	B	4	B	4
763	Sevilla	Tomares	37.37404	-6.045198	69.10	0.491	1.205	B	4	B	4	B	3
764	Sevilla	Umbrete	37.36993	-6.157722	126.03	0.522	1.268	B	4	B	4	B	4
765	**Sevilla**	**Utrera***	**37.18142**	**-5.781507**	**49.07**	**0.530**	**1.270**	**B**	**4**	**B**	**4**	**B**	**4**
766	Sevilla	Valencina de la Concepción	37.41601	-6.076959	150.98	0.541	1.247	B	4	B	4	B	3
767	Sevilla	Villamanrique de la Condesa	37.24630	-6.306533	32.62	0.389	1.112	B	4	B	4	B	3
768	Sevilla	Villanueva de San Juan	37.05036	-5.175473	467.65	0.681	1.257	C	2	C	4	C	4
769	Sevilla	Villanueva del Ariscal	37.39572	-6.141313	152.40	0.537	1.287	B	4	B	4	B	4
770	Sevilla	Villanueva del Río y Minas	37.66010	-5.714389	55.40	0.464	1.521	B	4	B	4	B	4

Id.	Province	City	Latitude	Longitude	Altitude	Climate Severity		Climatic zone CTE09 method		Climatic zone CTE13 method		Climatic zone AIM method	
						WCS	SCS	Winter	Summer	Winter	Summer	Winter	Summer
771	Sevilla	Villaverde del Río	37.58805	-5.873684	19.57	0.448	1.451	B	4	B	4	B	4
772	Sevilla	Viso del Alcor (El)	37.38826	-5.719357	145.28	0.552	1.280	B	4	B	4	B	4

** Reference cities*

ANNEX 2.- PUBLISHED ARTICLES

Energy rating for green buildings in Europe

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Abstract

The building sector is one of the main bodies responsible for primary energy consumption in Europe. Consequently, energy certification of buildings is being promoted under the policy to monitor and reduce energy consumption. By means of the European Directive 2002/91/EC on the Energy Performance of Buildings (EPBD), and the recast in the Directive 2010/31/EU, the legislative framework for all members of the European Union has been created and certification has become compulsory in all Member States. The primary aim of this energy framework is saving final energy and in consequence any related parameter such as primary energy, CO_2 emissions or energy costs, without compromising comfort or productivity.

Green building rating systems are developed to provide independent assessment standards that evaluate in a few categories about the performance and sustainability of buildings. However, and despite being based on the same legislative framework, the energy performance of buildings is calculated in different basis of methodology depending on the European country or region, and thus the same category might weigh differently in each of the rating systems.

Therefore, this paper aims to compile and compare the existing energy rating systems in European countries in order to better ascertain the uniformity of energy performance evaluation.
Keywords: energy rating, buildings, European framework, CO_2 emissions.

1 Introduction

The attenuation of climate change is a global priority due to the fact that CO_2 emissions are one of the greatest precursors of it [1]. With this purpose, the European Union created a legislative framework for all its member countries based on the Kyoto Protocol [2] by carrying out the corresponding transposition according to the necessities of each country. This framework is composed of the Directives 2002/91/EC [3] and 2010/31/EU [4] on Energy Performance of Buildings (EPBD).

Buildings dedicated to living quarters are responsible for 40% of the energy consumed and 36% of the CO_2 emissions to the atmosphere in Europe [3, 4]. Therefore these normative regulations were necessary to reduce this environmental impact generated by the building sector.

The regulation in terms of energy efficiency in buildings is critical for the assignment of the Qualified Experts (QEs) that will be involved in the process, as well as for their authorization and official tools to issue Energy Performance Certificates (EPCs) [5–7].

Throughout these regulations, the European objective is to achieve a Nearly Zero-Energy Building (NZEB) and thus make a comfortable building with minimum energy consumption by insulating the building envelope or encouraging the use of renewable energy in air conditioning systems, heating systems and domestic hot water (DHW), amongst other improvements for the accomplishment of savings in energy demand, CO_2 emissions and economical factors.

Taking the situation previously described into account, the objective of this review is to make a comparative analysis of the different transpositions of the EPBD within the European appointed countries (EU-28 and Norway).

2 Energy framework

The current challenge for the global energy sector is double: (i) increase dramatically the access to affordable and modern energetic services in countries that lack them and (ii) find the combination of energy sources, technologies, policies and behavioural changes that will reduce adverse environmental impacts [8]. A considerably large number of measurements have tried to be implemented as a response to the necessary fight against climate change; some of them are analysed in the section below.

2.1 Kyoto Protocol

The Kyoto Protocol [2] sets binding targets for 37 industrialized countries and the European community for reducing GHG emissions to an average of 5% against 1990 levels over the five-year period 2008–2012, varying among the different developed countries. By the end of the first commitment period of the Kyoto Protocol in 2012, a new extension for the period 2013–2020 was negotiated and ratified in order to deliver the stringent emission reductions the

Intergovernmental Panel on Climate Change (IPCC) had clearly indicated were needed.

Buildings are responsible for more than one third of total energy use and associated greenhouse gas emissions in society, both in developed and developing countries [9]. Therefore, the building sector is a large source of GHG emissions and has significant potential as a source of cost-effective emissions reductions [10]. With proven and commercially available technologies, the energy consumption in both new and old buildings can be cut by an estimated 30–50% without significantly increasing investment costs [10].

2.2 Directives 2002/91/EC and 2010/31/EU on the energy performance of buildings

To play a leading role in the reduction of greenhouse gases emissions, the European Union wanted to develop as quickly as possible a common position in the fight against climate change, and thus implemented its own measures to deal with climate change. In this regard, and due to the fact that more than 40% of EU energy consumption depends on buildings [11, 12], the Energy Performance Building Directive (EPBD 2002/91/EC) introduced the compulsory energy certification of buildings in the EU from 2006 and it has played a key role in the common policy to monitor and reduce energy consumption [12]. The recast of the EPBD in 2010 (2010/31/EU) seeks to clarify certain aspects of the 2002 Directive, extend its scope, strengthen certain provisions, and give the public sector a leading role in promoting energy efficiency.

The objective of these Directives is to promote the improvement of the energy performance of buildings within the Community, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness.

These Directives lay down requirements as regards: (a) general framework for a methodology of calculation of the integrated energy performance of buildings and building units; (b) application of minimum requirements on the energy performance of new buildings and new building units; (c) application of minimum requirements on the energy performance of: (i) existing buildings, building units and building elements that are subject to major renovation; (ii) building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are retrofitted or replaced; and (iii) technical building systems whenever they are installed, replaced or upgraded; (d) national plans for increasing the number of nearly zero- energy buildings; (e) energy certification of buildings or building units; (f) regular inspection of heating and air-conditioning systems in buildings; (g) independent control systems for energy performance certificates and inspection reports.

Together with an increased use of energy from renewable sources, measures taken to reduce energy consumption in the Union would allow the European Union to comply with the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), and to honour both its long term commitment to maintain the global temperature rise below 2°C, and its commitment to reduce, by 2020, overall greenhouse gas emissions by at least 20% below 1990 levels, and by 30% in the event of an international agreement being reached.

With these purposes, the Directives require Member States to set minimum requirements on energy performance and introduce a system of energy performance certification for buildings. It also requires Member States to develop plans for low or zero carbon buildings, with the public sector leading the way.

3 EPBD transpositions

Table 1 shows the transposition of the EPBD to the different EU countries and Norway, as well as the Accountable Public Administrations (APAs).

Table 1: EPBD transpositions and APAs.

COUNTRY	EPBD TRANSPOSITION	APAs
Austria (AT)	Energy Performance Certificate Law (EAVG) [13]	Austrian Institute of Construction Engineering (OIB)
Belgium – Brussels Capital Region (BE BR)	Brussels Air, Climate and Energy Code (BE) [14]	Regional Ministry of Energy of the Government of the Brussels Capital Region
Belgium – Flemish Region (BE FR)	Execution Order of May 11, 2005, adopted in 2009 [15]	Flemish Energy Agency (VEA)
Belgium – Walloon Region (BE WR)	Calculation Procedures and Minimum Requirements for New and Existing Buildings [16], Certification of New Buildings [17], Certification of Existing Residential Buildings [18] and Certification of Existing Non-Residential Buildings [19]	Department of Energy and Sustainable Buildings
Bulgaria (BG)	Energy Efficiency Act 2013 [20]	Sustainable Energy Development Agency (SEDA), supported by the Ministry of Economy and Energy and the Ministry of Regional Development
Croatia (HR)	Physical Planning and Building Act [21] and Energy Efficiency Act [22]	Ministry of Construction and Physical Planning
Cyprus (CY)	Law for the Regulation of the Energy Performance of Buildings [23]	Ministry of Energy, Commerce, Industry and Tourism
Czech Republic (CZ)	Regulation on Energy Performance of Buildings [24]	Ministry of Industry and Trade
Denmark (DK)	Danish Building Regulations (BR10) [25]	Ministry of Business and Growth
Estonia (EE)	Minimum Energy Performance Requirements [26]	Ministry of Economic Affairs and Communications
Finland (FI)	National Building Code [27]	Ministry of Environment and Ministry of Employment and the Economy

Table 1: Continued.

COUNTRY	EPBD TRANSPOSITION	APAs
France (FR)	Energy Performance Diagnosis (DPE) [28]	Ministry of Ecology and Sustainable Development Energy and Ministry of Territories and Housing
Germany (DE)	Energy Saving Ordinance (EnEV) [29] and Renewable Heating Law (EEWärmeG) [30]	Federal Ministry of Transport, Building and Urban Development and Federal Ministry of Economics and Technology, under the supervision of the Federal Ministry for Environment, Nature Conservation and Nuclear Safety
Greece (EL)	Law 3361 [31], KENAK (Regulation for Energy Performance of Buildings) [32], Presidential Decree 100/NG177 [33]	Ministry of Environment, Energy and Climate Change
Hungary (HU)	Ministerial Decree on the Establishment of Energy Characteristics of Buildings [34] and Decree of Minister about Determination of Energy Efficiency of Buildings [35]	Ministry of Interior
Ireland (IE)	Dwelling Energy Assessment Procedure (DEAP) and Non-Dwelling Energy Assessment Procedure (NEAP) [36]	Department of the Environment, Community and Local Government (DECLG)
Italy (IT)	Decree on the Promotion of the Use of Energy from Renewable Sources [37]	Ministry for Economic Development
Latvia (LV)	Law on the Energy Performance of Buildings (LEPB) [38]	Ministry of Economy
Lithuania (LT)	Law Energy Performance of Buildings [39]	Ministry of Environment and Ministry of Energy
Luxembourg (LU)	Grand-Ducal Regulation on the energy performance of buildings. Memorial and Functional [40]	Ministry of Economy and Foreign Trade and Ministry of Sustainable Development and Infrastructure
Malta (MT)	Legal Notice of Minimum Requirements on the Energy Performance of Buildings [41], Legal Notice of Energy Performance of Buildings Regulations [42] and Legal of Energy Performance of Buildings Regulations [43]	The Building Regulation Office (BRO)
Netherlands (NL)	Decree on Energy Performance of Buildings (BEG) [44] and Regulation on Energy Performance of Buildings (REG) [45]	Ministry of the Interior and Kingdom Relations
Poland (PL)	Construction Act Journal [46]	Ministry of Infrastructure and Ministry of Economy

Table 1: Continued.

COUNTRY	EPBD TRANSPOSITION	APAs
Portugal (PT)	System of Energy Certification (SCE) [47], Regulation of Energy Systems and Climatization of Buildings (RSECE) [48] and Regulation of the Characteristics of Thermal Conduct of Buildings (RCCTE) [49]	Ministry of Public Works, Transport and Communications Works
Romania (RO)	Law of Energy Performance of Buildings [50].	Ministry of Regional Development and Public Administration
Slovak Republic (SK)	Act on the Energy Performance of Buildings and on Amendment and Supplements to Certain Acts [51]	Ministry of Construction and Regional Development and Ministry of Economy
Slovenia (SI)	Regulation on Energy Performance [52]	Ministry of the Economy, Energy and Mining Inspectorate and Ministry of Environment and Spatial Planning
Spain (ES)	Basic Procedure for Certification of Energy Efficiency of Buildings [53], Regulation of Thermal Installations in Buildings (RITE) [54] and Technical Code of Edification (CTE) [55]	Ministry of Industry, Energy and Tourism and the Ministry of Development
Sweden (SE)	Law on Energy Declaration of Buildings [56], Performance Certificates for Buildings Ordinance [57] and Regulations by the National Board of Housing, Building and Planning [58]	Ministry of Enterprise, Energy and Communications and Ministry of the Environment
United Kingdom – England and Wales (UK – EW)	Building Regulations (amendments) Regulations [59] Energy Performance of Buildings [60]	Welsh Government
United Kingdom – Northern Ireland (UK – NI)	Building Regulations [61] and Energy Performance of Buildings (Certificates and Inspections) [62]	Department of Finance and Personnel Northern Ireland (DFPNI)
United Kingdom – Scotland (UK – S)	Building Act 2003, Building Regulations 2004, Building Procedure and Forms 2007, Energy Performance of Buildings Regulations 2008 [63]	Directorate for the Built Environment
Norway (NO)	Criteria for Passive Houses and Low Energy Buildings [64]	Water Resources and Energy Directorate (NVE)

4 Comparative analysis of the European energy rating systems

Due to the large volume of information that can be deduced from the different transpositions indicated in Table 1, the most important aspects have been summarized in Table 2. The information from each country has been structured according to: (i) characteristics of the EPC (calculation methodology, types of dwellings, energy rating scale, registration, improvements and validity) and (ii) requirements of the QEs.

Table 2: Characteristics of EPCs and QEs.

Country		EPCs									QEs	
		Method		Typology		Scale		Others			Quality	
		Demd	AEC	New	Exist	Levels	Cont	Reg	Imp	Valid	Cou	Ex
AT		X	-	X	X	9	-	-	-	10	-	-
BE	BR	X	-	X	X	17	-	X	X	5 to 15	X	-
	FR	X	-	X	X	-	X		X	10	X	X
	WR	X	-	X	X	8	-	X	-	10	-	-
BG		X	X	X	X	7	-	-	-	3 to 10	-	X
HR		X	-	X	X	8	-	X	X	10	X	X
CY		X	-	X	X	7	-	X	X	10	-	X
CZ		X	-	X	X	7	-	X	-	10	X	X
DK		X	-	X	X	8	-	-	-	7 to 10	-	-
FI		X	-	X	X	8	-	X	X	10	-	-
FR		X	X	X	X	7	-	X	X	10	-	X
DE		X	-	X	X	-	X	X	X	10	-	-
EE		X	-	X	X	8	-	X	-	10	X	X
EL		X	-	X	X	9	-	X	X	10	X	X
HU		X	-	X	X	9	-	X		10	X	-
IE		X	X	X	X	15	-	X	X	10	-	X
IT		X	-	X	X	8	-	X	-	10	X	X
LV		X	X	X	-	-	X	X	-	10	-	X
LT		X	-	X	X	9	-	X	-	10	X	X
LU		X	X	X	X	9	-	X	X	10	-	-
MT		X	X	X	X	7	-	X	-	10	X	-
NL		X	-	X	X	9	-	X	X	10	-	X
PL		X	-	X	X	-	X	X	-	10	X	X
PT		X	X	X	X	9	-	X	X	2 to 6	X	X
RO		X	X	X	X	7	-	X	X	5	X	X
SK		X	-	X	X	8	-		X	10	X	X
SI		X	X	X	X	7	-	X	-	10	X	-
ES		X	X	X	X	9	-	X	X	10	-	-
SE		-	X	X	X	7	-	X	X	10	-	X
UK	EW	X	-	X	X	7	-	X	X	10	-	-
	NI	X	-	X	X	7	-	X	X	10	-	-
	S	X	X	X	X	7	-	X	X	10	-	-
NO		X	-	X	X	7	-	X	X	10	-	-

Demd: Demand; AEC: Actual energy consumption; Exist: Existing; L: Levels; Cont: Continuous; Reg: Registry; Imp: Improvements; Valid: Validity (years); Cou: Course; Ex: Exam

4.1 Energy Performance Certificates (EPCs)

The EPCs calculation method is very similar in all countries, using the annual energy demand of the building to calculate the energy rating. However, the calculation method in Sweden is based on the real quantity of energy used, and other countries use a combination of both methods for the energy rating of the building (Table 2).

In the case of calculating the EPC by using the annual energy demand of the building, it is necessary to be very precise in defining the building envelope, materials, thermal bridges, heating and cooling, DHW, etc. This is due to the fact that this method is based on a prediction. This method has the advantage of knowing how the building is going to work before use in normal conditions. However, calculating the real amount of energy used, the measurement may vary between identical buildings in the same climate zone because of the human factor involved in the calculation method [65], although a more individualized result to each dwelling is obtained.

From the transposition of the EPBD, the EPC is carried out in the project phase in all countries except in Latvia, where the EPC is also performed in the existing buildings that are going to be sold or rent. As an exception, the EPC is not required in Sweden when the dwelling is going to be sold or rent to a member of the owner´s family.

Table 2 shows the scale to carry out the energy rating. As it can be observed, not all EU countries have adopted the same scale, ranging from scales with 7 levels (BG, CY, CZ, FR, MT, RO, SE, UK and NO) to scales of 17 levels (BE-BR). On the other hand, some of the countries have adopted a continuous scale (BE-FR, DE, LV and PL).

The registry of the EPC is mandatory in the majority of States. Moreover, it is compulsory to include proposals for energy improvement in the EPC. The validity of the EPC is 10 years generally, varying in some States due to variations such as the power of the heating and cooling facilities.

Regarding the price of the EPC, in the majority of the countries the price corresponds to the market price. Only Hungary has a fixed price that is established by the government.

4.2 Qualified Experts (QEs)

As is shown in Table 2, not all the countries have the same requirements for QEs. In some countries, a degree in architecture or engineering is required, whereas in other countries it is necessary to pass a course and/or an exam in addition to a university degree. The accreditation to QE may be given by the State, but the State can delegate this function to other bodies such as professional associations that would perform the courses and exams needed.

To know the available QEs, some States have online registers that can be consulted by the public. In other States it is necessary to go to professional associations where there are lists of the QEs. On the other hand, there are some States where this information is not public.

Another feature is that QEs can be divided into different categories. In countries with only one category of QEs, the inspection of buildings and facilities can be performed by the same expert, whereas there are countries with different categories of QE depending on building typologies and/or power of the facilities.

5 Conclusions

The transposition of the European framework to each country has created a series of regulations with the same origin but not homogeneous among themselves.
With the current transpositions it is impossible to compare the energy efficiency of two identical buildings in different States, even having the same climatic conditions, because the energy scales are different, as well as the calculation methods (energy demand, real consumption or both).

A QE in a State could not work in another State of the European Union as a QE because of the different requirements of each one. This fact impedes the free circulation of professionals.

Therefore, this study states the importance of a more homogeneous transposition of the EPBD in the different countries of the European Union, showing substantial differences between them in spite of being developed to achieve the same objective, which is the reduction of the energy consumption in dwellings by a proper building design.

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Comparative study by an expert panel of documents recognized for energy efficiency certification of buildings in Spain

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ABSTRACT

Approval of the European Directive 2002/91/EU was followed by its reformulation in Directive 2010/31/EU, with reference to the Energy Performance of Buildings (EPBD). The partial transposition of this norm in Spain took place through Royal Decree 235/2013, which describes the Basic Procedure for the Energy Performance Certification of Buildings and acknowledges four different documents to certify the energy simulation of buildings: (i) CALENER VYP as the general method, and (ii) CE3, CEX and CERMA, as simplified methods. This study analyzes and compares these documents through the qualified opinions of a panel of 105 multidisciplinary professionals of the sector that determined the strengths and weaknesses. To this end a survey was drawn up, including aspects as diverse as: the background and professional characteristics of the experts, the types of residences studied, the characteristics of the documents, the means of processing documents, and the final results in terms of reports and energy certifications. Data analysis shows that most technicians prefer using programs with a simple interface—namely, the CEX. Although all the documents recognized are equally valid for energy certification, when certain types of residence are involved, there may be as much as a 26% difference in the determination of CO_2 emissions. This translates into a higher or lower level in the final energy certification obtained for a building.

1. Introduction

The sectors of energy and construction are closely linked. A correct design and execution of a building, as well as the adequate use of its energy sources, are necessary to reach a zero energy house [1]. Renewable energies play a fundamental role, providing benefits such as economic savings, lesser CO_2 emissions, or an improved energy rating for a given construction [2]. In terms of functionality, energy simulation is a key tool for the energy-related assessment of a building [3]. It entails the use of computerized programs that can point out or predict any drawbacks deriving from construction characteristics and execution, as well as ways to remedy them.

In Spain, ratification of the European normative framework relative to the energy rating of buildings (European Directive 2002/91/EU [4], European Directive 2010/31/EU [5]), and its partial transposition through Royal Decree 235/2013 [6], Basic Procedure for the Energy Performance Certification of Buildings. Ministry of Industrial, Energy and Tourism meant the recognition of four software “documents” created for the energy simulation of buildings. CALENER VYP [7] applies a general method of reference with a higher level of detail, whereas CE3 [8], CEX [9] and CERMA [10] apply the simplified option of a prescriptive nature, whose indirect calculation is based on the general method. The simplified method is limited in that openings in the façade must constitute less than 60% of its total surface, and the percentage of skylights must be under 5% of the covered surface. Furthermore, excluded from the procedure are buildings whose enclosures consist of non-conventional constructive solutions.

All the above mentioned software documents are valid, as they are their results, which may rely on different parameters such as calculations, variables, means of data input, calculating engine, output report, etc. Consequently, the final results may be different both in CO_2 emissions and level of energy efficiency. Thus, the present contribution is a comparative analysis of the four documents mentioned above, based on a survey carried out with the active participation of professionals from the sector. Then, a horizontal comparison by means of a case study was performed to discern differences regarding the calculations of CO_2 emissions and the final energy rating of a residence.

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2. Materials and methods

In this section it has been defined the expert panel that carried out the survey about the documents recognized for the energy efficiency certification of buildings. The purpose of the survey is to analyze the strengths and weaknesses of each document, as well as to know the preferences of the experts. In addition, a standard building is defined as a model to develop the energy simulation with the different documents in order to compare the results obtained.

2.1. Documents recognized

The pertinent documents consulted were the CALENER VYP [7] (general procedure for buildings in project or terminated), and the CE3 [8], CEX [9] and CERMA [10], the latter three involving simplified procedures for existing buildings, described in the Royal Decree 235/2013 [6]. In addition, CERMA is valid to study new buildings in the design phase of the project [10], but for this study only the option of existing buildings will be analyzed.

2.2. Panel of experts

For the purposes of this study, we first generated an expert panel. This resource for data collection is commonly used in a wide range of fields, from medicine [11–14], to education [15,16], or biology [17], as well as construction [18].

The expert panel consisted of 105 technicians: 63 from the architecture sector and the other 42 from the engineering sector. They were identified through professional associations and universities in Spain. The experts have been selected attending to their professional relationship with the different documents, as well as considering their experience in energy performance certificates. All the experts of different professional associations interested in taking part have been represented. The participants are competent technicians that are qualified for elaborating reports on energy efficiency according to the Royal Decree 235/2013 [6].

An *ad hoc* questionnaire, shown in Table 1, was provided to the panel of experts. The structure of the survey and the items it contained were intended to determine the priority of the different experts when choosing one of the software tools of study, how they appraised it, and which strong points and weak points they encountered.

Data gathering through the surveys was carried out using Google Drive software, and the data obtained were statistically processed with predictive analytical software SPSS 20.0.0, licensed to the University of Granada.

2.3. Building type

A representative building was chosen in view of the predominating geometric and construction characteristics in Spain, a typology determined based on data from the National Statistical Institute of

Table 1
Structure of the ad hoc questionnaire given to the panel of experts.

	Question	Answer
Technician's background data	1.1. Degree	Architect; Architectural technician/Building engineer; Industrial engineer; Industrial technical engineer; Civil engineer; Technical engineer of public works; Others degrees (specify)
	1.2. Province	52 provinces
	1.3. Professional association	Yes/No (where)
	1.4. Sex	Man/Woman
	1.5. Age	18–99
Preferences	2.1. Geometric definition considered more accurate	Predefined types; surface and orientation; DXF blueprints
	2.2. Geometric definition used	Predefined types; Surface and orientation; DXF blueprints
	2.3. Preferences of document acknowledged by sectors	
	2.3.1. Interface	CALENER VIP; CE3; CEX; CERMA
	2.3.2. Input data	CALENER VIP; CE3; CEX; CERMA
	2.3.3. Final report	CALENER VIP; CE3; CEX; CERMA
	2.3.4. Material database	CALENER VIP; CE3; CEX; CERMA
	2.3.5. Calculating engine	CALENER VIP; CE3; CEX; CERMA
	2.3.6. Intuitive	CALENER VIP; CE3; CEX; CERMA
	2.3.7. Global	CALENER VIP; CE3; CEX; CERMA
	2.4. Other documents used	Yes/No (which one)
Times and surfaces	3.1. Single-family residence	
	3.1.1. Time per certification	Hours
	3.1.2. Average surface	m^2
	3.2. Multi-family residence	
	3.2.1. Time per certification	Hours
	3.2.2. Average surface	m^2
	3.3. Small teritiary sector	
	3.3.1. Time per certification	Hours
	3.3.2. Average surface	m^2
Qualification of document	4.1. CALENER	1–10
	4.2. CE3	1–10
	4.3. CEX	1–10
	4.4. CERMA	1–10
Recommendations for energy improvement suggested by the software	5.1. Insulation in opaque closures	CALENER VIP; CE3; CEX; CERMA
	5.2. Modification/substitution of openings	CALENER VIP; CE3; CEX; CERMA
	5.3. Installation/modification of solar protection	CALENER VIP; CE3; CEX; CERMA
	5.4. Improvements in systems, fuels, performance	CALENER VIP; CE3; CEX; CERMA
	5.5. Global	CALENER VIP; CE3; CEX; CERMA

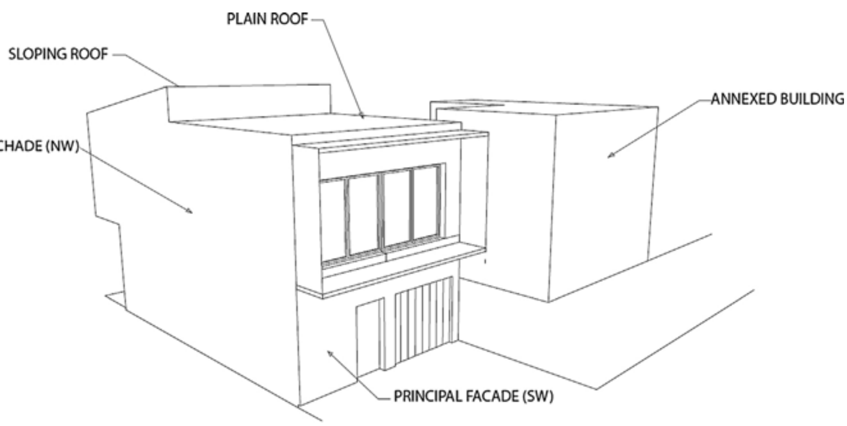

Fig. 1. Prototype residence.

Spain [19] and reports issued by the Upper Council of the Schools of Architects [20].

As seen in Fig. 1, the prototype building consists of a single-family residence structured on one floor and separated into different spaces: living room (17.60 m^2), kitchen (8.16 m^2), bathroom (4.42 m^2), hall (5.29 m^2) and two bedrooms (9.42 m^2 and 10.46 m^2). The total useable space amounted to 55.35 m^2. The most important materials in the thermal covering and thermal transmittance (U) used were: plain roof (0.48 W/m^2 K), sloping roof (0.45 W/m^2 K), unaccessible roof (0.75 W/m^2 K), exterior vertical closures (0.40 W/m^2 K), wooden door (2.20 W/m^2 K) and windows (1.87 W/m^2 K). The principal façade is oriented toward the southwest. A comfortable indoor temperature of 17 °C to 20 °C in winter, and between 24 °C and 26 °C in summer, was estimated. The climatic data were obtained from the database of the regional Environmental Council (*Consejería de Medio Ambiente y Ordenación del Territorio*) of the Junta de Andalucía [21].

As the heating system, a natural gas heater that provides for heating throughout the residence while also providing domestic hot water (DHW) was adopted, with the following specifications: heating potential 20 kW, efficiency 90%, temperature of water expulsion 50 °C for ACS and 80 °C for heating, and DHW volume of 31 l/day. The living room and bedrooms were air conditioned by a multi-zone installation with conducts having a potency of 7.1 kW and an air flow of 1500 m^3/h.

The representative residence was located in the city of Jaén (Southern Spain). According to Köppen Climate Classification [22], Jaén features a Temperate Climate (Type C) with a C4 climatic zone [23]. The Temperate Climate predominates in Spain as a whole [24].

The Government of Spain [25], using statistical data from numerous case studies categorized by climate zone [26–28], elaborated tables indicating cases where a similar residence would lose or win a grade on the energy scale (7 levels) because CALENER VYP was the document of reference. Table 2 shows the statistics corresponding to the climate and house type of study (residence in a block of apartments in climatic zone C4).

Table 2
Comparison of the energy class with the different documents acknowledged. CALENER VYP is the reference.

	Gains one level (%)	Same level (%)	Loses one level (%)	Loses two levels (%)
CE3	0.00	76.73	22.06	1.21
CEX	0.21	69.24	18.39	12.17
CERMA	0.00	88.14	11.86	0.00

3. Results and discussion

3.1. Comparative study of documents

3.1.1. Population

Shown in Fig. 2 are the characteristics of the 105 technicians on the expert panel. The most representative participating group was that of Architectural Technician/Building Engineers (51 participants), followed by Industrial Engineers (18), Industrial Technical Engineers (18), Architects (12) and other technical degrees (6) (3 Civil Engineers, 2 Public Works Engineers and 1 Mining Engineer). On the one hand, and according to Chapter III of the Law of Building Ordinance (*Ley de Ordenación de la Edificación*) (LOE) [29] related to the agents of the construction, only Architects and Architectural Technicians/Building Engineers have competence in residential edification. However, and basing on Article 1.3.p. and on the Fourth Additional Provision (Other technicians authorized) of the Royal Decree 235/2013 [6], all the technicians considered for this expert panel, as well as those listed in Resolution of 15th January 2009 [30], can issue official certification of energy efficiency.

Of the 105 experts, 94 were members of Professional Associations, while 11 – equally distributed geographically, from all over Spain – affirm that it is not necessary for the execution of their profession. A breakdown by sex shows that 95 are male, 10 are female; and as for age, most are between 31 and 45 years of age (61), followed by age 46 to 60 (26), 18 to 30 (15) and age 61 or over (3). Fig. 2 depicts the corresponding percentages.

3.1.2. Preferences

In view of the number of experts offering an opinion about the different documents, those most frequently used by the experts to perform the energy efficiency certification (N) are CE3 and CEX (both having $N = 90$), followed by CALENER VYP ($N = 82$) and finally CERMA ($N = 43$). The low number of expert users of CERMA indicates that it is not the most common document to carry out the energy efficiency certificates. This situation does not affect the evaluations of the document, since only experts using CERMA have valued the document. The standard deviations of CALENER VYP, CE3 and CEX have very similar values (1.985–2.099), whereas CERMA shows a substantially greater value (2.228), reflecting wider discrepancies among the participants.

Overall, the mark received per document is not very high. As seen in Fig. 3, on the scale of 0 to 10, not one single document surpassed a mark of 7. However, with the understanding that a mark less than 5 would be a negative evaluation, it can be said that no method fails. The document best appraised, far above the

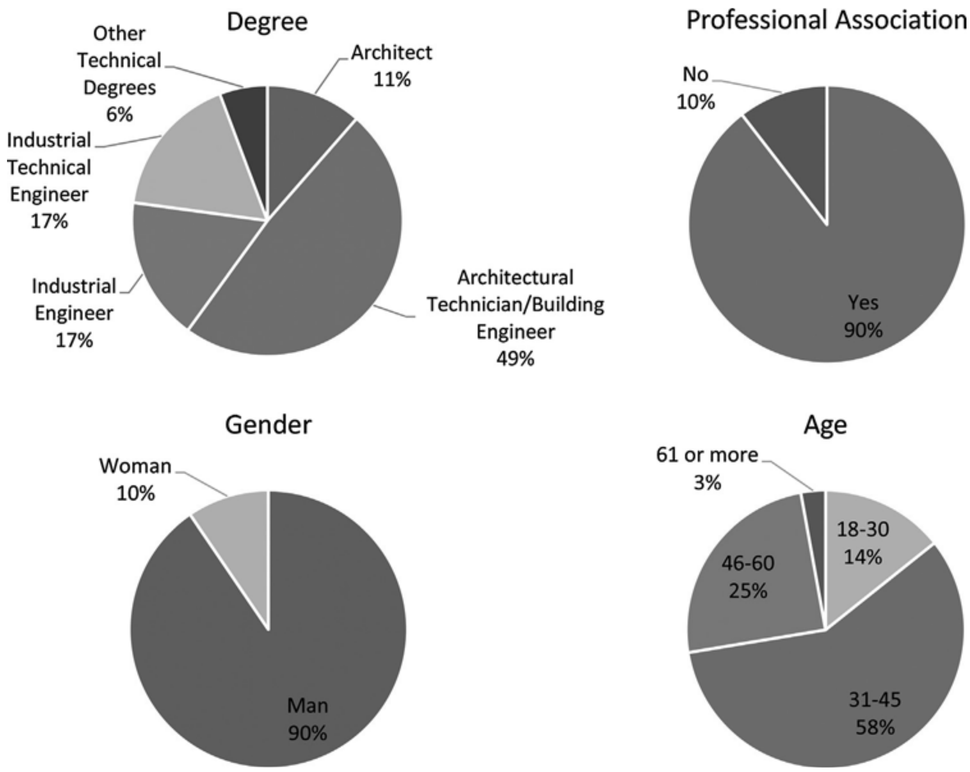

Fig. 2. Population surveyed.

rest, was CEX, rated 6.64 on the average, followed by CALENER VYP, CERMA and CE3, these three obtaining similar averages around 5.

The four documents of study use different procedures to introduce the geometry of the living quarters. There were manifest differences of opinion about the means used by technicians and the one considered most precise. Thus, 73% of the experts participating in this study used as input data the surface and orientation, followed by 20% who relied on the DXF blueprints, whereas 7% use predefined types. Most experts hold that the most precise means is DXF blueprints (60%), while surfaces and orientation are supported by 37%. Just 3% advocate the predefined types, whose low acceptance rate suggests they are not considered reliable by experts. Although a majority affirms that the most widely used method is the one based on surfaces and orientation, most reportedly consider it more exact to introduce the data by means of DXF blueprints. Such a contradictory message, affirming that one is used but the other is more precise, can be explained by the data input procedure. Indeed, introducing DXF prints is more complex; yet equally valid results, according to the legal norm, can be obtained using the simpler procedures [6].

As for choice of sections (Table 3), the preferred document in all categories except one is CEX. The exception is the calculating engine, where CALENER VYP is preferred, as all the other documents are based upon it. In this part of the survey, the participating experts (*N*) were the total number of participants. In other words, the least used documents, as observed earlier, were the ones less selected by sections, as is the case of the CERMA—despite being better appraised than the CE3, it harvested the lowest evaluation overall.

Finally, in terms of the energy improvements suggested by the software, as seen in Table 4, the document gaining the highest consideration in all the categories was CEX, followed by CE3, CALENER VYP and CERMA.

Table 3
Preference of document, as acknowledged by sections.

N = 105	CALENER VYP (%)	CE3 (%)	CEX (%)	CERMA (%)
Interface	7.6	31.4	59.0	1.9
Input data	4.8	36.2	55.2	3.8
Final report	14.3	28.6	50.5	6.7
Material database	34.3	25.7	37.1	2.9
Calculating engine	38.1	26.7	30.5	4.8
Intuitive	3.8	30.5	64.8	1.0
Global	16.2	31.4	49.5	2.9

Table 4
Preference of recommendations of energy improvement by document acknowledged.

N = 105	CALENER VYP (%)	CE3 (%)	CEX (%)	CERMA (%)
Insulation in opaque closures	19.0	35.2	41.0	4.8
Openings in façade	16.2	35.2	43.8	4.8
Solar protection	20.0	32.4	44.8	2.9
Systems, fuels, performance	18.1	34.3	44.8	2.9
Global	15.2	32.4	48.6	3.8

3.2. Practical case study

By applying the different documents to the prototype residence adopted in this study, differences appear in terms of CO_2 emissions and the corresponding energy certification for the same building type (Table 5). For comparative purposes, CALENER VYP was taken as the reference, as it is the only document that uses the general method.

The analysis of the results carried out by the authors with the different documents shows that use of the CE3 means a 2.21% increase in the calculation of CO_2 emissions. In contrast, documents CEX and CERMA present lower values for emissions, with respective

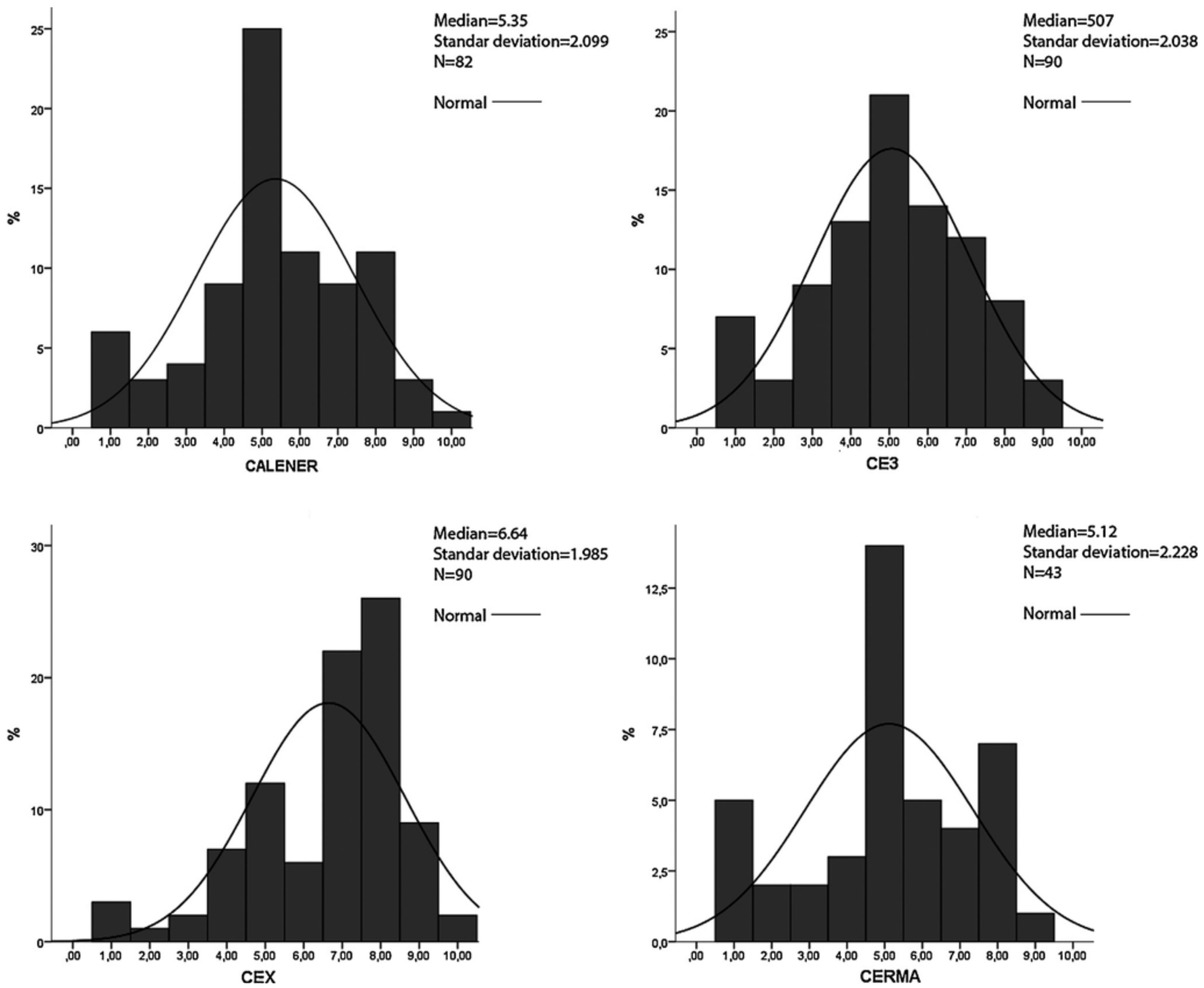

Fig. 3. Evaluation of the documents acknowledged.

Table 5
CO_2 emissions and energy rating with the different documents.

	CALENER VYP	CE3	CEX	CERMA
CO_2 emissions (kg/m^2 year)	54.4	55.6	40.1	41.1
A–G	E	E	D	E

reductions of 26.29% and 24.49%. Despite the fact that this discrepancy introduces the same values with the different documents, it generates serious errors. These results could be future mistakes in the calculation of the right materials needed for the thermal envelope or the thermal system.

With regard to the energy certification, on a scale of 7 levels (A–G) [6], all the documents except one obtained the grade of E. The exception was CEX, which overall gave a better result, D. The fact that one may obtain a better or worse result depending on the document of choice may have considerable implications for the market value of a building. Moreover, it may impede getting subventions for residential energy rehabilitation.

Comparing these results with the statistics provided by the Government of Spain (Table 2), it is seen that the use of document CE3 enables one to obtain the same rating in 76.73% of cases; with CERMA the same E certification is similarly obtained in 88.14% of the cases. In sharp contrast, however, with CEX a grade one level higher is attained (0.21% of cases). In view of these results, it can be stated that the document recognized as representing the lowest CO_2 emissions and the best energy certification would be the CEX.

4. Conclusions

Consultation with a panel of experts who evaluated the documents used for the energy certification of buildings leads to two noteworthy conclusions. First, although all the documents acknowledged have the same validity when processing an energy certification, most experts prefer a user-friendly interface, as is the case of CEX. Generally speaking, it is the most widely used document by the expert panel, together with CE3, followed by CALENER VYP and CERMA; it is also the best appraised one (6.64), followed by CALENER VYP (5.35), CERMA (5.12) and CE3 (5.07).

The application of the four documents to a single residential type gave diverse results. In the case of CO_2 emissions, there is a substantial discrepancy of 26%, which means a higher or lower final level of energy certification. Currently, the government reports are CE3 vs. CALENER, CEX vs. CALENER and CERMA vs. CALENER. This first study is a starting point for a future analysis of the four documents with real cases in parallel (CE3 vs. CEX vs. CERMA vs. CALENER).

In view of the results reported here, entailing subjective appraisals on the part of the expert panel and objective findings regarding CO_2 emissions and energy certifications, it can be said that the outstanding software document for energy certifications is the CEX. Further studies are necessary to harmonize all the recognized documents in order to ensure more homogenous results than the ones reflected here.

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Impact of using biomass boilers on the energy rating and CO_2 emissions of Iberian Peninsula residential buildings

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ABSTRACT

Adequate energy efficiency in any residential building calls for a number of factors to be taken into account as specified in the energy certification of buildings under European Union Directive 2002/91/EU. In particular, the heating systems are essential to optimize the use of energy, that are both efficient and environmentally sustainable, which generally imply the use of renewable energy sources. This paper examines the impact of using biomass boilers on the energy rating and CO_2 emissions in six cities located in the Iberian Peninsula with different climatic conditions. The study compares the use of fossil fuels (natural gas and gasoil) and a renewable energy source (biomass) in heating and hot water systems in two types of residential buildings. The results underline the influence of the climate in reducing CO_2 emissions and economic costs, and improving the energy rating. A remarkable decline of up to ≈95% in CO_2 emissions may be achieved with the use of biomass, as compared to fossil fuels, with the economic savings being as much as ≈88%. It is concluded that the use of biomass can significantly improve the energy rating—in the best cases the improvement can reach four classes on a scale of seven levels.

1. Introduction

Global warming is directly linked with the emission of greenhouse gases, which include CO_2, CH_4 and N_2O. In recent years, their emissions have grown exponentially, leading to important environmental problems [1], and underlining the need to control their impact [2]. Energy use in residential buildings is responsible for about 36% of the total CO_2 emissions [3].

The estimation of the energy necessary to comply with the demands of a building under normal conditions of occupancy and functioning is known as the energy efficiency rating. By comparing a number of indicators of the mean energy use in model buildings of reference, a real building can be qualified and certified on an energy scale established for this purpose [4,5]. The energy rating of buildings and their systems of heating and cooling stand, from final users point of view, as a guarantee about the energy requirements for a comfortable interior temperature, reduced emissions of CO_2 to the atmosphere, and economic savings. In addition, governmental energy strategies feature provisions for future grants for residences that have optimal energy ratings.

The European Union, through its Directive 2002/91/CE [6], introduced the energy performance certification for newly constructed buildings. This is one of the initiatives of the European Union against climate change deriving from the Kyoto Protocol [2], meant to reduce the environmental burden of emissions from the use of fossil fuels [1,2]. Directive 2002/91/CE replaces previous Directive 92/42/CEE, regarding boilers, Directive 89/106/CEE, regarding the products of construction, and the provisions related with buildings corresponding to the program SAVE [7,8]. Each country is responsible for incorporating the guidelines specified in Directive 2002/91/CE into the domestic legislative framework. For example, in Spain, the normative that regulates the energy rating of buildings was partially transposed through the Royal Decree 47/2007, *Procedimiento Básico para la Certificación de Eficiencia Energética de Edificios de Nueva Construcción* (Basic Procedure for Certification of Energy Efficiency of Buildings New Construction) [4], repealed by the Royal Decree 235/2013, *Procedimiento Básico para la Certificación de Eficiencia Energética de Edificios de los Edificios* (Basic Procedure for Certification of Energy Efficiency of Buildings) [5], *Reglamento de Instalaciones Térmicas en los Edificios* (RITE) (Regulation of Thermal Installations in Buildings) [9] and the *Código Técnico de la Edificación* (CTE) (Technical Code of Edification) in its *Documento Básico de Ahorro de Energía* (DB-AE) (Basic Document of Energy Savings) [10]. In the case of Portugal, analogously, there is a *Sistema de Certificação Energética* (SCE) (System of

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Energy Certification) [11], *Regulamento dos Sistemas Energéticos e de Climatização nos Edifícios* (RSECE) (Regulation of Energy Systems and Climatization of Buildings) [12] and *Regulamento das Características de Comportamento Térmico dos Edifícios* (RCCTE) (Regulation of the Characteristics of Thermal Conduct of Buildings) [13]. The Royal Decree 47/2007 [4] was formerly applicable only to new buildings, repealed by Royal Decree 235/2013 [5], applicable to all living units to be bought, sold or rented out in existing buildings.

Historically, on the Iberian Peninsula, little attention was paid to the thermal performance of buildings, either during the design stage or during the construction so that a very significant percentage of buildings would fail current energy examinations. For instance, over 50% of the installed boilers run on fossil fuels [14]. Given the need to reduce the CO_2 emissions, the use of renewable fuels, such as biomass, should be encouraged. At present, 80% of the world energy is supplied by fossil fuels and 14% comes from renewable sources, with 9.6% thereof coming from traditional biomass [15]. This is an economically favorable alternative [16,17], which makes it possible to obtain beneficial energy ratings for the existing buildings.

This study concentrates on the impact of using biomass boilers on the energy rating and CO_2 emissions of Iberian Peninsula residential buildings. Related studies using thermal simulations have been conducted in a number of countries for various conditions. For example, Pisello et al. [18] evaluated the influence of the climatic zone on the energy rating of buildings. Buratti et al. [19] concluded that glazing systems and building orientation improves the thermal comfort and reduces the energy demand up to 67% in non-residential buildings. Studies in China [20], Spain [21] and United Kingdom [21] examined the energy efficiency performance in buildings using renewable energy sources for heating and domestic hot water (DHW), including biomass [20,21] and solar DHW [22]. Wang et al. [22] also applied passive design methods and advanced façade designs to minimize the load requirements for heating and cooling purposes through building energy simulations and analysis of the local climate data. All these studies analyzed factors affecting energy efficiency separately. The novelty of the present research is that it compares different parameters, including different climatic zones, conventional and renewable fuels for heating and DHW and different types of dwellings in regard to: (i) energy demand; (ii) environmentally effects; (iii) economic effects and (iv) energy rating.

In this context, the specific objective of the present study is to determine the environmental and economic advantages of using biomass in systems for heating and DHW, as opposed to conventional energy sources, with reference to the energy rating of residential buildings on the Iberian Peninsula. Furthermore, this investigation allows determining the variables that bear the greatest influence on the energy rating of a building, and how the use of biomass can contribute to an improved rating. The study is conducted for six cities located in the Iberian Peninsula with different climatic conditions.

2. Material and methods

2.1. Simulation software used

The energy rating of a building is determined by means of theoretical thermal simulations. The use of software designed for this purpose began in the 1980s [23]; and eventually sophisticated tools arose, including exhaustive climate records, libraries of materials with different constructive solutions, and complete CAD integration. The various programs differ in terms of how the characteristics of the building are introduced as input, and in the output provided [24].

The Housing Ministry of Spain has an array of tools validated for rating energy use (Article 3 of Royal Decree 235/2013 [5]), which include CERMA [25], a software program based on two other well established methods, CALENER-VYP [26] and LIDER [27]. In the case of Portugal, there is no official computer program specifically developed for energy rating so that the software chosen for this study was also CERMA.

2.2. Characteristics of the buildings studied

The thermal simulations carried out using CERMA have allowed us to gather a vast amount of data. A number of construction characteristics, including geometry, orientation and materials, buildings location and local climate along with the type of fuel used in the systems for heating, DHW and cooling have been introduced. This section summarizes the main features of the buildings studied. The blueprints and measurements of the constructions were processed by means of Autocad [28].

2.2.1. Geometry and materials

Two types of buildings located in the Iberian Peninsula were selected: (i) a single-family house, and (ii) a multi-family residential building, placed among other constructions. Both types of dwelling, with the given surface areas and construction solutions, are representative of the current residential offer in Spain and Portugal, according to the census of residences of the National Statistical Institute of Spain [29] and that of Portugal [30], as well as with the reports published by professional associations of architects and technical architects, based on their official inspections [31–33].

Fig. 1 shows the plan of the single-family house and Table 1 shows its main features. As can be seen, the single-family dwelling consists of three floors: a basement, a ground floor and a first floor. The house is located on a gentle slope, which means that the basement is completely underground on one side, yet above the ground on the other side of the house.

Similarly, Fig. 2 shows the plan of the residential building or multi-family dwelling and Table 1 shows its main features. It is seen that the residential building or multi-family dwelling has five stories: a ground floor, a first, a second and a third floor, and a tower. In this case, the building is a rectangle on a corner so that the north and east sides of it are fully in contact with other constructions, while the south and west façades are exposed.

Table 2 shows the elements and materials used in the buildings considered in this study. To ensure a low thermal transmittance limit (U), all the materials involved in the construction of the buildings have adequate thermal insulation. Emphasis is also placed on the thermal bridges, given their role in the heat losses; for instance, inadequate execution of exterior closures of a double brick wall can mean 30% more thermal losses [34]. For similar reasons, it is considered continuous insulation in the junctions with framework slab, and constant closure to the line of the doorjamb, lintel or windowsill.

2.2.2. Boilers

For the thermal simulation at each building and city, boilers with similar characteristics, able to fire either gasoil, natural gas or biomass, have been chosen. The thermal load selected for each boiler was set to 24 kW. For the single-family house one boiler (24 kW) was considered, whereas for the multi-family dwelling three boilers were installed (total boiler load of 72 kW). For all boilers it was considered a thermal efficiency of 90%, with an outlet water temperature of 50 °C for DHW and 80 °C for heating. The flow rate of DHW in the single-family house was 235.80 l/day, and in the multi-family dwelling 568.72 l/day. Both residences have an accumulator; specifically with a capacity of 200 l in the single-family house and 500 l in the multi-family dwelling. In both cases the

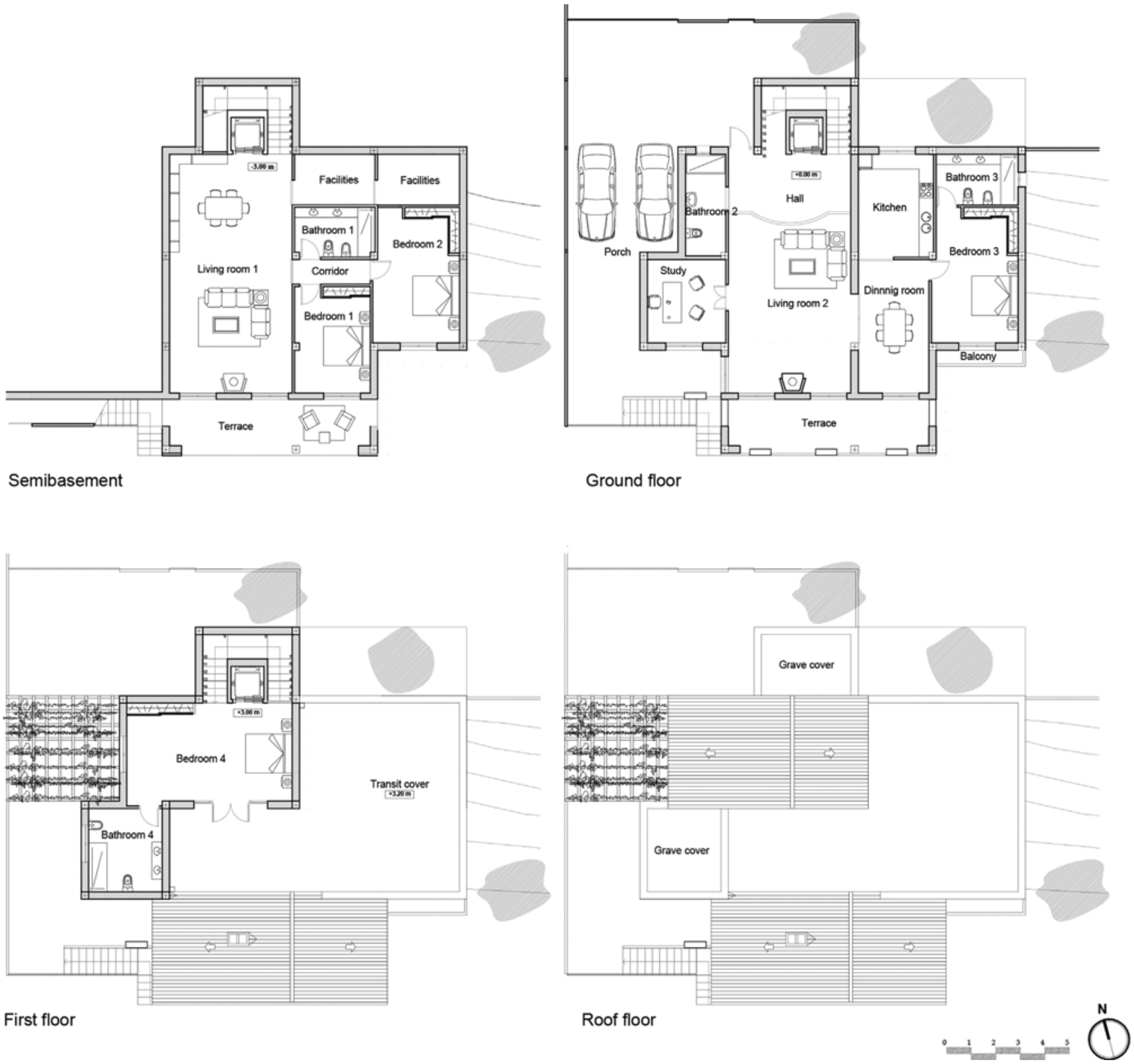

Fig. 1. Plan of the single-family house.

water temperature varied between 60 °C and 80 °C, with the global heat transfer coefficient (U × A) being 1 W/K.

The present study focus on the heating and DHW since this system uses fuel directly (gasoil, natural gas or biomass). Because the energy rating procedure calls for choosing a system of refrigeration as well, it is considered an electrical based refrigeration system, which is the most commonly used system in residential buildings in Spain and Portugal.

2.2.3. Climatic zone, orientation and internal temperature

Classification of the climatic zones where the present buildings are located accounts for the severity of the climate in winter and in summer, and the combined influence of outside temperature and solar radiation. The scale used depends on the country of the European Union considered [2]. For example, in France there are three separate zones, in Italy six, in Portugal three, and in Spain five. To establish a common criterion in order to compare the results, it was adopted as reference the CTE scale corresponding to Spain [35]. Hence, for the winter five climate zones are considered, designated by the letters A–E, and for the summer four zones, designated by the numbers 1–4.

The buildings studied here are all located in the Iberian Peninsula; specifically in three Portuguese cities (Évora, Lisbon and Bragança), and in three Spanish cities (Almería, Granada and Burgos), as shown in Fig. 3. The selection process sought comparatively hot summer climates (Almería and Évora), cold winter climates (Burgos and Bragança) and moderate climates (Granada and Lisbon) [10,11], thereby covering most of the CTE climate classifications. In the case of the Spanish cities, the assignment was done automatically through the CTE DB-HE1, Appendix D, Table D1; for the Portuguese cities, not included in the CTE, it was used Appendix D, Section 2, of the CTE DB-HE1 plus the climate records from Energy Plus [36]—a program of thermal and energy simulation created by the US Department of Energy (DOE). Table 3 shows the equivalences that this procedure yielded.

To enhance the objectivity of the present results, buildings with the same orientation were chosen, regardless of the city. In the case of the single-family house, most of the windows, living quarters, and main façade faced the south; in the case

Table 1
Distributions of the areas in the buildings studied.

Usable area			
Single-family house		Residential building	
Dwelling	Surface (m^2)	Dwelling	Surface (m^2)
Semibasement		Ground floor	
Living room	48.04	Garage[a]	144.01
Facilities	13.77	Storerooms[a]	46.53
Corridor	3.18	Facilities[a]	48.47
Bedroom 1	12.51	Hall	31.51
Bedroom 2	17.42	Stair	9.94
Bathroom 1	6.60	1–3 floor	
Stairs	7.21	A-Living room	32.74
Ground floor		A-Kitchen	12.13
Living room	36.16	A-Bathroom	8.74
Dining room	15.70	A-Bedroom 1	17.97
Kitchen	13.00	A-Bedroom 2	12.13
Study	12.00	A-Bedroom 3	11.79
Bedroom 3	19.14	A-Corridor	12.25
Bathroom 2	6.90	B-Living room	36.01
Bathroom 3	6.90	B-Kitchen	17.15
Stairs	7.21	B-Bathroom 1	5.44
First floor		B-Bathroom 2	8.74
Bedroom 4	26.00	B-Bedroom 1	16.21
Bathroom 4	10.25	B-Bedroom 2	21.58
Semibasement	108.73	B-Bedroom 3	16.96
Ground floor	117.01	B-Hall	18.30
First floor	36.25	Common area	
		Hall	9.02
		Stair	9.94
		Top floor	
		Transit cover	272.48
		Hall	9.02
		Stair	9.94
		Ground floor	41.45
		1–3 floor	801.30
		Top floor	18.96
Total usable	261.99	Total usable	861.71

[a] Not computable for heating, DHW and cooling.

of the multi-family dwelling, the main façade was facing the west.

Finally, an indoor temperature that would prove comfortable yet not wasteful in terms of energy was established; specifically, between 17 °C and 20 °C in winter, and between 24 °C and 26 °C in summer.

2.3. Energy rating

Not all European Union countries use the same criteria scale for energy ratings, and the number of levels can vary as well. For example, Austria has nine levels, Ireland has fifteen, and there are seven levels in Spain, France and Portugal [35]. The scale used in this study comprises seven levels, the most efficient denoted by A, and the least efficient one designated by G. As no new buildings would have level F or G, these are used only for renovated structures [37]. Table 4 gives the upper and lower bounds of each energy level for each city and building type.

2.4. Economic considerations

In evaluating the costs of the different heating systems—gasoil and natural gas in conventional boilers; olive pit, pine chips and bulk wood pellets in biomass boilers—it was taken into account the prices of the different fuels as presented in [38–40], without considering other factors such as their seasonal availability or geographic abundance. For instance, olive pit is only cost-effective if it is naturally available nearby the house since the cost of transport would be substantial [41], while wood pellets may be costly but the supply can be guaranteed. Table 5 shows the characteristics of the fuels studied (gasoil, natural gas, olive pit, pine chips and wood pellets) as well as their unitary cost [38–40]. Based on the characteristics of each fuel and the demand of each residence, the total fuel needed was calculated. Then, based on the total fuel and cost per unit, the final cost was determined. These costs refer only to the annual fuel consumption, being the initial investment in the equipment and maintenance not considered here.

3. Results and discussion

3.1. Energy and environmental factors

3.1.1. Energy demand

The indoor temperature of the residences is determined by the climate, season, and the heating/cooling system used. Fig. 4 displays the annual indoor temperature variation in Almería and Burgos, which are two cities with extremely cold climates. Burgos shows fairly even temperatures in all months of the year, except during summer, revealing that heating systems provide a very stable indoor temperature in winter (between 17 °C and 20 °C). During summer, temperatures are somewhat irregular since there is no need for cooling, with a mean temperature of 21 °C and a maximum of 24 °C. The lowest temperatures, in May and June (from 3500 to 4000 h in Fig. 4), can be attributed to an interruption in the use of heating together with outdoor temperatures generally lower than 17 °C. In contrast, the dwellings situated in Almería show very irregular temperature during winter since the outdoor temperature often reaches 22–23 °C so that heating is not required, whereas during summer the indoor temperatures are regulated by the usual use of a cooling system.

Table 6 shows the energy demand, CO_2 emissions and energy rating in the buildings and cities studied. The energy demand data obtained through simulations of ideal and equivalent situations, using the CERMA software, indicate the objectives to attain in the blueprint stage; once a residence is occupied, the "user factor" affects significantly the results, depending on the residents' particular habits, maintenance and use of the home. For example, two adjacent and identical dwellings can show up to 40% variability in their heating expenses due to excessive ventilation [42]. This implies that real data may vary 50–150% with regard to the theoretical calculations [43]. Furthermore, minor modifications in the original configuration of the home could lead to considerable changes in energy demands. For instance, adding a glass protector of 0.35 mm provides for 6% savings in heating, but an increase of 6% in cooling. Moreover, modifying the color of the façade in view of the climate (e.g., a light color in hot climates) can lead to 2% savings in summer, but also to 2% losses during the winter in the south. Also, increasing openings in the north façade by 20% can lead to 5% savings in heating and 2% in cooling with respect to the original buildings [21].

All the houses studied in this study have the same essential features so that the only factor influencing the energy demand is the climatic zone, which has a great impact on the results. Table 6 reveals that the total energy demand ranges from 55.7 kWh/m^2 year in Almería to 164.1 kWh/m^2 year in Burgos for single-family houses, and from 44.7 kWh/m^2 year in Almería to 136.5 kWh/m^2 year in Burgos for multi-family residences. The variations are particularly high in the case of cities with harsher climates, where the heating demand is greater [17,22].

It is also observed that the single-family house uses 20.22–24.61% more energy than the multi-family home, depending on the climatic zone. In fact, the enclosure of a building (m^2) and its volume (m^3) are 26% greater for the single-family residence, which means larger exposure to the elements. Accordingly, the

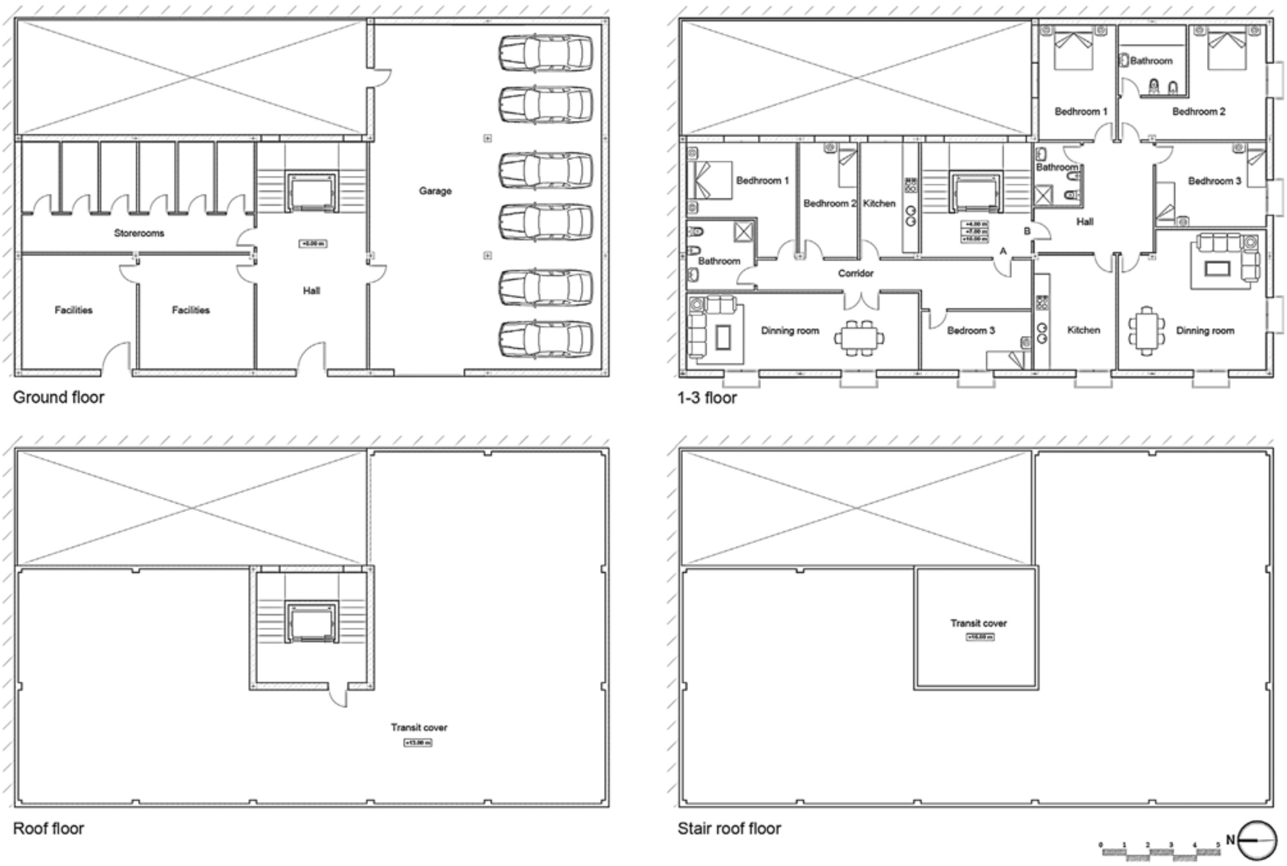

Fig. 2. Plan of the residential building or multi-family dwelling.

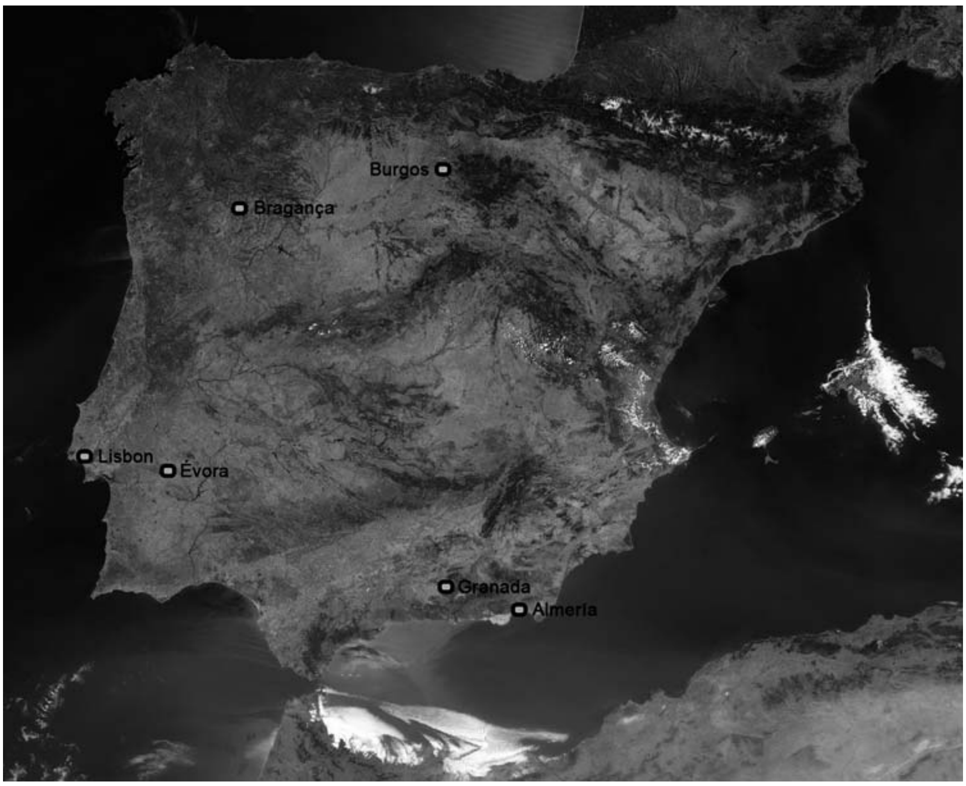

Fig. 3. Location of the cities studied.

Table 2
Elements and materials used in the buildings studied.

System	U (W/m² K)	Surface (m²)	Orientation	Material	k (W/m K)	Thickness (m)
Single-family house						
Roof						
Roof 1	0.48	47.60		Ceramic tiles	1.00	0.006
he = 25.00 W/m² K				Lime mortar for rendering d > 2000	1.80	0.024
he = 10.00 W/m² K				Mortar lightweight aggregate [vermiculite perlite]	0.41	0.040
				Polyvinyl chloride [PVC]	0.17	0.001
				Mineral wool [0.04 W/[m K]]	0.04	0.060
				High density polyethylene [HDPE]	0.50	0.002
				Concrete with lightweight aggregate 1800 < d < 2000	1.35	0.100
				Floor structure	0.94	0.250
				Plaster rendering 1000 < d < 1300	0.57	0.015
				Total		0.498
Grave roof	0.43	19.30		Sand and gravel [1700 < d < 2200]	2.00	0.050
he = 25.00 W/m² K				Sublayer felt	0.05	0.001
he = 10.00 W/m² K				Polyvinyl chloride [PVC]	0.17	0.001
				Sublayer felt	0.05	0.001
				Extruded polystyrene, expanded with carbon dioxide [XPS] [0.034 W/[m K]]	0.03	0.060
				Low density polyethylene [LDPE]	0.33	0.020
				Concrete with lightweight aggregate 1800 < d < 2000	1.35	0.100
				Floor structure	0.94	0.250
				Plaster rendering 1000 < d < 1300	0.57	0.015
				Total		0.498
Sloping roof	0.45	36.90	W	Polyvinyl chloride [PVC]	0.17	0.001
he = 25.00 W/m² K		24.70	E	Extruded polystyrene expanded with carbon dioxide [XPS] [0.034 W/[m K]]	0.03	0.060
he = 10.00 W/m² K				Low density polyethylene [LDPE]	0.33	0.002
				Floor structure	0.94	0.250
				Plaster rendering 1000 < d < 1300	0.57	0.015
				Total		0.328
External walls						
External wall	0.54	69.00	N	Lime mortar for rendering d > 2000	1.80	0.015
he = 7.69 W/m² K		66.80	W	6 in. perforated metric brick or Catalan brick 80 mm < G < 100 mm	0.54	0.115
		79.80	S	Slightly ventilated vertical air chamber	0.00	0.050
		91.40	E	Extruded polystyrene, expanded with carbon dioxide [XPS] [0.034 W/[m K]]	0.03	0.040
				Double hollow brick breeze-block [60 mm < E < 90 mm]	0.43	0.070
				Plaster rendering 1000 < d < 1300	0.57	0.015
				Total		0.305
Underground wall	0.62	96.20		Ground		
Deep (m) = 1.00				6 in. perforated metric brick or Catalan brick 40 mm < G < 50 mm	0.99	0.115
he = 7.69 W/m² K				Lime mortar for rendering d > 2000	0.55	0.010
				Expanded polystyrene [EPS] [0.037 W/[m K]]	0.04	0.030
				Double hollow brick breeze-block [60 mm < E < 90 mm]	0.43	0.060
				Plaster rendering 1000 < d < 1300	0.57	0.010
				Total		0.225
Floor						
Ground floor – 3.30	0.29	118.00		Tile	1.30	0.020
Deep (m) = 3.30				Expanded polystyrene [EPS] [0.037 W/[m K]]	0.04	0.043
Perimeter (m) = 48.70			Lime mortar for rendering d > 2000	0.55	0.010	
he = 5.88 W/m² K				Mass concrete 2000 < d < 2300	1.65	0.250
				Pressed adobe clay blocks [1770 < d < 2000]	1.10	0.020
				Ground		
				Total		0.343
Ground floor – 0.30	0.65	18.00		Tile	1.30	0.020
Deep (m) = 0.30				Expanded polystyrene [EPS] [0.037 W/[m K]]	0.04	0.043
Perimeter (m) = 21.80				Lime mortar for rendering d > 2000	0.55	0.010
he = 5.88 W/m² K				Mass concrete 2000 < d < 2300	1.65	0.250
				Pressed adobe clay blocks [1770 < d < 2000]	1.10	0.020
				Ground		
				Total		0.343

Table 2 (*Continued*)

System	U (W/m² K)	Surface (m²)	Orientation	Material	k (W/m K)	Thickness (m)
Residential building						
Roof						
Roof 1	0.48	272.5		Identical to single-family house		
Grave roof	0.43	20.1		Identical to single-family house		
External walls						
External wall	0.54	144.60	N	Identical to single-family house		
		213.00	W			
		125.50	S			
		35.40	E			
Uninhabitable local	0.52	236.20		Plaster rendering 1000 < d < 1300	0.57	0.015
he = 7.69 W/m² K				Double hollow brick breeze-block [60 mm < E < 90 mm]	0.43	0.07
				Mineral wood [0.031 W/[m K]]	0.03	0.04
				Double hollow brick breeze-block [60 mm < E < 90 mm]	0.43	0.07
				Plaster rendering 1000 < d < 1300	0.57	0.015
				Total		0.21
Dividing wall	0.52	267.8		Plaster rendering 1000 < d < 1300	0.57	0.015
he = 7.69 W/m² K				Double hollow brick breeze-block [60 mm < E < 90 mm]	0.43	0.07
				Mineral wool [0.031 W/[m K]]	0.03	0.04
				Double hollow brick breeze-block [60 mm < E < 90 mm]	0.43	0.07
				Plaster rendering 1000 < d < 1300	0.57	0.015
				Total		0.21
Floor						
Uninhabitable local	0.49	260.6		Ceramic tiles	1	0.06
he = 10.00 W/m² K				Plasterboard 750 < d < 900	0.25	0.012
				Plasterboard 750 < d < 900	0.25	0.012
				Mineral wool [0.04 W/[m K]]	0.04	0.03
				Floor structure	0.26	0.25
				Plaster rendering 1000 < d < 1300	0.57	0.015
				Total		0.379
Ground floor – 0.30	0.65	312.1		Identical to single-family house		
Deep (m) = 0.30						
Perimeter (m) = 81.20						
he = 5.88 W/m² K						

d: density (kg/m³); E: thickness (mm).

Table 3
Cities studied and climatic zone.

City	Country	Climatic zone (CTE)
Almería	Spain	A4
Lisbon	Portugal	B3
Évora	Portugal	C4
Granada	Spain	C3
Bragança	Portugal	D2
Burgos	Spain	E1

Table 5
Fuel characteristics.

Fuel	LHV	Density	Price
Gasoil [38]	11.89 kWh/kg	850 kg/m³	1.100 €/l
Natural gas [39]	11.63 kWh/m³	n/n	0.059 €/kWh
Olive pit [40]	4.49 kWh/kg	n/n	0.060 €/kg
Pine chip [40]	4.19 kWh/kg	n/n	0.0580 €/kg
Wood pellet [40]	5.01 kWh/kg	n/n	0.170 €/kg

LHV: lower heating value; n/n.: not necessary for this study.

total energy demand of the coldest city of the Iberian Peninsula considered here, with respect to the hottest one, is 294.6% greater for the single-family house, and 305.4% greater for the multi-family dwelling.

There is a progressive increase in energy demand from warmer to colder areas. The heating demand in Burgos is 1048.9% greater than that in Almería for a single-family house, and 708.8% greater for a multi-family house. It may be concluded that energy demand

Table 4
Energy rating. Thresholds in the buildings and cities studied.

City	CZ	A	B	C	D	E
Single-family house						
Almería	A4	<4.4	4.4 < 8.3	8.3 < 14.0	14.0 < 22.5	≥22.5
Lisbon	B3	<5.1	5.1 < 9.8	9.8 < 16.5	16.5 < 26.5	≥26.5
Évora	C4	<7.0	7.0 < 12.4	12.4 < 20.0	20.0 < 31.5	≥31.5
Granada	C3	<8.1	8.1 < 14.3	14.3 < 23.1	23.1 < 36.3	≥36.3
Bragança	D2	<9.6	9.6 < 15.8	15.8 < 24.5	24.5 < 37.7	≥37.7
Burgos	E1	<16.9	16.9 < 25.9	25.9 < 38.6	38.6 < 57.8	≥57.8
Residential building						
Almería	A4	<2.8	2.8 < 5.3	5.3 < 8.9	8.9 < 14.3	≥14.3
Lisbon	B3	<3.3	3.3 < 6.2	6.2 < 10.5	10.5 < 16.9	≥16.9
Évora	C4	<4.7	4.7 < 8.3	8.3 < 13.5	13.5 < 21.2	≥21.2
Granada	C3	<5.6	5.6 < 9.8	9.8 < 15.8	15.8 < 24.9	≥24.9
Bragança	D2	<6.5	6.5 < 10.7	10.7 < 16.6	16.6 < 25.5	≥25.5
Burgos	E1	<11.6	11.6 < 17.8	17.8 < 26.6	26.6 < 39.8	≥39.8

Measured in kg CO_2/m² year; CZ: climatic zone.

Table 6
Energy demand, CO_2 emissions and energy rating in the buildings and cities studied.

	Single-family house					
	A4 Almería	B3 Lisbon	C4 Évora	C3 Granada	D2 Bragança	E1 Burgos
Demand (kWh/m^2 year)						
Heating	13.7 C	32.5 D	47.2 D	62.3 D	76.5 D	143.7 D
Cooling	23.8 C	12.9 C	18.3 C	11.5 B	9.9 B	
DHW	18.2	18.7	18.8	18.8	19.2	20.4
Total	55.7	64.1	84.3	92.6	105.6	164.1
CO_2 emissions (kg CO_2/m^2 year)						
Gasoil						
Heating	4.6 C	10.7 D	16.1 D	22.0 D	26.3 D	51.1 E
Cooling	9.1 D	4.9 D	7.0 D	4.4 D	3.8 C	
DHW	6.0 E	6.1 E	6.2 E	6.1 E	6.3 E	6.6 E
Total	19.7 D	21.7 D	29.3 D	32.5 D	36.4 D	57.7 D
Natural gas						
Heating	3.4 C	7.9 C	12.1 C	16.6 C	19.8 D	38.9 D
Cooling	9.1 D	4.9 D	7.0 D	4.4 D	3.8 C	
DHW	4.2 E	4.4 E	4.4 E	4.4 E	4.5 E	4.7 E
Total	16.7 D	17.2 D	23.5 D	25.4 D	28.1 D	43.6 D
Biomass						
Heating	0.5 A	1.0 A	2.1 A	3.4 A	3.6 A	8.8 A
Cooling	9.1 D	4.9 D	7.0 D	4.4 D	3.8 C	
DHW	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Total	9.6 C	5.9 B	9.1 B	7.8 A	7.4 A	8.8 A
	Residential building					
	A4 Almería	B3 Lisbon	C4 Évora	C3 Granada	D2 Bragança	E1 Burgos
Demand (kWh/m^2 year)						
Heating	17.1 E	35.5 E	46.8 E	60.9 E	72.0 E	121.2 E
Cooling	14.0 C	7.9 C	9.3 B	6.8 B	6.2 B	
DHW	13.6	14.0	14.1	14.0	14.4	15.3
Total	44.7	57.4	70.2	81.7	92.6	136.5
CO_2 emissions (kg CO_2/m^2 year)						
Gasoil						
Heating	5.7 E	11.8 E	15.6 E	20.3 E	24.2 E	41.8 E
Cooling	5.3 D	3.0 D	3.5 C	2.6	2.4 C	
DHW	4.5 E	4.6 E	4.6 E	4.6 E	4.7 E	5.0 E
Total	15.5 E	19.4 E	23.7 E	27.5 R	31.3 RE	46.8 E
Natural gas						
Heating	4.3 D	8.9 D	11.8 D	15.3 D	18.4 D	32.1 D
Cooling	5.3 D	3.0 D	3.5 C	2.6 C	2.4 C	
DHW	3.2 E	3.3 E	3.3 E	3.3 E	3.3 E	3.5 C
Total	12.8 D	15.2 D	18.6 D	21.2 D	24.1 D	35.6 D
Biomass						
Heating	0.9 B	1.9 B	2.4 A	3.2 A	4.1 B	8.0 A
Cooling	5.3 D	3.0 D	3.5 C	2.0 C	2.4 C	
DHW	0.0 A	0.0 A	0.0 A	0.0 AS	0.0 A	0.0 A
Total	6.2 C	4.9 B	5.9 B	5.2 B	6.5 A	8.0 A

H: heating; DHW: domestic hot water.

for heating is inversely proportional to the winter outdoor temperatures.

In the case of cooling, Almería is the city with the greatest demand, requiring 204.4% more energy than the single-family residence in the second coldest city, Bragança, and 225.8% more than the multi-family house. Burgos was not included in this aspect of the study since it does not need cooling in the summer, when the outdoor temperature remains within the comfort zone. Hence, there is a progressive increase in the energy demand for cooling related to higher temperatures.

Finally, regarding DHW, the demand appears to depend largely upon the area of the living quarters. The influence of the climatic zone is minimal, giving differences between the two cities with extreme climates of 12.1% for the single-family unit and 12.5% for the multi-family unit.

3.1.2. CO_2 emissions

Table 6 also shows the CO_2 emissions, expressed in kg CO_2/m^2 year, released to the atmosphere by the residential units, as a consequence of the energy demands, calculated using the CERMA software. The emissions due to the heating systems are much higher for the coldest city studied, regardless of the type of house, with values ranging from 0.5 kg CO_2/m^2 year using biomass in the single-family house in Almería to 51.1 kg CO_2/m^2 year for the single-family house in Burgos using gasoil. Some variation maybe attributed to the type of fuel used. The single-family house shows an increase of 1110.9% in CO_2 emissions with gasoil, 1144.1% with natural gas, and 1760.0% with biomass; whereas in the multi-family residential building, the increases are 733.3%, 746.5% and 888.8%, respectively.

Gasoil is the fuel that releases more CO_2 during its combustion for the purpose of heating and DHW [17], while biomass is the most favorable fuel from CO_2 emissions point of view [17,44,45]. Table 7 compares the CO_2 emissions from systems using gasoil, natural gas and biomass. It is seen that the use of natural gas, instead of gasoil, for heating and DHW purposes leads to CO_2 emissions that are lower in 23.93–28.30%, respectively. Ruiz and Romero [21] studied the CO_2 emissions for a single-family house using different types of

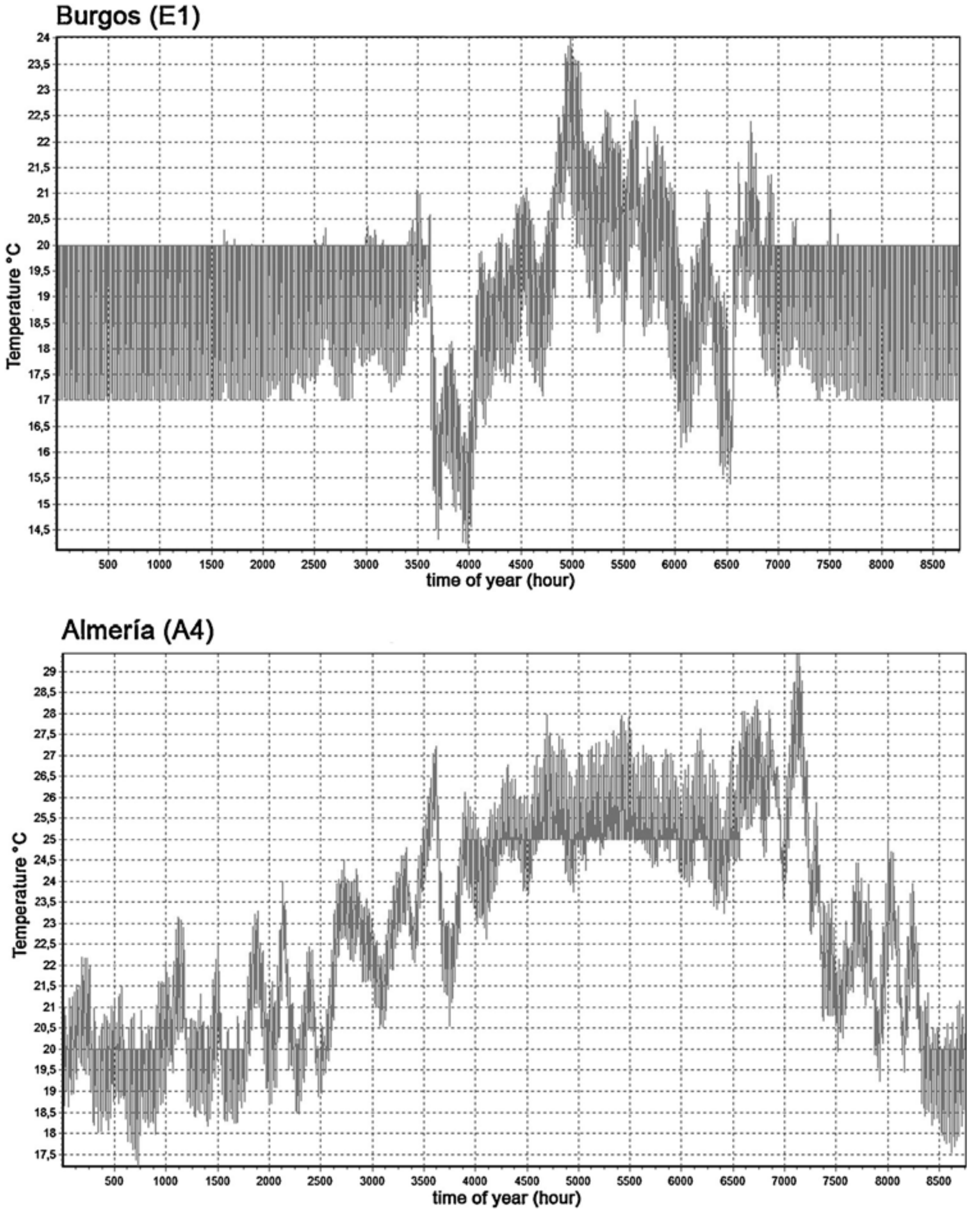

Fig. 4. Annual variation of the in-house temperature in the studied buildings located in Almería and Burgos.

fuels in the same climatic zone (C3), arriving at savings with natural gas, as compared with gasoil, that amounted to 31.31% [21]. This figure is consistent with the value 24.55% obtained in this study. The small discrepancy is, most likely, due to differences in the geometry, orientation and construction materials of the buildings considered. Ruiz and Romero [21] have also compared other fuels with gasoil. They obtained CO_2 emissions 16.68% higher with the use of coal, and 118.51% higher with the use of electricity. In addition, the present study shows that replacing gasoil by biomass leads to reductions in the CO_2 emissions that range from 82.91% to 95.28%. Similar results have been obtained by Pardo and Thiel [17] who reported reductions of around 95% in CO_2 emissions using biomass for the Southern Europe, compared with conventional fossil fuel fired-systems. Note that comparative studies such as that of Ruiz and Romero [21] analyzed the CO_2 emissions solely in an exclusive climatic zone, while the present study examined a number of variables, namely, six different climate zones, renewable fuels and two types of constructions (single-family house and multi-family dwelling) to allow for more comprehensive comparisons.

The present study reveals that the replacement of gasoil by any other fuel for heating and DHW purposes reduces the CO_2 emissions, although the use of biomass is the most favorable. This is a very noteworthy finding since natural gas is nowadays extensively used in the Iberian Peninsula—18.96% of homes in Portugal [46] and 24.5% in Spain [47].

Returning to Table 6, it is seen that the CO_2 emissions per square meter of living quarters are 1.4–1.9 higher for the single-family house than for the multi-family home in equivalent conditions. As discussed earlier regarding the energy demand, the structural characteristics of the single-family residence lead to larger exterior exposure.

Table 7 indicates that the CO_2 emissions from heating and DHW for the single-family units are quite similar to those for the multi-family unit when using gasoil. Consequently, it is the type of fuel and the climatic zone that determine the CO_2 emissions. For both types of buildings studied here, it is seen that the warmer the city, the greater the CO_2 emissions reduction, regardless of the fuel type. This tendency toward savings is reversed when cooling by

Table 7
CO_2 emissions from systems using gasoil, natural gas and biomass.

	Single-family house					
	A4 Almería	B3 Lisbon	C4 Évora	C3 Granada	D2 Bragança	E1 Burgos
Natural gas vs gasoil						
Heating	26.09%	26.17%	24.84%	24.55%	24.71%	23.87%
H + DHW	28.30%	26.79%	26.01%	25.27%	25.46%	24.44%
H + DHW + cooling	15.23%	20.74%	19.80%	21.85%	22.80%	24.44%
Biomass vs gasoil						
Heating	89.13%	90.65%	86.96%	84.55%	86.31%	82.78%
H + DHW	95.28%	94.05%	90.58%	87.90%	88.96%	84.75%
H + DHW + cooling	51.27%	72.81%	68.94%	76.00%	79.67%	84.75%
	Residential building					
	A4 Almería	B3 Lisbon	C4 Évora	C3 Granada	D2 Bragança	E1 Burgos
Natural gas vs gasoil						
Heating	24.56%	24.58%	24.36%	24.63%	23.97%	23.21%
H + DHW	26.47%	25.61%	25.25%	25.30%	24.91%	23.93%
H + DHW + cooling	17.42%	21.65%	21.52%	22.91%	23.00%	23.93%
Biomass vs gasoil						
Heating	84.21%	83.90%	84.62%	84.24%	83.06%	80.86%
H + DHW	91.18%	88.41%	88.12%	87.15%	85.81%	82.91%
H + DHW + cooling	60.00%	74.74%	75.11%	81.09%	79.23%	82.91%

H: heating; DHW: domestic hot water.

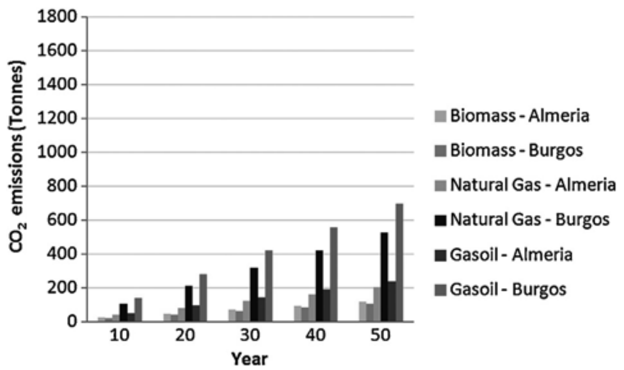

Fig. 5. Accumulated CO_2 emissions during a 50 years period for the single-family house.

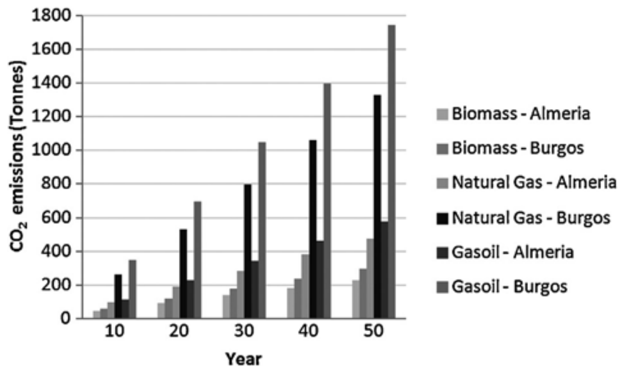

Fig. 6. Accumulated CO_2 emissions during a 50 years period for the residential building.

electricity is included, i.e., savings in CO_2 emissions are higher in the colder cities.

To sum up and in order to assess the long term CO_2 emissions, Figs. 5 and 6 show the accumulated CO_2 emissions resulting from the three fuels studied, based on an estimated useful life of 50 years for the buildings [48]. It is seen that the CO_2 emissions per square meter are higher for the single-family house regardless of the fuel used (again, because of its exposure). It is also noted that the differences in CO_2 emissions from one climatic zone to another one depend not only on the energy demand, but also on

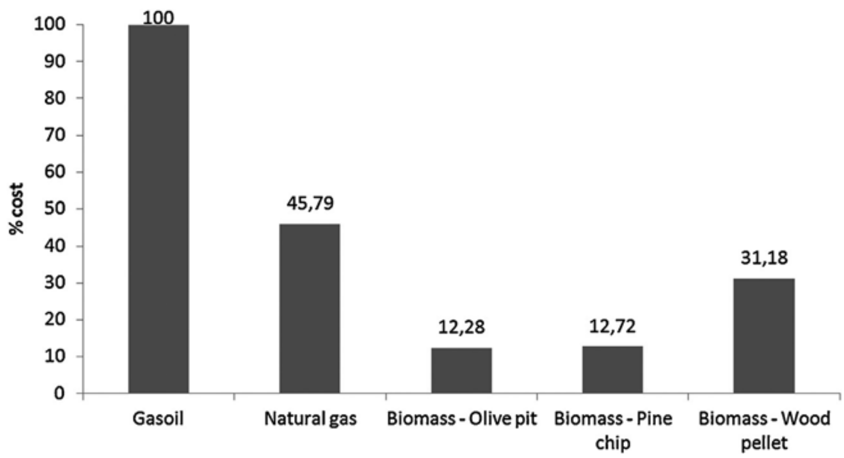

Fig. 7. Costs. Gasoil is the reference fuel.

Table 8
Total annual cost of the different fuels.

	Single-family house											
	A4 Almería		B3 Lisbon		C4 Évora		C3 Granada		D2 Bragança		E1 Burgos	
	l	€	l	€	l	€	l	€	l	€	l	€
Gasoil												
Heating	327.12	359.84	776.03	853.63	1127.03	1239.73	1487.58	1636.34	1826.64	2009.31	3431.23	3774.35
DHW	434.57	478.03	446.51	491.16	448.90	493.79	448.90	493.79	458.45	504.30	487.11	535.82
H + DHW	761.70	837.87	1222.54	1344.79	1575.93	1733.52	1936.48	2130.13	2285.10	2513.61	3918.33	4310.16
	m^3	€	m^3	€	m^3	€	m^3	€	m^3	€	m^3	€
Natural gas												
Heating	284.27	195.06	674.37	462.73	979.39	672.03	1292.71	887.02	1587.36	1089.20	2981.74	2045.98
DHW	377.65	259.13	388.02	266.25	390.10	267.67	390.10	267.67	398.40	273.37	423.30	290.45
H + DHW	661.92	454.19	1062.39	728.98	1369.49	939.70	1682.81	1154.69	1985.75	1362.57	3405.04	2336.44
	kg	€	kg	€	kg	€	kg	€	kg	€	kg	€
Olive pit												
Heating	736.32	44.18	1746.75	104.80	2536.82	152.21	3348.38	200.90	4111.58	246.69	7723.31	463.40
DHW	978.18	58.69	1005.05	60.30	1010.43	60.63	1010.43	60.63	1031.93	61.92	1096.42	65.79
H + DHW	1714.50	102.87	2751.80	165.11	3547.24	212.83	4358.81	261.53	5143.50	308.61	8819.74	529.18
Pine chip												
Heating	789.04	45.76	1871.81	108.57	2718.45	157.67	3588.12	208.11	4405.96	255.55	8276.30	480.03
DHW	1048.22	60.80	1077.01	62.47	1082.77	62.80	1082.77	62.80	1105.81	64.14	1174.92	68.15
H + DHW	1837.26	106.56	2948.83	171.03	3801.22	220.47	4670.90	270.91	5511.77	319.68	9451.22	548.17
Wood pellet												
Heating	659.90	112.18	1565.45	266.13	2273.51	386.50	3000.85	510.14	3684.83	626.42	6921.69	1176.69
DHW	876.65	149.03	900.74	153.13	905.55	153.94	905.55	153.94	924.82	157.22	982.62	167.05
H + DHW	1536.55	261.21	2466.18	419.25	3179.07	540.44	3906.40	664.09	4609.65	783.64	7904.31	1343.73
	Residential building											
	A4 Almería		B3 Lisbon		C4 Évora		C3 Granada		D2 Bragança		E1 Burgos	
	l	€	l	€	l	€	l	€	l	€	l	€
Gasoil												
Heating	1259.54	1385.50	2614.84	2876.33	3447.17	3791.89	4485.74	4934.32	5303.34	5833.68	8927.29	9820.02
DHW	1001.74	1101.92	1031.21	1134.33	1038.57	1142.43	1031.21	1134.33	1060.67	1166.74	1126.96	1239.66
H + DHW	2261.29	2487.42	3646.05	4010.65	4485.74	4934.32	5516.95	6068.65	6364.01	7000.41	10,054.26	11,059.68
	m^3	€	m^3	€	m^3	€	m^3	€	m^3	€	m^3	€
Natural gas												
Heating	1094.55	751.05	2272.31	1559.19	2995.60	2055.49	3898.12	2674.78	4608.62	3162.30	7757.84	5323.20
DHW	870.52	597.32	896.12	614.89	902.52	619.28	896.12	614.89	921.72	632.46	979.33	671.99
H + DHW	1965.06	1348.37	3168.43	2174.08	3898.12	2674.78	4794.24	3289.67	5530.34	3794.76	8737.17	5995.19
	kg.	€	kg.	€	kg.	€	kg.	€	kg.	€	kg.	€
Olive pit												
Heating	2835.10	170.11	5885.73	353.14	7759.21	465.55	10,096.92	605.82	11,937.25	716.23	20,094.37	1205.66
DHW	2254.81	135.29	2321.13	139.27	2337.71	140.26	2321.13	139.27	2387.45	143.25	2536.67	152.20
H + DHW	5089.91	305.39	8206.86	492.41	10,096.92	605.82	12,418.05	745.08	14,324.70	859.48	22,631.03	1357.86
Pine chip												
Heating	3038.09	176.21	6307.14	365.81	8314.76	482.26	10,819.85	627.55	12,791.94	741.93	21,533.10	1248.92
DHW	2416.26	140.14	2487.32	144.26	2505.09	145.30	2487.32	144.26	2558.39	148.39	2718.29	157.66
H + DHW	5454.34	316.35	8794.46	510.08	10,819.85	627.55	13,307.17	771.82	15,350.33	890.32	24,251.39	1406.58
Wood pellet												
Heating	2540.83	431.94	5274.83	896.72	6953.86	1182.16	9048.94	1538.32	10,698.25	1818.70	18,008.72	3061.48
DHW	2020.78	343.53	2080.22	353.64	2095.07	356.16	2080.22	353.64	2139.65	363.74	2273.38	386.47
H + DHW	4561.62	775.47	7355.05	1250.36	9048.94	1538.32	11,129.15	1891.96	12,837.90	2182.44	20,282.10	3447.96

Gasoil: 1.10 €/l [38]; natural gas: 0.059 €/kWh [39]; olive pit: 0.06 €/kg [40]; pine chip: 0.058 €/kg [40]; wood pellet: 0.17 €/kg [40].

the fuel type. Accordingly, for the single-family unit (Fig. 5), the CO_2 emissions resulting from the use of gasoil are higher than those resulting from the other fuels, reaching a value as high as ≈700 tons of CO_2 (57.7 kg CO_2/m^2 year) emissions accumulated over 50 years in Burgos. Yet, the accumulated CO_2 emissions for the use of biomass in the same scenario would yield just ≈60 tons of CO_2 (8.8 kg CO_2/m^2 year). The multi-family unit (Fig. 6) yields analogous results, originating ≈1800 tons of CO_2 (46.8 kg CO_2/m^2 year) emissions in Burgos using gasoil, noting that during the entire useful life of the building the amount of CO_2 emissions would be ≈ 200 tons (8.0 kg CO_2/m^2 year) using biomass.

3.1.3. *Energy rating*

The CERMA software, based on existing legislation, marks the rating interval determined for buildings under consideration based on a calculation with respect to a model building and other reference data such as, for example, housing units available in Spain in the year 2006. Table 6 also displays the energy rating for the buildings and cities studied. It is seen that the threshold limits of the levels of energy ratings depend on the type of residence, climatic zone, and fuels used.

Improvement in the energy rating of a building is directly related with the fuel type. Gasoil and natural gas imply the assignment of rating D for single-family dwellings, and E for multi-family units in all six cities studied here. In the case of biomass, the rating depends on climate, but is independent of the housing type, with improvements associated with the lower winter mean temperatures, which may result in upgradings up to four levels, i.e., C would be the rating in the case of the hottest city, A in the coldest three cities, and B for the remaining cases.

Pérez-Lombard et al. [49] described the existing thresholds for the energy rating, including those established in the Royal Decree 235/2013 [5]. Note that similar results for reductions in the CO_2 emissions may lead to different energy ratings according with the scale used because of the different number of categories in the different methods. For example, the Royal Decree 235/2013 has three savings categories (A–C), the CEN method [50] has two (A and B) and the Building Research Establishment Environmental Assessment Methodology (BREEAM) method [51] has a total amount of 15 (1–15).

3.2. Economic factors

To determine the costs involved in using the heating systems with the different fuels an economic analysis has been performed. Bearing in mind the fuel costs (Table 5) and the energy demand (Table 6), costs were evaluated for heating and DHW, alone and together, for each housing type in all cities considered. Table 8 summarizes the results of this analysis. It is seen that costs are directly related with the energy demand. In regard to the most economical city, Almería, the following results were obtained, regardless of the fuel used: (i) for single-family unit, costs in Lisbon were 60.50% higher, in Évora 106.90%, in Granada 154.30%, in Bragança 300.00% and in Burgos 414.42%; and (ii) for multi-family unit, costs in Lisbon were 61.24% higher, Évora 98.37%, Granada 143.97%, Bragança 181.43% and Burgos 344.62%.

It should stressed that the savings achieved by changing the gasoil by bulk wood pellets is 68.82%, by pine chips is 87.28%, and by olive pit is 87.72%. The use of natural gas instead of gasoil yields savings of 54.21%. Therefore, it may be concluded that the most economic fuel is generally biomass, although savings will depend on the type of biomass used (Fig. 7). Other studies have determinated savings of ≈95% in the Central and Northern Europe and ≈75% in the case of Southern Europe regions in comparison with conventional systems [17]. These results in Southern Europe are similar to those obtained in this study.

Finally, in the warmest city of the Iberian Peninsula considered in this study (Almería), the annual production cost of DHW using any of the fuels considered here is higher than the cost of heating. This result was obtained only for the single-family house in Almería. In the remaining cities studied, the cost of heating is always higher than that of DHW. As discussed earlier, DHW is less conditioned by the atmospheric climate than is heating, so that the differences are minimal.

4. Conclusions

This study led to the conclusion that the use of biomass in heating and DHW residential systems presents important advantages as follows: (i) reduces the environmental costs since releases significantly less CO_2; (ii) provides a very favorable energy rating; (iii) originates important economic savings. Moreover it was found that (iv) the energy demands are significantly affected by the climatic zone and the type of dwelling.

The CO_2 emissions depend directly on the climatic zone, where the house is located, in addition to the fuel used. Gasoil was found to yield the higher CO_2 emissions, regardless of the housing type. However, the use of biomass, instead of gasoil or natural gas, brings about an important reduction of the CO_2 emissions in all cases. Specifically, if gasoil is replaced by biomass reductions in CO_2 emissions of 95.25% for single-family units and 91.18% for multi-family units are achieved. Bearing in mind that 40% of the energy consumed in Europe and 36% of the CO_2 emissions to the atmosphere are produced by buildings dedicated to living quarters, the choice of fuel stands as a significant factor in evaluating emissions derived from heating and DHW.

Using biomass for heating purposes enhances the energy rating of the housing units in all cases. In the best case scenario, improvements are of four points on the scale of residential energy performance, which would put the unit into the top category, A. In comparison, with the use of fossil fuels, the best rating is D for the single-family residence and E for the multi-family one.

Cost-effectiveness is another important area where savings by means of solid biofuels are noteworthy. In comparison with gasoil, the use of wood pellets can lead to economic savings of up to 70%, and approximately 88% when wood chips or olive pits are used.

Finally, in regard to the energy demands of a residence, the climatic zone is clearly a determinant factor. The coldest cities on the Iberian Peninsula may require ten times more energy than the warmest ones, to satisfy heating demand. Likewise, for a joint demand of heating, DHW and cooling, consumption would be three times higher in a cold city. A single-family house, more exposed to the elements, proved to have substantially more energy requirements than a multi-family dwelling.

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Impact of the envelope design of residential buildings on their acclimation energy demand, CO_2 emissions and energy rating

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Abstract

Building envelopes are the part of the buildings most exposed to the inclement weather and thus have significant impact on the energy performance as a consequence of higher thermal transfers produced. Therefore, new solutions for building envelopes are required as a way to save energy in residential buildings. In this regard, the European Directives 2002/91/EC and 2010/31/EU on Energy Performance of Buildings (EPBD) have laid down the application of minimum requirements to the energy performance of building elements that form part of the envelope. Designers require, in the early stages, a method to obtain information about the energy performance of the building, as design decisions made at this stage might compromise the performance of the final design. Among the possible energy-savings solutions the most effective are not only those related to the construction design but also those that consider constructive materials with low thermal transmittance. Consequently, the objective of this study is to analyze and compare, by means of energy simulations, different constructive solutions applied to the building envelopes in terms of construction design and constructive materials. The results obtained showed that the energy demand and CO_2 emissions of residential buildings can be reduced by 60% and 95% respectively when constructive solutions with low U-values are implemented. These reductions make also possible the enhancement of the energy rating of the buildings.
Keywords: envelope, energy rating, buildings, CO_2 emissions.

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1 Introduction

Due to the fact that the building sector is a potentially large energy consumer, special attention has been paid in order to reduce its environmental impact [1, 2]. Acclimation energy consumption of buildings is mainly affected by local climatic conditions, indoor temperature, shape factor, windows-to-wall ratio and building envelope performance. Therefore, new solutions for building envelopes are required because they are the part of the buildings most exposed to the inclement weather and thus where higher thermal transfers are produced. Accordingly, a proper design of the thermal properties of building envelopes would lead to energy-saving in residential buildings.

With this objective, the European Union has created a legislative framework for all its member countries based on the Kyoto Protocol [3] and the Directives 2002/91/EC [1] and 2010/31/EU [2] on Energy Performance of Buildings (EPBD). These regulations have laid down the application of *"minimum requirements to the energy performance of building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are retrofitted or replaced"*. However, it is important to highlight the existence of different transpositions of the EPBD for each European country (EU-28 and Norway), which means that there are different regulations but with the common objective of achieving a Nearly Zero-Energy Building (NZEB) able to combine both comfort and minimum energy consumption [4].

Besides having to comply with regulations on energy performance, buildings have long life cycles and are potentially large energy consumers. As a consequence, several studies on energy efficiency of existent buildings have been performed [5–11]. These studies have primarily focused on the improvement of the energy efficiency of currently existing envelopes in private and public buildings considering the weather as much in summer as in winter. Nevertheless, the construction techniques to improve an existent envelope differ from those that can be applied to new construction units.

Considering this point, the aim of the present study is to study how the different constructive solutions affect the thermal envelope of residential buildings under different climate conditions. In addition, it analyses the influence of the thermal envelope design in the energy demand, CO_2 emissions and energy rating of two different types of buildings located in six climatic zones.

2 Material and methods

2.1 Envelope of the buildings

2.1.1 Composition

The thermal envelope of a building is composed by the elements represented in Fig. 1, which includes all the enclosures that mark out the habitable spaces from the outside, and the interior partitions, which demarcate the living spaces from the non-habitable spaces in contact with the outside [12].

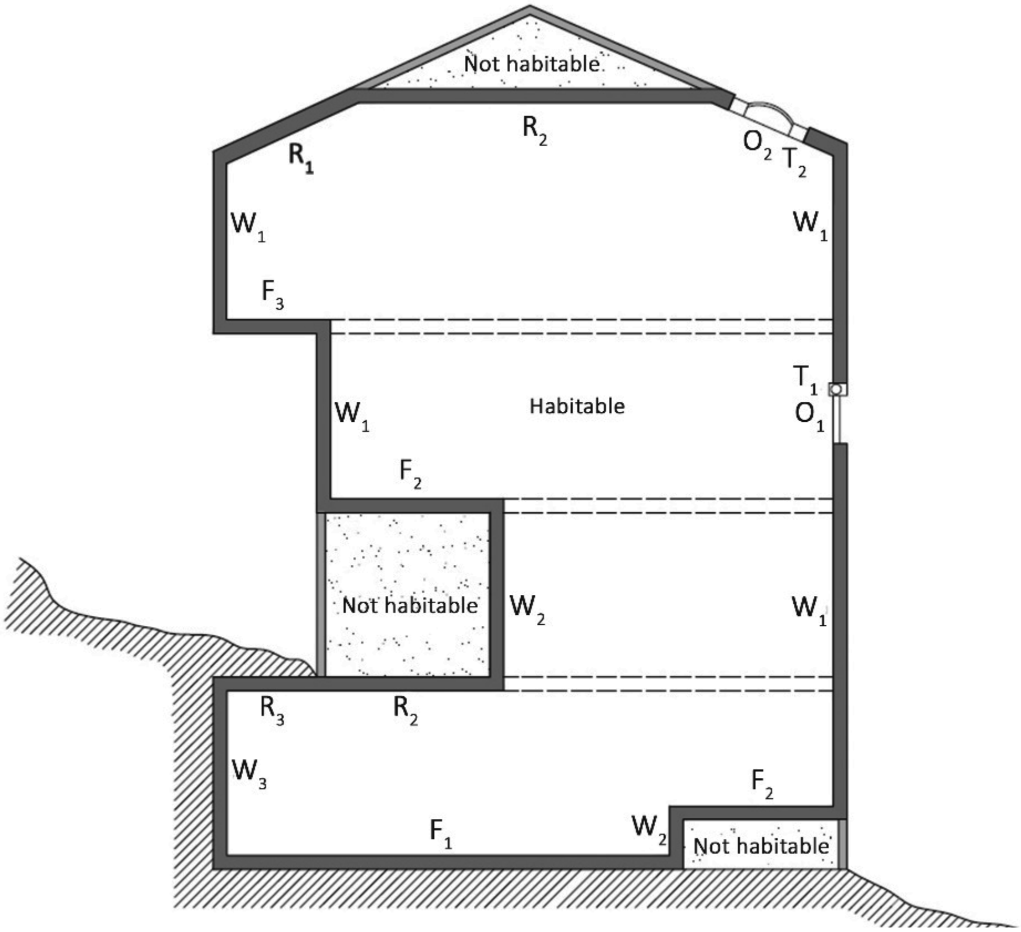

Figure 1: Composition of the thermal envelope of a building: Vertical external walls (W); Horizontal roofs (R); Floors (F); Openings (O); and Thermal bridges (T) [13].

2.1.2 Thermal transmittance

Thermal transmittance, also known as U-value, is defined as the rate of transfer of heat under uniform conditions through one square metre of a structure, divided by the difference in temperature across the structure (the lower the U-value, the better the insulating ability). It is expressed in $W/m^2 K$ and can be calculated by eqns. (1) and (2), where: R_{si} is the inside resistance; R_{se} is the external resistance; and R_t is the thermal resistance of the construction material ($m^2 K/W$), which is formed by thermally homogeneous layers with their own resistances (R_1, R_2…R_n).

$$U = \frac{1}{R_{si}+R_t+R_{se}} \qquad (1)$$

$$R_t = R_1 + R_2 + R_3 + \ldots + R_n \qquad (2)$$

R-value is the thermal resistance of a solid material to conductive heat transfer (the higher the number, the better the building insulation's theoretical effectiveness).

$$R = \frac{e}{\lambda} \quad (3)$$

This energy flow is produced when there is a difference between the inside temperature and the temperature outside, and can be calculated by eqn. (3), where: e is the thickness of the material (m); and λ is the thermal conductivity (W/mK).

2.2 Buildings characteristics

2.2.1 Description of buildings

Two types of buildings were selected to develop this study: (i) a single-family house; and (ii) a multi-family residential building placed among other constructions.

The single-family dwelling consists of three floors with total usable area 261.99 m^2: a basement (108.73 m^2), a ground floor (117.01 m^2) and a first floor (36.25 m^2). The house is located on a gentle slope, which means that the basement is completely underground on one side, yet above the ground on the other side of the house.

The multi-family dwelling has five stories with total usable area 861.71 m^2: a ground floor (267.10 m^2), a first (267.10 m^2), a second (267.10 m^2), a third floor (267.10 m^2), and a tower (18.96 m^2). In this case, the building is a rectangle on a corner so that the north and east sides of it are fully in contact with other constructions, while the south and west façades are exposed.

For the thermal simulation of each building and climatic zone, boilers with similar characteristics were chosen. The fuel in all boilers is biomass. The thermal load selected for each boiler was set to 24 kW. For the single-family house, just one boiler (24 kW) was considered, whereas for the multi-family dwelling three boilers were installed (total boiler load of 72 kW). For all boilers, the thermal efficiency value adopted was 90%, with an outlet water temperature of 50°C for domestic hot water (DHW) and 80°C for heating. The flow rate of DHW in the single-family house was 235.80 liters/day, and in the multi-family dwelling 568.72 liters/day. Both types of residence featured an accumulator; specifically, it had a capacity of 200 liters in the single-family house and 500 liters in the multi-family dwelling. In both cases the water temperature varied between 60°C and 80°C, the global heat transfer coefficient (U×A) was 1 W/K.

2.2.2 Constructive solutions

Three different solutions have been studied to define the thermal envelope of the buildings previously described (Tables 1 and 2 and Fig. 2). Considering the thermal transmittance mentioned in section 2.1.2, Solution 1 was that with the highest thermal transmittance, followed by Solution 2 and being Solution 3 the constructive solution with lower U-value.

Table 1: Elements and materials used. Thermal characteristics.

		Material	*e*	λ	R
External walls	Solution 1	Lime mortar for rendering 1000 < d < 1250	0.015	0.550	0.027
		12 in. perforated metric brick 40 mm < G < 50 mm	0.240	1.529	0.157
		Plaster rendering 1000 < d < 1300	0.015	0.570	0.026
		U = 2.63 W/m^2 K	0.270		
	Solution 2	Lime mortar for rendering d > 2000	0.015	1.800	0.008
		Thermal blocks	0.290	0.426	0.681
		Plaster rendering 1000 < d < 1300	0.015	0.570	0.026
		U = 1.13 W/m2 K	0.320		
	Solution 3	6 in. perforated metric brick 40 mm < G < 50 mm	0.115	0.991	0.116
		Lime mortar for rendering 1000 < d < 1250	0.015	0.550	0.027
		Expanded polystyrene [EPS] [0.037 W/[m K]]	0.080	0.037	2.162
		Double hollow brick breeze-block [60 mm < E < 90 mm]	0.075	0.432	0.174
		Plaster rendering 1000 < d < 1300	0.015	0.570	0.026
		U = 0.37 W/m^2 K	0.300		
Roofs	Solution 1	Ceramic tiles	0.006	1.000	0.006
		Lime mortar for rendering d>2000	0.024	1.800	0.013
		Floor structure	0.250	1.154	0.217
		Plaster rendering 1000 < d < 1300	0.015	0.570	0.026
		U = 2.49 W/m^2 K	0.295		
	Solution 2	Ceramic tiles	0.006	1.000	0.006
		Lime mortar for rendering d > 2000	0.024	1.800	0.013
		Mortar lightweight aggregate [vermiculite perlite]	0.040	0.410	0.098
		Polyvinyl chloride [PVC]	0.001	0.170	0.006
		Ceramic tiles	0.030	1.000	0.030
		Slightly ventilated air chamber	0.100	0.000	0.000
		Floor structure	0.300	1.304	0.230
		Plaster rendering 1000 < d < 1300	0.015	0.570	0.026
		U = 1.56 W/m^2 K	0.516		
	Solution 3	Sand and gravel [1700 < d < 2200]	0.050	2.000	0.025
		Sublayer felt	0.001	0.050	0.020
		Polyvinyl chloride [PVC]	0.001	0.170	0.006
		Sublayer felt	0.001	0.050	0.020
		Extruded polystyrene, expanded with carbon dioxide [XPS] [0.034 W/[m K]]	0.060	0.034	1.765
		Low density polyethylene [LDPE]	0.002	0.330	0.006
		Concrete with lightweight aggregate 1800 < d < 2000	0.100	1.350	0.074
		Floor structure	0.250	0.256	0.977
		Plaster rendering 1000 < d < 1300	0.015	0.570	0.026
		U = 0.33 W/m^2 K	0.480		

e (mm); λ (W/m K); R (m^2 K/W)

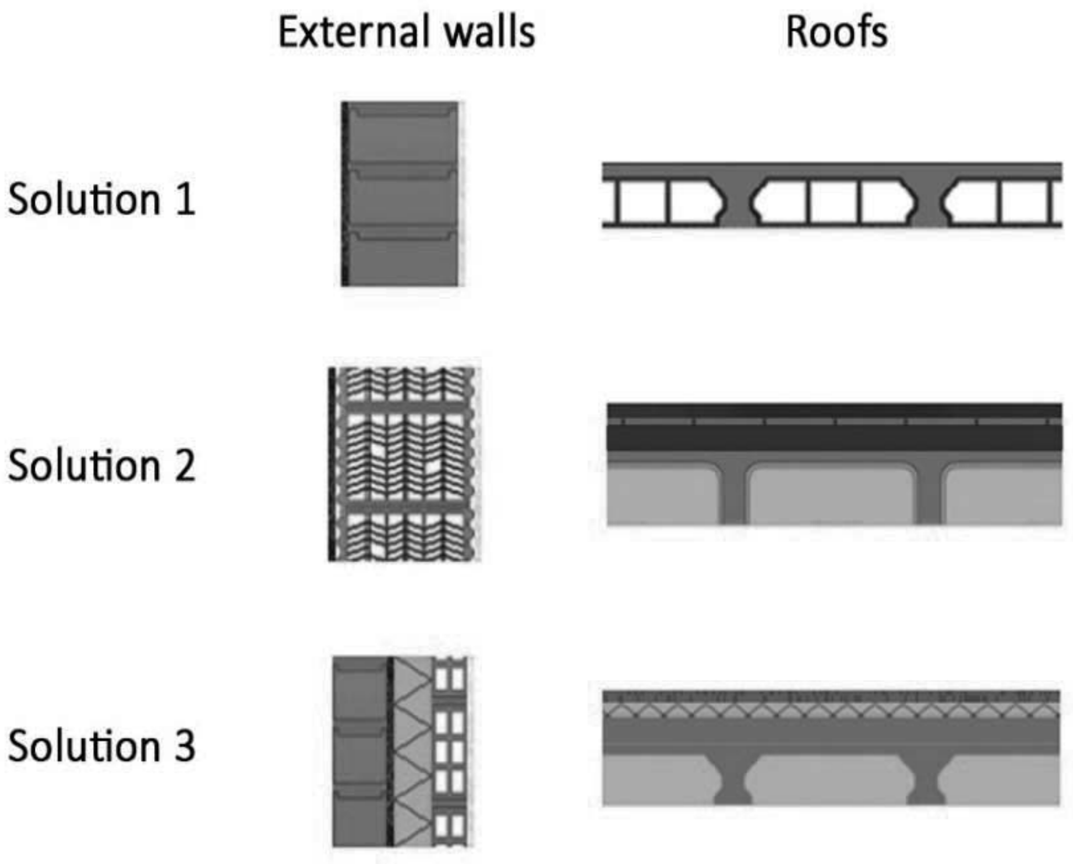

Figure 2: Elements and materials used. Graphic details.

Table 2: External openings. Thermal characteristics.

	Material	U (W/m^2 K)
Solution 1	Glass (85%): Monolithic (4)	5.700
	Frame (15%): Metallic without thermal break	5.700
	Total	5.700
Solution 2	Glass (85%): Double (4-6-4)	3.300
	Frame (15%): Low density wood	2.000
	Total	3.170
Solution 3	Glass (85%): Double low-e < 0.03 (4-9-4)	1.900
	Frame (15%): Three chambers PVC	1.800
	Total	1.880

2.2.3 Climatic zones

In this study, the most common climatic zones in Spain were selected [13, 14], because of including extremes zones (A4 and B3 as the warmest, and D2 and E1 as the coldest) and intermediate zones (C4 and C3).

2.3 Simulation software

The energy simulation software solutions available nowadays differ in terms of how the characteristics of the building are introduced as input, and also in the output supplied [15], but all providing valid results. In this study, CERMA [16] has been chosen as the simulation software. This software calculates the energy demand, the CO_2 emissions and the energy rating basing on the constructive solutions, buildings design and location.

Regarding the energy rating, this program works on the scale of seven levels [13], which are represented in Fig. 3.

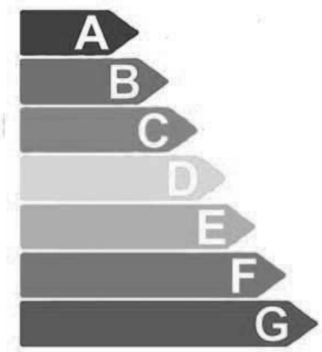

Figure 3: Energy rating. Scale of seven levels [13].

3 Results and discussion

Table 3 and Figs 4 and 5 show the energy demand, CO_2 emissions and energy rating, which are dependent on: the envelope design of the constructive solution; the type of building (single-family or multi-family); and the climatic zone where the building is located.

3.1 Energy demand

Fig. 4 shows that the total energy demand ranged from 42.9 kWh/m^2 year in a multi-family building located in the climatic zone A4 with Solution 3 as a constructive solution, to 356.2 kWh/m^2 year in a single-family house with Solution 1 located in E1.

The results have revealed that A4 was the climate zone that required a lower total energy demand with any constructive solution in the both types of buildings studied. On the contrary, E1 was the climate zone that higher total energy demand required.

Regarding the envelope design characteristics of the different constructive solutions considered, and owing to the low thermal transmittance values of solution 3 (Table 1), it was the constructive solution with the lowest energy demand for the types of buildings studied.

In the case of the single-family house, the implementation of Solution 2 supposed an increase of 49%–62% with respect to the energy demand required with Solution 3, and the same house with Solution 1 increased its energy demand within the range 130%–171% depending on the climate zone. When the multi-family building was considered, the use of the constructive Solution 2 resulted in an increment of its energy demand from 45% to 60%, and 109%–143% was the growth in case of implementing Solution 1 in comparison with Solution 3 (Fig. 4).

In general, the single-family house was the building that obtained larger improvement because of having more envelope surface per m^2 and thus more surface to be improved by constructive solutions.

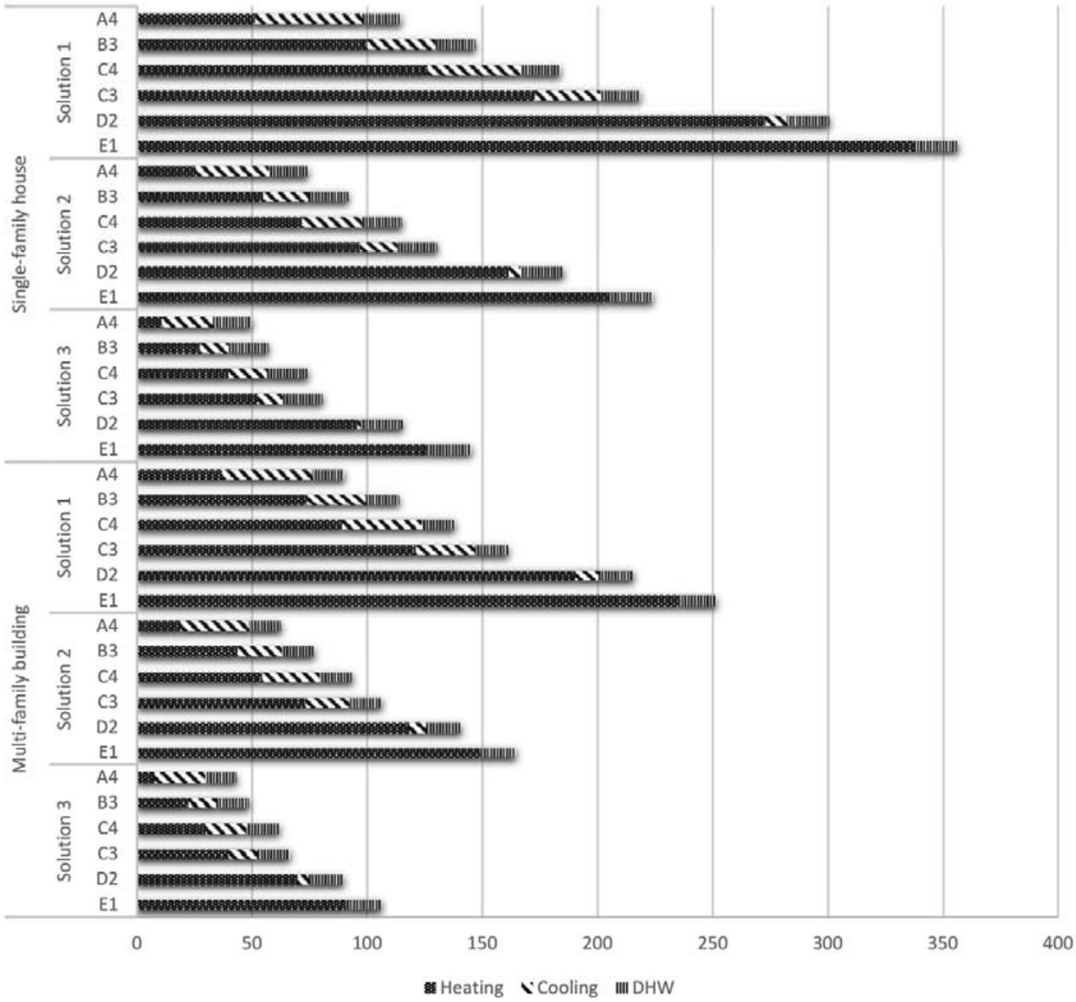

Figure 4: Energy demand (kWh/m^2 per year).

3.2 CO_2 emissions and energy rating

Taking into account that the building sector represents 40% of the energy consumption and 36% of the CO_2 emissions in Europe [1, 2], the use of energy-efficient materials in the thermal envelopes of buildings leads not only to a reduction of the energy demanded, but also to a significant reduction of the environmental impact derived from this sector.

Table 3 and Fig. 5 show the CO_2 emissions generated as a consequence of the energy demanded. In this section, and due to the fact that the energy consumption for DHW production is associated with the energy produced for heating because of using the same boiler, both were considered as a whole.

In order to discuss the results obtained, Solution 3 was considered as the point of reference because of being the optimum constructive solution (with minimum energy demand and near-zero emissions). From this point, it was observed that the use of Solution 2 resulted in an increase of 44%–300% regarding the CO_2 emissions generated in the single-family house, whereas this increment varied between 41% and 68% when the multi-family building was considered (Fig. 5).

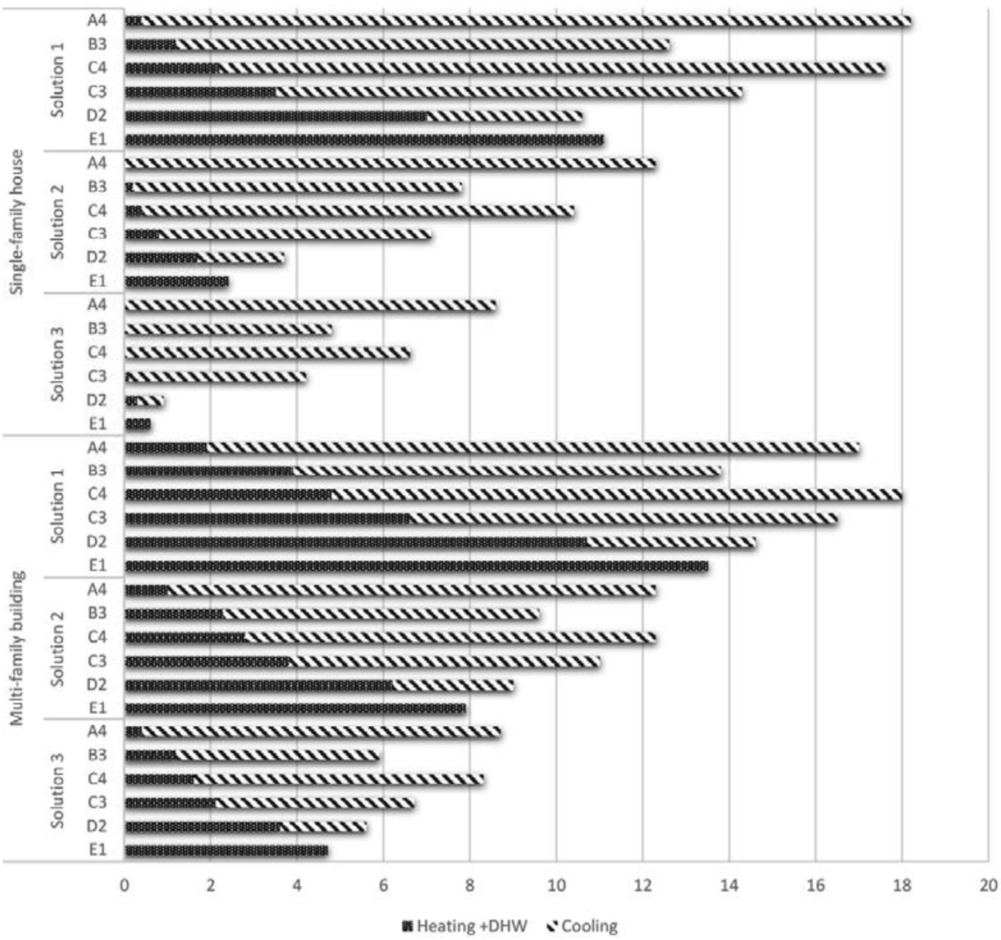

Figure 5: CO_2 emissions ($kgCO_2/m^2$ per year).

The higher values of the intervals corresponded to the coldest areas (E1), while on the contrary the minimum values of increment were achieved in the warmest climate zones (Table 3). These ranges were substantially enlarged when the Solution 1 was implemented, achieving 112%–1,750% of increment in the case of the CO_2 emissions generated in the single-family house and corresponding the major percentage to the house located in the climatic zone E1.

As observed with Solution 2, the ranges of increment were also reduced for Solution 1 when the multi-family building was analyzed, being the growth of CO_2 emissions within 95%–187%.

As in the case of the energy demand, larger reductions in CO_2 emissions are achieved in the case of the single-family house because of having more envelope surface to be improved by constructive solutions.

On the other hand, and because of the existent relationship between the CO_2 emissions and the energy rating of the buildings [13], a higher quality of the materials used in the envelope of a building led to higher energy ratings. As shown in Table 3, the use of the Solution 3 entailed the obtaining of two positive energy rating levels in both types of buildings in comparison with the energy ratings that resulted from the use of Solution 1.

Table 3: Energy demand, CO_2 emissions and energy rating.

		CZ	Energy demand (kWh/m^2 per year)				CO_2 emissions (kg CO_2/m^2 per year)			
			Heating	Cooling	DHW	Total	Heating + DHW	Cooling	Total	ER
Single-family house	Solution 1	A4	51.2	46.7	16.6	114.5	0.4	17.8	18.2	D
		B3	99.6	30.0	17.1	146.7	1.2	11.4	12.7	C
		C4	126.0	40.4	17.2	183.6	2.2	15.4	17.6	C
		C3	172.6	28.4	17.1	218.1	3.5	10.8	14.3	C
		D2	272.6	9.5	18.2	300.3	7.0	3.6	10.6	A
		E1	337.4	0.0	18.8	356.2	11.1	0.0	11.1	A
	Solution 2	A4	25.1	32.2	16.6	73.9	0.0	12.3	12.4	C
		B3	54.6	19.8	17.1	91.5	0.2	7.6	7.8	B
		C4	71.6	26.1	17.2	114.9	0.4	10.0	10.4	B
		C3	96.6	16.4	17.1	130.1	0.8	6.3	7.1	A
		D2	161.3	5.1	18.2	184.6	1.7	2.0	3.6	A
		E1	204.7	0.0	18.8	223.5	2.4	0.0	2.4	A
	Solution 3	A4	10.5	22.6	16.6	49.7	0.0	8.6	8.6	C
		B3	27.3	12.5	17.1	56.9	0.0	4.8	4.8	A
		C4	39.5	17.2	17.2	73.9	0.0	6.6	6.6	A
		C3	52.4	10.9	17.1	80.4	0.1	4.1	4.2	A
		D2	95.4	1.5	18.2	115.1	0.3	0.6	0.9	A
		E1	126.2	0.0	18.8	145.0	0.6	0.0	0.6	A
Multi-family building	Solution 1	A4	36.8	39.4	13.6	89.8	1.9	15.1	17.0	E
		B3	73.6	25.9	14.0	113.5	3.9	9.9	13.8	D
		C4	88.8	34.7	14.1	137.6	4.8	13.2	18.0	D
		C3	120.8	26.0	14.0	160.8	6.6	9.9	16.5	D
		D2	190.2	10.2	14.8	215.2	10.7	3.9	14.6	C
		E1	235.6	0.0	15.3	250.9	13.5	0.0	13.5	B
	Solution 2	A4	18.9	29.7	13.6	62.2	1.0	11.3	12.3	D
		B3	43.7	19.1	14.0	76.8	2.3	7.3	9.6	C
		C4	54.2	24.9	14.1	93.2	2.8	9.5	12.3	C
		C3	73.2	18.8	14.0	106.0	3.8	7.2	11.0	C
		D2	118.2	7.3	14.8	140.3	6.2	2.8	9.0	B
		E1	148.9	0.0	15.3	164.2	7.9	0.0	7.9	A
	Solution 3	A4	7.5	21.8	13.6	42.9	0.4	8.3	8.7	C
		B3	22.1	12.3	14.0	48.4	1.2	4.7	5.9	B
		C4	29.8	17.6	14.1	61.5	1.6	6.7	8.3	B
		C3	40.0	12.2	14.0	66.2	2.1	4.6	6.7	B
		D2	69.4	5.2	14.8	89.4	3.6	2.0	5.6	A
		E1	90.6	0.0	15.3	105.9	4.7	0.0	4.7	A

CZ: Climatic zone; ER: Energy rating

4 Conclusions

This study has demonstrated that an appropriate envelope design of buildings implies important advantages such as the following: (i) reduction of the total energy demand; (ii) reduction of CO_2 emissions to the atmosphere; (iii) higher energy rating.

The use of constructive solutions with high values of thermal transmittance could require from 179% to 211% of the energy demanded in the same building when a constructive solution of low U-value is implemented. The use of these high-quality solutions also reduces considerably the CO_2 emissions, achieving values of 95% of reduction in the single-family house and 65% in the multi-family building. In addition, the use of constructive solutions with high thermal resistance enhances the energy rating of the housing units in all the cases.

However, the improvement of the energy efficiency of the buildings is also dependent on the type of building considered (single-family or multi-family) and the climatic zone. Single-family houses get larger benefits from the use of high-quality materials in the envelope because of having more surface of envelope per m^2 of building surface. In addition, buildings located in warm climatic zones are those that in general terms have a lower energy demand with any of the constructive solutions studied.

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A proposed method based on approximation and interpolation for determining climatic zones and its effect on energy demand and CO_2 emissions from buildings

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ABSTRACT

The accuracy in assigning a climatic zone to a city is essential for studying the correct sizing of domestic hot water, heating, and cooling systems, as well as of construction materials. In Spain, the current system for allocating climate zones is one proposed by the *Código Técnico de la Edificación* (Technical Building Code) (CTE) and includes a method based on Royal Decree 235/2013, *Procedimiento Básico para la Certificación de Eficiencia Energética de Edificios de los Edificios* (Basic Procedure for Certification of Energy Efficiency of Buildings), as well as on the recognized document CERMA to calculate energy demands, CO_2 emissions, and energy ratings. The climatic data of cities is not always available, so the CTE method has proposed some solutions, but they are not always precise enough. In this paper, we propose an alternative classification of climatic zones as a result of applying a new method based on approximation and interpolation functions, with a maximum error of 5.773e − 15 in summer and 6.661e − 16 in winter. This new method has been applied and tested in Andalusia in Southern Spain, a region with 772 municipalities. According to the climatic data available, the new proposed method has resulted in more precise climatic zones than the two versions of the CTE (2009 version and the 2013 update). The results are closer to reality, and the method is exportable to any region.

1. Introduction

A climatic zone is defined as an area for which common external conditions for calculating the energy demand are defined using a few parameters [1]. This concept is applicable in different scopes such as: buildings, to define energy rating [2]; urban ecosystems, to decide upon more suitable urban vegetation [3]; agriculture, to determine potential production [4]; civil engineering, to decide upon more suitable materials [5]; and atmospheric pollution, to determine the amount of organic matter in the air [6].

In relation to the use of climatic zones to determine the energy rating of buildings, the European Directive 2002/91/EC [7] and the recast in the Directive 2010/31/EU [8] on the Energy Performance of Buildings (EPBD), regulates the energy rating of buildings and their respective legislative transpositions to different countries, generating in some cases differences in criteria [9]. It has been transposed to the Spanish legal framework and, at this moment, Royal Decree 235/2013, *Procedimiento Básico para la Certificación de la Eficiencia Energética de los Edificios* (Basic Procedure for Certification of Energy Efficiency of Buildings) [10] contains the necessary requirements for determining buildings' energy efficiency rating, including new and existing constructions.

The energy rating of a building strongly depends on its energy demand, which is defined as the quantity of energy necessary to make a user enjoy certain comfort conditions. The rating depends on the building's architectural characteristics, its end use, and the climatic characteristics of the place where the building is located, which is defined according to the notion of *climatic zone* [1]. Two methods to determine the climatic zone were proposed in the *Código Técnico de la Edificación* (Technical Building Code) (CTE) [1] and the following updating documents, CTE09 [11] and CTE13 [12]. The first one used climatic registers and the second one, which is applicable when climatic data are not available, uses tabulated values that only depend on the provincial capital where a building is located. In consequence, experience has shown some illogical

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results; for example, municipalities with significant altitude differences could be included in the same climatic zone.

Similar methods are used by other countries in order to assign the climatic zone to a municipality: e.g. India uses a method based on degree-days, which are calculated by using three different methods(ASHRAE formula; equations; and UKMO Kehrig Schoenau-based method for different temperatures [13]); Portugal uses the degree-days system in base 20 [14], as well as Spain [1]. Other countries such as China use an hourly weather database [15]. All countries have in common that their methods are based on statistical weather data in the last years. The number of climatic zones depends on each country; e.g., India defines 4 [13], Portugal defines 9 [14], China defines 10 [15], Spain defines 20 [1], etc. The number of climatic zones depends on the thresholds, so it is difficult to make a direct comparison between the countries.

The objective of this paper is to propose a more rigorous method to determine climatic zones using the approximation and interpolation theory. Official climate registers from 47 municipalities in Andalusia in Southern Spain were used to develop the new method that was applied to determine a new climatic zone classification of 772 municipalities in the same region. The new classification was validated in areas with available climatic data, and it was also compared to the theoretical classifications according to the CTE methods. Finally the new classification was used to analyse its influence on buildings' theoretical CO_2 emissions, energy demand and energy rating compared to the CTE methods. CO_2 emissions, energy demand and energy rating have been calculated with CERMA [16], which is based on the Energy Efficiency Indicators method.

The phases of the present study are the following: (i) definition of the methods to determine the climatic zones; (ii) identification of the municipalities with real climate data in the studied area; (iii) utilization of the real climate data to determine the climatic severities of the municipalities by the method mentioned above; (iv) comparison of the results with the actual climate of the areas and definition of the best method to determine the climatic zone; (v) comparison of all the methods with a real case by means of calculating the energy demand, CO_2 emissions and energy rating; (vi) extration of the conclusions from the results previously obtained.

2. Materials and methods

2.1. Methods to determinate climatic zone

2.1.1. Methods established by Technical Building Code (CTE09 and CTE013)

To determine climatic zones, the CTE introduced the notion of *climatic severity* and included a winter climatic severity (WCS) and a summer climatic severity (SCS) [1]. The concept of climatic severity combines degree per day and solar radiation at a location such that two locations with the same winter severity climate (WCS) demand approximately the same quantity of heating energy if they have similar characteristics. The same notion is applied in the case of summer climate severity (SCS) for the energy demand for cooling [11]. Climatic severity is defined as the ratio between the energy demands of a building in any given location over the same building in a reference-point location. In the case of Spain, the reference point is Madrid, so the climatic severity there is the unit (1) [1]. Eqs. (1) and (2) are used to calculate climatic severity, depending on the availability of climatic data. In these equations, *CS* is the climactic severity (WCS or SCS); *DG* is the average value of winter degrees/day in base 20 for January, February, and December in the case of WCS, and for June, July, and August for SCS (they are calculated for each month in time base and then divided by 24); *Rad*, in kW h/m^2, is the average value of the global gathered radiation for January, February, and December in the case of WCS and for June, July and August for SCS; *n*/*N*, is the ratio between the maximum hours of sunlight, added separately for each of January, February, and December in the case of WCS and for each of June, July, and August for SCS; the values of *a*, *b*, *c*, *d*, *e* and *f* are included in Table 1.

Depending on the calculated values, WCS and SCS could be classified in five (A, B, C, D, and E) and four (1, 2, 3, and 4) different intervals, respectively, according to the values in Table 2 [1]. The combination of these intervals supposes a total of 20 possible different climatic zones (Table 2), although some of them could not be identified in Spain because not all climates are possible, e.g. an Antarctic climate and a Sahara desert climate [1].

The method proposed by the CTE [1], according to its *Documento Básico de Ahorro de Energía* (DB-AE) (Basic Document of Energy Savings) [11] was referred in this study by the CTE09 method, and it includes the following two alternatives to determinate a locality's climatic zone:

- Using climatic registers. WCS and SCS are calculated from climatic registers of each locality. Climate data are obtained by a historical register of global radiation and the municipality's temperatures in summer and winter.
- Using tabulated values based on climate zone data from Spain's 52 provincial capitals and the city's altitude in the province. Altitude differences lower than 200 m or lower than the capital's result in the same climate zone classification. See Table 3 for the Andalusian capitals' altitude value thresholds included in the DB-AE [11].

The *Actualización del Documento Básico de Ahorro de Energía* (DB-AE) (Actualization of Basic Document of Energy Savings) [12] has been identified in this study by the CTE13 method; comparing it to the CTE09 method, the modification only affects the determination of climatic zone using tabulated values. In this case, a lower altitude than the provincial capital value has not resulted in the same climatic zone classification. There is an adjustment period (year 2014) where it is possible use both (CTE09 and CTE13) until all tools are adjusted. Final classification depends on each province and, according to Table 4, in the case of Andalusia region [12].

2.1.2. Approximation and interpolation method (AIM)

There are several techniques for approximating a large amount (*N*) of data. Approximation and interpolation employing radial basis functions (RBF) has found significant applications since the early 1980s. Hardy [17], who originally presented the method for the multiquadric (MQ) radial function, introduced the RBF methodology in 1971. The method emerged from a cartography problem, where a bivariate interpolant of sparse and scattered data was needed to represent topography and to produce contours. None of the existing interpolation methods (e.g. Fourier, polynomial, bivariate splines) were satisfactory because they were either too smooth or too oscillatory.

A radial basis function (RBF) is a real-valued function whose value depends only on the distance from the *origin*, so that $\phi(x) = \phi(\|x\|)$; or, alternatively, on the distance from some other point *c*, called a *centre*, so that $\phi(x,c) = \phi(\|x - c\|)$. Any function ϕ that satisfies the property $\phi(x) = \phi(\|x\|)$ is a *radial function*. The norm is usually the *Euclidean distance*, although other *distance functions* are also possible.

The new method proposed in this study has been identified by the AIM method, and it has the objective of fitting the given data set with a radial basis expansion to within a given tolerance. To accomplish this, a specific technique named *adaptive least square*, which employs a data reduction process, starting with a good fit and successively reducing the number of knots used to reach a certain given tolerance. The main advantage of the proposed method could be arriving at a continuous classification to determine a new

Table 1
Values of coefficients *a*, *b*, *c*, *d*, *e* and *f* to calculate WCS and SCS.

		a	*b*	*c*	*d*	*e*	*f*
Winter Climate Severity (WCS)	Eq. (1)	-8.35×10^{-3}	3.72×10^{-3}	-8.62×10^{-6}	4.88×10^{-5}	7.15×10^{-7}	-6.81×10^{-2}
	Eq. (2)	2.395×10^{-3}	-1.111	1.885×10^{-6}	7.026×10^{-1}	5.709×10^{-2}	–
Summer Climate Severity (SCS)	Eq. (1)	3.724×10^{-3}	1.409×10^{-2}	-1.869×10^{-5}	-2.053×10^{-6}	-1.389×10^{-5}	-5.434×10^{-1}
	Eq. (2)	1.090×10^{-2}	1.023	-1.638×10^{-5}	-5.977×10^{-1}	-3.370×10^{-1}	–

Table 2
Climatic zones according to CTE methods.

		Summer Climate Severity (SCS)			
		1SCS ≤ 0.6	20.6 < SCS≤0.9	30.9 < SCS ≤ 1.25	4SCS > 1.25
Winter Climate Severity (WCS)	A WCS ≤ 0.3	A1	A2	A3	A4
	B 0.3 < WCS ≤ 0.6	B1	B2	B3	B4
	C0.6 < WCS ≤ 0.95	C1	C2	C3	C4
	D0.95 < WCS ≤ 1.3	D1	D2	D3	D4
	E WCS > 1.3	E1	E2	E3	E4

Table 3
Climatic zone. Altitude thresholds. CTE09 method.

Capital of province	Capital	Reference altitude (m)	Unevenness between the locality and the capital of the province (m)				
			≥200<400	≥400<600	≥600<800	≥800<1000	≥1000
Almería	A4	0	B3	B3	C1	C1	D1
Cádiz	A3	0	B3	B3	C1	C1	D1
Córdoba	B4	113	C3	C2	D1	D1	E1
Granada	C3	754	D2	D1	E1	E1	E1
Huelva	B4	50	B3	C1	C1	D1	D1
Jaén	C4	436	C3	D2	D1	E1	E1
Málaga	A3	0	B3	C1	C1	D1	D1
Sevilla	B4	9	B3	C2	C1	D1	E1

climatic zone instead of a step approximation. The algorithm proposed was created and run using the software MatLab Release 2012a y 2013a® [18,19] with a license to the University of Granada. This popular commercial software provides an interactive environment for numeric computations and graphics using an interpreted programming language that can optionally be compiled. The proposed algorithm included the following three steps:

i. Normalizing and scaling data set points. Available data set points – latitude, longitude, and altitude – were normalized between 0 and 1 and scaled for uniformity. City altitude is more important than latitude and longitude in terms of temperature, so data were weighted in that order.
ii. Approximating data set points. Data set points were approximated by four types of radial basis functions:
   - Gaussian (Eq. (3)): where the first term, which is used for normalising the Gaussian, is missing, because in our sum, every Gaussian has a weight, so the normalisation is not necessary.
   - Inverse multiquadric (Eq. (4))
   - Multiquadric (Eq. (5))
   - Wendland function (Eq. (6))Rippa's method was implemented in the algorithm to find the optimal value of ε (shape parameter) of the radial functions for trilinear interpolation.
iii. Obtaining new climatic zone classification. The output was the prediction index of a location. An estimation of the relative error for each function was computed to determine the best approximate function, and finally the new climatic zone classification could be determined for all Andalusian localities.

2.2. Geographical area considered for the study

This study was carried out in Andalusia in Southern Spain (Fig. 1), an area of Spain of 87 thousand km^2, which comprises 17% of Spain. It is between the latitudes 36°0′46″ (Tarifa, Cádiz) and 38°35′44″ (Santa Eufemia, Córdoba), the longitudes −7°28′4″ (Sanlucar de Guadiana, Huelva) and −1°44′44″ (Pulpí, Almería). Its altitude is from sea level to 3479 m (Mulhacén, Sierra Nevada, Cordillera Penibética), with the highest altitude city at 1532 m

Table 4
Climatic zone. Altitude thresholds. CTE13 method.

Capital of province	Capital	Altitude (m)	A4	A3	A2	A1	B4	B3	B2	B1	C4	C3	C2	C1	D3	D2	D1	E1
Almería	A4	0	$h < 100$				$h < 250$	$h < 400$				$h < 800$			$h \geq 800$			
Cádiz	A3	0		$h < 150$				$h < 450$				$h < 600$	$h < 850$			$h \geq 850$		
Córdoba	B4	113					$h < 150$				$h < 550$				$h \geq 550$			
Granada	C3	754	$h < 50$				$h < 350$				$h < 600$	$h < 800$			$h < 1300$			$h \geq 1300$
Huelva	B4	50	$h < 50$				$h < 150$	$h < 350$				$h < 800$			$h \geq 800$			
Jaén	C4	436					$h < 350$				$h < 750$				$h < 1250$			$h \geq 1250$
Málaga	A3	0						$h < 300$				$h < 700$			$h \geq 700$			
Sevilla	B4	9					$h < 200$				$h < 200$							

h: Altitude of the locality.

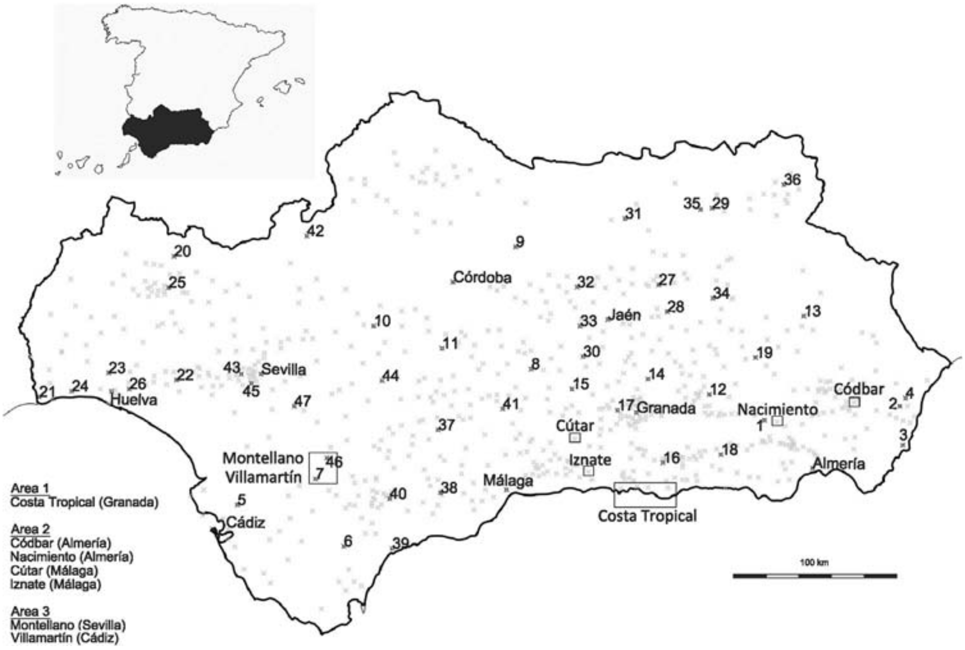

Fig. 1. Plan of the 47 reference cities and the 772 total cities of Andalusia.

(Trevélez, Granada) [20]. These factors contribute to a region with a significant range of climates, including subtropical, temperate, and cool [20].

The climatic data used in this study (Table 5), WCS and SCS, consisted of a representative number of years, solar radiations, and temperatures for all days of the year in 47 of the 772 Andalusian municipalities. The data were provided by Agencia Andaluza de la Energía (Andalusian Energy Agency) [21] at the Consejería de Economía, Innovación, Ciencia y Empleo (Ministry of Economy, Innovation, Science and Employment) of Junta de Andalucía (Government of Andalusia).

The use of tabulated values with the CTE09 and CTE013 methods [11,12] Table 6 had special application problems in the following areas:

- Area 1. Localities at lower altitudes than the province capital. In these cases, the same climate zone was assigned without considering other factors.
- Area 2. Localities at the highest threshold limits. In these cases, cities with minimum altitude variations were considered to be in different climate zones.
- Area 3. Localities near the borders of the provinces. In these cases, the localities' province capitals were used for reference so that cities geographically closer and with similar climates, but belonging to different provinces, could be classified in different climate zones.

According to the conflictive defined areas, and with the objective of checking new classifications of the climatic zones obtained with this method, the following 13 localities in Andalusia were selected for this study, whose characteristics and locations are included in Table 6 and in Fig. 1:

- Area 1. Albuñol, Almuñecar, Benaudalla, Jete, Molvízar, Motril, and Vélez de Benaudalla (Costa Tropical—South of Granada). All these localities were at sea level.
- Area 2. Nacimiento, Cóbdar, (Almería), Cútar, and Iznate (Málaga).
- Area 3. Montellano (Sevilla) and Villamartín (Cádiz). These localities were 57 and 69 km away away from Sevilla and Cádiz, respectively, and only 16 km apart from each other.

2.3. Thermal simulation

Energy demands, CO_2 emissions, and energy ratings of a housing type were calculated using the methods considered in this study to determine and to compare the effects of the climatic zone classifications.

2.3.1. Simulation software used

Theoretical thermal simulations were performed with the software CERMA [16] to determine buildings' energy demands, CO_2 emissions, and energy ratings. This software is a validated tool for rating energy by The Housing Ministry of Spain (Article 3 of Royal Decree 235/2013 [10]). CERMA is based on the Energy Efficiency Indicators method. The estimation of the energy necessary to comply with the demands of a building under normal conditions of occupancy and functioning is known as the Energy Efficiency Rating. By comparing a number of indicators of the mean energy use in model buildings of reference, a real building can be qualified and certified on an energy scale established for this purpose [10,22]. The Energy Efficiency Indicators (EEI) in residential buildings are: (i) EEI heating demand; (ii) EEI cooling demand; (iii) EEI of heating emissions; (iv) EEI of cooling emissions; (v) EEI of emissions for DHW; and (vi) EEI of total emissions.

The blueprints and measurements of the constructions were processed by means of AutoCAD LT® 2014 [23] with license to the University of Granada.

2.3.2. Characteristics of the building studied

A single-family housing type was selected to do thermal simulations (Fig. 2); it consisted of three floors and had a total usable area of 254.60 m^2: ground floor (135.70 m^2), first floor (88.12 m^2), and second floor (30.78 m^2). The most important materials in the thermal enclosure and the thermal transmittance limit (U) used were: roof (0.48 $W/m^2 K$), uninhabitable area roof (0.75 $W/m^2 K$), external wall (0.54 $W/m^2 K$), ground floor (0.65 $W/m^2 K$), wood

Table 5
47 Reference cities.

Province	Id	City	Geographical data			Climate Severity		Climatic zone CTE09 method		Climatic zone CTE13 method		Climatic zone AIM method	
			Latitude	Longitude	Altitude	WCS	SCS	Winter	Summer	Winter	Summer	Winter	Summer
Almería	1	Abla	37.1411	−2.7801	871.17	0.780	1.160	C	1	D	3	C	3
	2	Antas	37.2452	−1.9175	107.26	0.320	1.160	A	4	B	4	B	3
	3	Carboneras	36.9966	−1.8950	6.72	0.120	1.260	A	4	A	4	A	4
	4	Cuevas de Almanzora	37.2971	−1.8815	97.29	0.210	1.330	A	4	A	4	A	4
Cádiz	5	Jerez de la Frontera	36.6866	−6.1372	55.75	0.430	1.490	A	3	A	3	B	4
	6	Jimena de la Frontera	36.4340	−5.4535	131.44	0.410	1.510	A	3	A	3	B	4
	7	Villamartin	36.8613	−5.6418	167.81	0.560	1.560	A	3	B	3	B	4
Córdoba	8	Carcabuey	37.4436	−4.2734	628.29	0.780	1.420	D	1	D	3	C	4
	9	Montoro	38.0262	−4.3819	201.33	0.600	1.560	B	4	C	4	C	4
	10	Palma del Río	37.7016	−5.2838	60.92	0.450	1.640	B	4	B	4	B	4
	11	Santaella	37.5663	−4.8451	238.22	0.410	1.740	B	4	C	4	B	4
Granada	12	Guadix	37.3004	−3.1346	919.40	1.140	1.020	C	3	D	3	D	2
	13	Huescar	37.8095	−2.5397	959.98	1.150	1.010	D	2	D	3	D	3
	14	Iznalloz	37.3927	−3.5275	816.34	1.160	1.020	C	3	D	3	D	3
	15	Montefrio	37.3210	−4.0114	835.14	1.070	1.050	C	3	D	3	D	3
	16	Órgiva	36.9022	−3.4240	465.87	0.650	1.210	C	3	C	4	D	3
	17	Santa Fe	37.1894	−3.7191	582.65	1.100	0.900	C	3	C	4	D	3
	18	Ugíjar	36.9608	−3.0548	547.52	0.760	1.110	C	3	C	4	D	3
	19	Zújar	37.5402	−2.8428	771.52	1.230	1.010	C	3	C	3	D	3
Huelva	20	Aracena	37.8942	−6.5612	674.00	0.830	1.270	C	1	C	3	C	4
	21	Ayamonte	37.2147	−7.4098	3.16	0.310	0.900	B	4	A	4	B	2
	22	Bollullos	37.3362	−6.5358	116.02	0.430	1.700	B	4	B	4	B	4
	23	Gibraleón	37.3750	−6.9701	29.22	0.360	1.600	B	4	A	4	B	4
	24	Lepe	37.2543	−7.2033	24.54	0.350	1.130	B	4	A	4	B	3
	25	Minas de Río Tinto	37.6939	−6.5918	417.64	0.600	1.510	B	3	C	3	B	4
	26	Moguer	37.2747	−6.8366	53.91	0.330	1.290	B	4	B	4	B	4
Jaén	27	Baeza	37.9934	−3.4692	759.48	0.740	1.820	C	3	D	3	C	4
	28	Bedmar y Garcíez	37.8227	−3.4118	645.47	0.690	1.590	C	3	C	4	C	4
	29	Castellar	38.2562	−3.1319	755.20	0.980	1.410	C	3	D	3	D	4
	30	Castillo de Locubín	37.5283	−3.9437	702.94	0.930	1.440	C	3	C	4	C	4
	31	Guarroman	38.1815	−3.6865	348.13	0.760	1.650	C	4	B	4	C	4
	32	Lahiguera	37.9705	−3.9892	372.68	0.660	1.820	C	4	B	4	C	4
	33	Martos	37.7228	−3.9663	739.37	0.960	1.160	C	3	C	4	D	3
	34	Peal del Becerro	37.9133	−3.1217	548.82	0.930	1.550	C	4	C	4	C	4
	35	Santisteban del Puerto	38.2475	−3.2064	706.27	0.810	1.600	C	3	C	4	C	4
	36	Torres de Albanchez	38.4145	−2.6771	830.67	1.050	1.200	C	3	D	3	D	3
Málaga	37	Campillos	37.0454	−4.8615	458.55	0.720	1.250	C	1	C	3	C	3
	38	Casarabonela	36.7852	−4.8422	469.91	0.380	1.700	C	1	C	3	B	4
	39	Estepona	36.4248	−5.1449	9.66	0.190	1.190	A	3	B	3	A	3
	40	Ronda	36.7420	−5.1664	721.03	0.920	0.890	C	1	D	3	C	2
	41	Villanueva de Algaidas	37.1863	−4.4508	542.55	0.960	1.190	C	1	C	3	D	3
Sevilla	42	Alanís	38.0375	−5.7153	674.50	0.780	1.140	C	1	C	4	C	3
	43	Espartinas	37.3800	−6.1236	129.53	0.530	1.240	B	4	B	4	B	3
	44	Lantejuela, La	37.3535	−5.2230	152.55	0.510	1.720	B	4	B	4	B	4
	45	Puebla del Río, La	36.9956	−5.5709	270.64	0.460	1.450	B	4	B	4	B	3
	46	Montellano	37.2675	−6.0626	21.87	0.440	1.120	B	3	C	4	B	4
	47	Utrera	37.1814	−5.7815	49.07	0.530	1.270	B	4	B	4	B	4

Latitude and longitude in decimal degrees. Altitude in meters. W: winter; S: summer.

door (2.20 W/m^2 K), garage door (3.20 W/m^2 K), and windows (2.47 W/m^2 K). The windows have the following areas and orientations: north 6.00 m^2; west 2.80 m^2; south 7.60 m^2 and east 2.10 m^2. Furthermore, the garage door and the wood door are south-facing, with an area of 6.60 m^2 and 3.20 m^2, respectively. The main façade faced south in all cases. A comfortable indoor temperature, between 17 °C and 20 °C in winter, and between 24 °C and 26 °C in summer, was selected.

Table 6
Studied areas.

Studied Area			Geographical data			Climate Severity		Climatic zone					
								CTE09		CTE13		AIM	
Area	Province	City	Latitude	Longitude	Altitude	WCS	SCS	W	S	W	S	W	S
1	Granada	Albuñol	36.79125	−3.203485	247	0.262	1.402	C	3	B	4	A	4
	Granada	Almuñécar	36.73454	−3.690736	24	0.205	1.367	C	3	A	4	A	4
	Granada	Jete	36.79732	−3.668151	134	0.264	1.483	C	3	B	4	A	4
	Granada	Molvízar	36.78689	−3.607518	239	0.298	1.477	C	3	B	4	A	4
	Granada	Motril	36.74467	−3.516718	41	0.197	1.376	C	3	A	4	A	4
	Granada	Salobreña	36.74626	−3.587108	21	0.197	1.363	C	3	A	4	A	4
	Granada	Vélez de Benaudalla	36.83195	−3.516209	171	0.272	1.478	C	3	B	4	A	4
2	Almería	Cóbdar	37.26199	−2.210223	607	0.833	1.008	C	1	C	3	C	3
	Almería	Nacimiento	37.10497	−2.647740	597	0.822	1.035	B	3	C	3	C	3
	Málaga	Cútar	36.83069	−4.228007	298	0.384	1.563	B	3	B	3	B	4
	Málaga	Iznate	36.77612	−4.183560	305	0.353	1.571	B	3	C	3	B	4
3	Sevilla	Montellano	36.99564	−5.570882	271	0.460	1.450	B	3	C	4	B	4
	Cádiz	Villamartín	36.86132	−5.641834	168	0.560	1.560	A	3	B	3	B	4

Latitude and longitude in decimal degrees. Altitude in meters. W: winter; S: summer.

In relation to the heating and the domestic hot water (DHW) systems, a biomass fuel boiler was selected due to the increased use in Andalusia, as currently biomass is the source that most contributes to Andalusian energy infrastructures of renewable energies, including 78.7% of the renewable energy consumption and 6.3% of the total primary energy consumption [24], and the quantity of biomass available in the area—land surface of 8,759,531.18 ha ≈40% forest and ≈60% farmland [25]. The thermal load selected for the boiler was set to 24 kW, with a thermal efficiency of 90% and an outlet water temperature of 50 °C for DHW and 80 °C for heating. The flow rate of DHW was 229 l/day. The house had an accumulator with a capacity of 200 litres. The water temperature varied between 60 °C and 80 °C, with the global heat transfer coefficient ($U \times A$) being 1 W/K.

3. Results and discussion

3.1. Climatic zoning classification

The results of the application of the CTE09 [11], CTE013 [12], and AIM methods for the 772 localities of Andalusia are included in Tables 6–9, and they are described and discussed below.

3.1.1. CTE09 method

After the application of the CTE09 method, the WCS most common in the region was C (45.9%) followed by B (29.8%), D (15.7%), and A (8.6%); The E classification did not appear in the studied area. However, the most common SCS classification in the region was 3 (40.8%) followed by 1 and 4 with similar percentage (26.3 and 25.4%, respectively); the 2 classification was below the norm, with only 7.5% of the municipalities. Finally, the combination of WCS and SCS classifications resulted in 10 of the 20 possible climatic zones in Andalusia (Table 7); as result, the most common climatic zone in this region was C3 (22%) followed by other combinations, as shown in Table 7.

Climactic zones were particularly studied in specific localities that did not have available climatic data, and they were identified in areas with special application problems. The results are summarized in Table 6 and discussed below.

- Area 1. This region includes seven cities that are located in the Costa Tropical. It is at sea level and is characterized by a Subtropical Climate with an average annual temperatures around 20 °C, a minimum of 14 °C, and a maximum of 33 °C [26]. The capital of the province, Granada, has an altitude of 754 m and is characterized by a Mediterranean Climate, cold winters or a Continental-Mediterranean Climate, extreme temperatures (differences between day and night could be greater than 20 degrees), long and very cold winters (temperatures lower than −10 °C) and hot summers (temperatures higher than 40 °C) [26]. The climate zone of Granada was included in CTE, considering the climate data available. It resulted in a zone C3 [11], which was the same classification that resulted after the application of CTE09 for the seven cities in this area despite the significant climate differences between Granada and the coastal cities studied.
- Area 2. This area included four localities at the limits of the highest thresholds in two different provinces, Almería and Málaga: Cóbdar (C1) and Nacimiento (B3) in Almería province, and Cútar (B3) and Izanate (B3) in Málaga province. All four municipalities here showed several climatic zones within themselves (Table 6), but all of them had a Continental-Mediterranean Climate [26], the same real climate but with variations in WCS and SCS.
- Area 3. This case included two nearby cities belonging to two different provinces, Sevilla and Cádiz. Both cities are characterized by the typical Mediterranean Climate, with dry and hot summers, average temperatures around 22 °C, and wet and rainy winters with mild temperatures [26]. The application of the CTE09 method resulted in different classifications for WSC for both municipalities and thus different climatic zones, although they have the same climatic characteristics. The results for Montellano, located south of Sevilla, put this city in the B3 climatic zone, and Villamartín, located north of Cadiz, was included in the A3 climatic zone. In this case, the differences between the climatic zones of both cities were not strongly different and only affected WCS; however, these results could mean differences in determining the heating energy consumption during the winter, in spite of the similarities in the climatic characteristics in both cities.

The results showed that the CTE09 method is not consistent with reality in the case of the three areas with special application problems. In consequence, it was possible to conclude that CTE09 is not a suitable method for determining climatic zones.

3.1.2. CTE13 method

The application of the CTE13 method showed that the most common WCS in Andalusia was C (41.6%) followed by B and D (25.8 and 25.4%, respectively), A (6.7%), and E (0.5%). In the case of SCS, the most common classification was 3 (61.3%) followed by 4

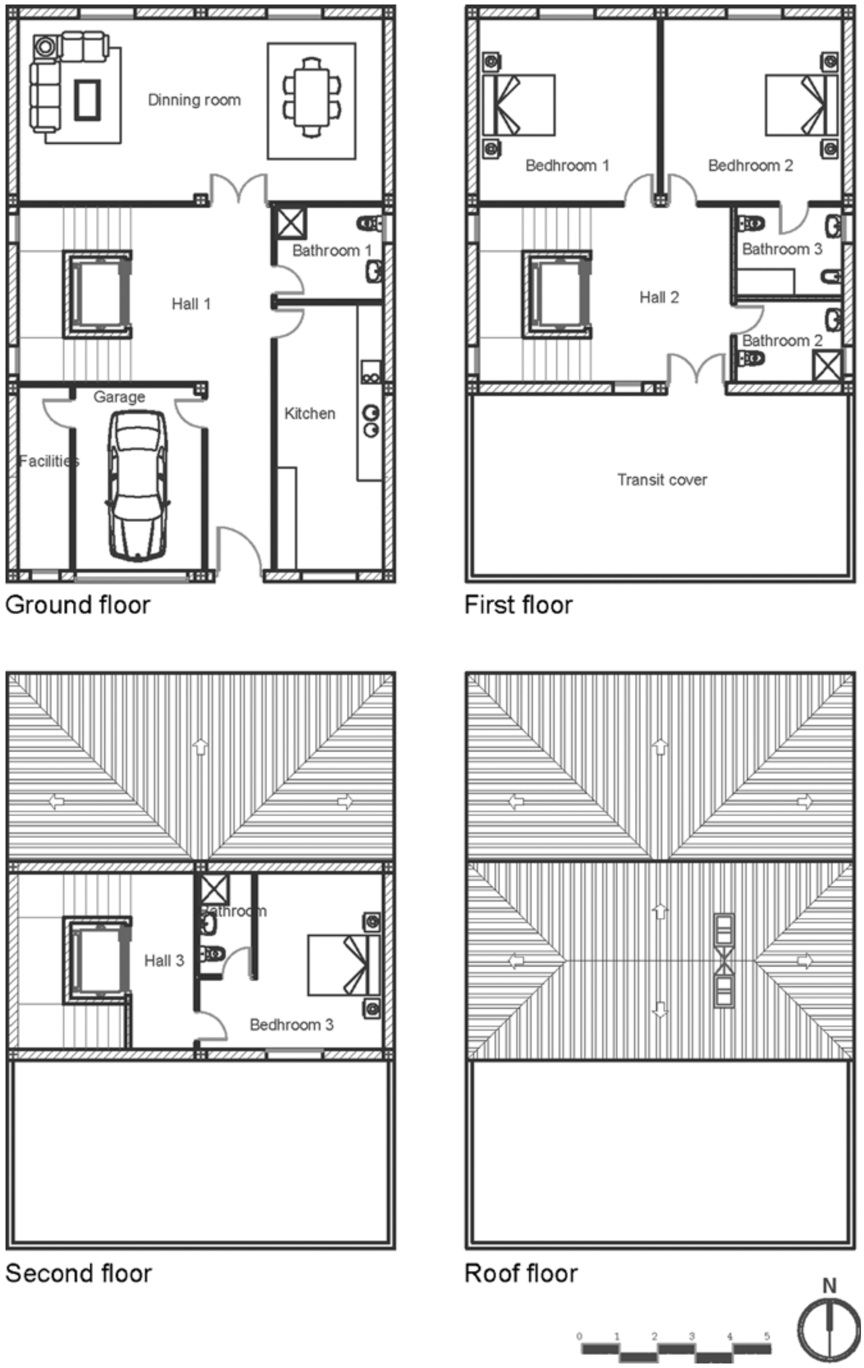

Fig. 2. Plan of the single-family house.

Table 7
Combination of climate zone in winter and in summer. Percentage of locations in Andalusia.

CZ	CTE09					CTE13					AIM				
	1	2	3	4	Σ	1	2	3	4	Σ	1	2	3	4	Σ
A	–	–	6.0%	2.6%	8.6%	–	–	3.1%	3.6%	6.7%	–	–	1.7%	6%	7.7%
B	–	0	12.8%	1.7%	29.8%	–	0	9.1%	16.7%	25.8%	–	0.4%	6.7%	26.3%	33.4%
C	16.2%	1.9%	22.0%	5.8%	45.9%	–	0.7%	23.8%	17.1%	41.6%	–	2.3%	17%	19.9%	39.2%
D	10.1%	5.6%	–	–	15.7%	–	0.1%	25.3%	–	25.4%	–	1.2%	17.6%	0.9%	19.7%
E	–	–	–	–	–	0.5%	–	–	–	0.5%	–	–	–	–	–
Σ	26.3%	7.5%	40.8%	25.4%	100%	0.5%	0.8%	61.3%	37.4%	100%	0	3.9%	43%	53.1%	100%

Table 8
Errors for the studied functions. AIM method.

	Summer		Winter	
	Max. error	RMS error	Max. error	RMS error
Gauss (ep = 20)	1.088019e − 14	4.511634e − 16	7.438494e − 15	3.575953e − 16
Multiquadric	1.088019e − 14	4.511634e − 16	1.054712e − 14	6.166019e − 16
Inverse mult.	**5.773160e − 15**	**2.390121e − 16**	**6.661338e − 16**	**3.924787e − 17**
Wendand (C2)	9.863221e − 13	5.422403e − 14	2.543521e − 13	1.554525e − 14

Table 9
Energy ratings.

Studied area			Energy rating		
Area	Province	City	CTE09	CTE13	AIM
1	Granada	Albuñol	A	B	B
	Granada	Almuñécar	A	B	B
	Granada	Jete	A	B	B
	Granada	Molvízar	A	B	B
	Granada	Motril	A	B	B
	Granada	Salobreña	A	B	B
	Granada	Vélez de Benaudalla	A	B	B
2	Almería	Cóbdar	A	A	A
	Almería	Nacimiento	A	A	A
	Málaga	Cútar	A	A	A
	Málaga	Iznate	A	A	A
3	Sevilla	Montellano	A	B	A
	Cádiz	Villamartín	B	A	A

(37.4%) and finally 1 and 2, with similar percentages (0.5 and 0.8%, respectively). Finally, the most common climatic zone was D3 (25.3%), followed by other combinations shown in Table 7.

In the following section the municipalities of conflict areas were studied with the CTE13 method:

- Area 1. The application of CTE 13 to the cities in Area 1 resulted in the A4 (Almuñecar, Motril, and Salobreña) and the B4 (Albuñol, Jete, Molvízar, and Vélez de Benaudalla) climatic zones. In this case, the classifications of these municipalities' climatic zone was completely different from Granada's capital classification (C3), and they came closer to their real Subtropical Climate [26]. The results also considered slight differences between the cities located just at sea level (Almuñecar, Motril and Salobreña) and those located near the sea but with an altitude between 134 and 247 (Table 6).
- Area 2. The CTE13 method in Area 2 changed the threshold limits, as shown in Table 4. Using the CTE09 (Table 3) method, all cities had a Continental-Mediterranean Climate [26]. This situation caused the climatic zones of the bordering cities to change. In CTE13 in Almería province, Cóbdar and Nacimiento had the same climate zone, C3, because the new limit was 800 meters (Table 4). In contrast, in Málaga province, Cútar and Iznate, with CTE13, obtained different climatic zones, B3 and C3, respectively, because the new limit between climatic zones was 300 meters (Table 4).
- Area 3. For Montellano, located south of Sevilla, the results placed the city as a C4 climatic zone; and Villamartín, located north of Cádiz, had a B3 climatic zone. So the differences of WCS and the SCS were observed, and all cities had a Mediterranean Climate [26].

The results obtained have shown that the new tabulated values proposed by the CTE13 method improved the procedures for determining the climatic zones of cities located in provinces with a capital with a higher altitude than the other municipalities (Area 1). However, in the rest of the areas with special application problems (Areas 2 and 3), the method was still not consistent with reality, showing different climatic zones to nearby municipalities

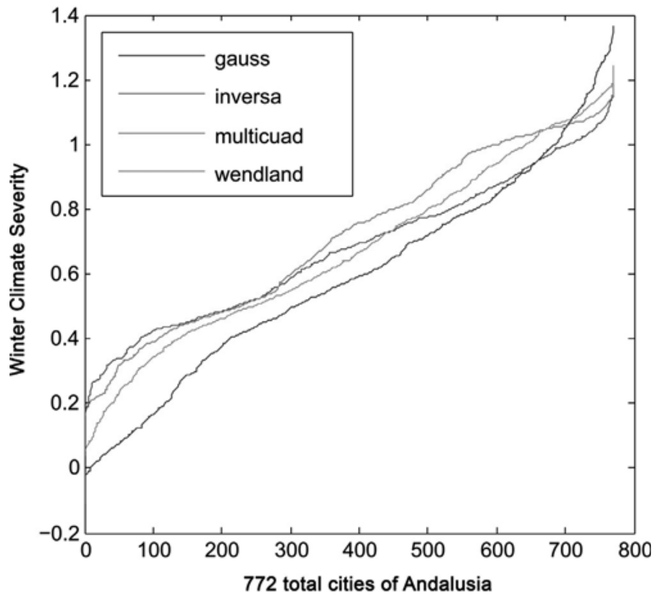

Fig. 3. Approximation functions for Winter Climate Severity.

characterized by the same climate as the CTE09 method. This is due to the use of the capital as the reference point to determine the climatic zone for the rest of the localities.

3.1.3. AIM method

For the AIM method, the altitude, latitude, and longitude data of 47 data set points (Table 5) were normalized and scaled for uniformity, while city altitude was weighted. Consequently, data set points were approximated by the following radial basis functions: (i) Gaussian, (ii) inverse multiquadric, (iii) multiquaddric, and (iv) Wendland to get a quantitative measure of the degree of approximation provided by each approximant; Figs. 3 and 4 show approximation functions for WCS and SCS. Finally an estimation of the relative error was computed to determine the best approximant function. Table 8 summarizes the maximum error and the relative

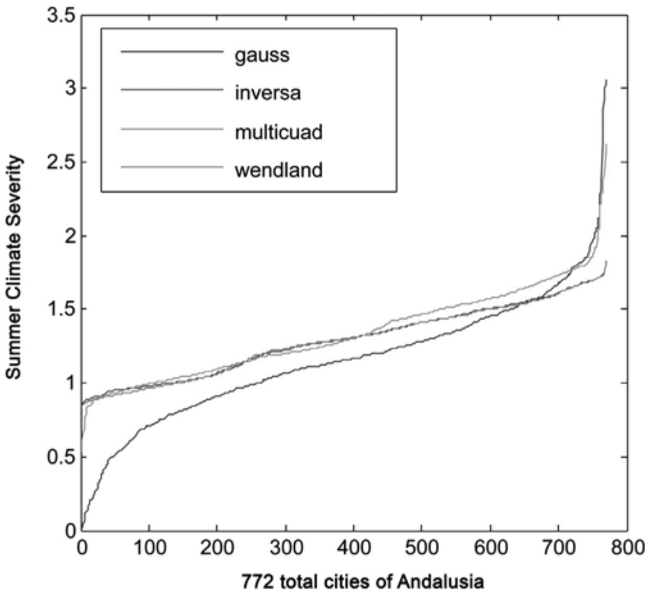

Fig. 4. Approximation functions for Summer Climate Severity.

mean square error (RMS) for them, depending on the season, concluding that the function that resulted in the best approximation was the inverse multiquadric function, so it was used to determine WCS and SCS for all the Andalusian municipalities (Table 7).

The application of the AIM method results placed C as the most common WCS in Andalusia (39.2%), followed by B (33.4%), D (19.7%), and A (7.7%); The E classification did not appear in the studied area. The most common SCS classification in the region was 4 (53.1%), followed by 3 (43%), and 2 (3.9%); The 1 classification did not appear in the studied area. Finally, as result of combining the WCS and SCS classifications, the most common climatic zone in the region was B4 (26.3%), followed by the other combinations shown in Table 7.

The results in conflict areas were also compared, and they obtained the following:

- Area 1. In the case of Area 1, The AIM method gave the closest classification to the reality of the Subtropical Climate [26] that characterizes municipalities included in this area, by considering the cities below the provincial capital with a suitable climate zone.
- Area 2. The application of the CTE09 and the CTE13 methods provided different results for Area 2, depending on the value of the threshold elevation. With the implementation of the AIM method, these thresholds disappeared, and the results were closer to reality, with a Continental-Mediterranean Climate [26]. These results indicate the AIM method as the most appropriate because the threshold limits were eliminated, thus giving a more progressive classification.
- Area 3. The AIM method removed the restriction to referencing a municipality to the capital of its province, as CTE09 and CTE13 methods required. The results obtained for Area 3 with the AIM method reference only other nearby municipalities with actual climate data, thus bringing the results closer to Area 3's actual Mediterranean Climate [26].

The results have shown that the new proposed method, AIM, improved the procedures for determining climatic areas that had special application problems in representing reality. Just as noted above, the AIM method covers the CTE methods' deficiencies. Regarding the cities below their provincial capitals, threshold limits are eliminated, and the results reference instead only nearby municipalities. Although the best method was carried out with real climate data, in the cities without data the proposed method (AIM method) resulted to be the more accurate because it is based in nearby cities with real climate data. This method has interpolated the altitude, latitude and longitude, and was validated with the climate of the 47 municipalities with climate data, as well as with the 8 capitals of province.

3.1.4. Comparison of methods

Table 7 shows the percentages of global climactic zones and SWC and SCS climatic zones, respectively, obtained by the CTE09, CTE13, and AIM methods. The applied methods have resulted in different climatic zones for the studied Andalusian municipalities, showing significant variations in the percentages of each climate zone. On the one hand, comparison of climate areas obtained applying the CTE09 and the AIM methods showed an increase in A by 1%, C by 7%, 1 by 26%, and 2 by 3%, as well as a decrease in B by 4%, D by 4%, 3 by 4%, and 2 by 28%; E remained unchanged, only in CTE13 but with a minimum variation. On the other hand, comparing the CTE13 and AIM methods showed an increase in C by 2%, D by 6%, E by 1%, and 1 by 1%, and a decrease of A by 1%, B by 8%, 2 by 3%, and 4 by 16%. In consequence, the CTE13 and AIM methods had higher coincidence rates than the CTE09 method.

The analysis of the results also showed similar tendencies in the distribution of Winter Climatic Zones regardless of the method applied, with slight differences in percentages between them; however, significant differences were detected in Summer Climatic Zones, resulting in the warmest climatic zone 4 as the most frequent (Fig. 5). The percentage of municipalities included in the hottest SCS classification (number 4) was higher in the case of AIM method and, in consequence, the percentage in the coldest classification (number 1) was lower. This increase was due to the fact that the new method took into account the latitude, altitude and longitude conditions of the cities but not the difference of altitude between the municipalities or the altitude of the capital of province. In consequence, many coastal cities were included in a warmer climatic zone than the real one.

With each method, the following were observed: With the CTE09 method, the most common climatic area was C3. This classification is related to a climate characterised by dry and hot summers, mild winters and irregular rainfall, according to the typical climate of the region, a Mediterranean Climate [27]. With the CTE13 method, the most common was D3, a climate zone similar to C3, D3 fits in a Continental-Mediterranean Climate, with extreme temperatures and cold winters [26]. Finally, with the AIM method, the most common was B4, which is characterized by a Continental-Mediterranean Climate, becoming in some cases a Dry Mediterranean Climate, with warmer winter temperatures and less rainfall than the Continental Mediterranean [26]; this climatic zone is the one that best identifies the Andalusian climate as characterised by its many hours of sunshine per year [27].

3.2. Energy demand, CO_2 emissions

The use of an inappropriate climatic zone affects the previous calculations in a building's thermal performance, resulting in erroneous estimations of its energy demands [28]; furthermore, a misallocation of climate zone has also affected the theoretical calculations of CO_2 emissions [29]. As a consequence, energy demands and CO_2 emissions for areas with special application problems and for housing types have been determined with different methods to analyse the effect of the climate zone classification.

Fig. 6 shows that the CTE09 method supposed an increase (280.13%) of heating demand in coastal cities and a decrease

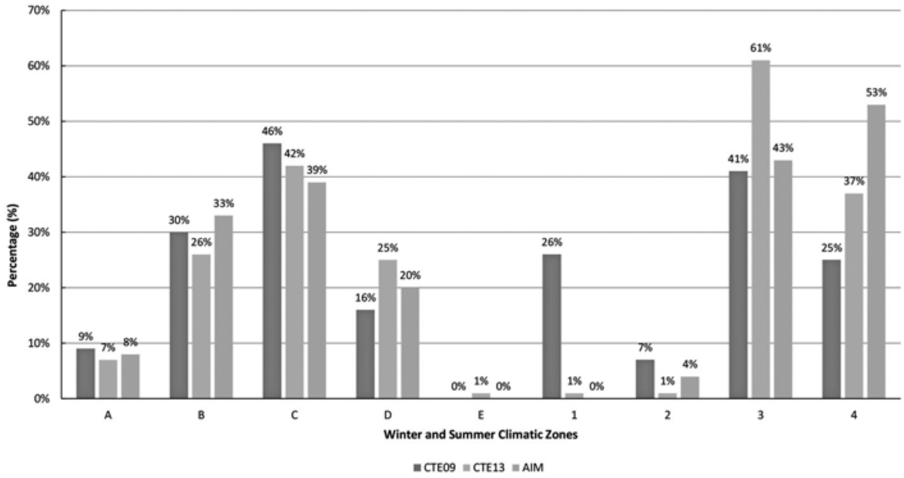

Fig. 5. Tendency of the distribution of WCZ and SCZ with CTE09, CTE13 and AIM method.

(70.26%) in cooling, compared to the AIM method. Fig. 7 shows that these results have also implied an increase of CO_2 emissions (285.71%) in heating and a reduction (60.34%) for cooling, comparing the CTE09 to the AIM method.

Finally, for all the studied areas, the DHW resulted in zero CO_2 emissions, independently of the considered area because it was associated with heating. The influence of the climatic zone was minimal because the demand appeared to depend largely upon the area of the living quarters.

3.3. Energy rating

The energy ratings of housing types were determined in areas with special application problems using different methods to analyse the effects of the climate zone classification, but no significant differences were detected (Table 9). In the case of cities located in a coastal area (Area 1), the CTE13 and the AIM methods obtained the same classification (B) while CTE09 obtained a better classification (A) because of the better ratio of demand with respect to

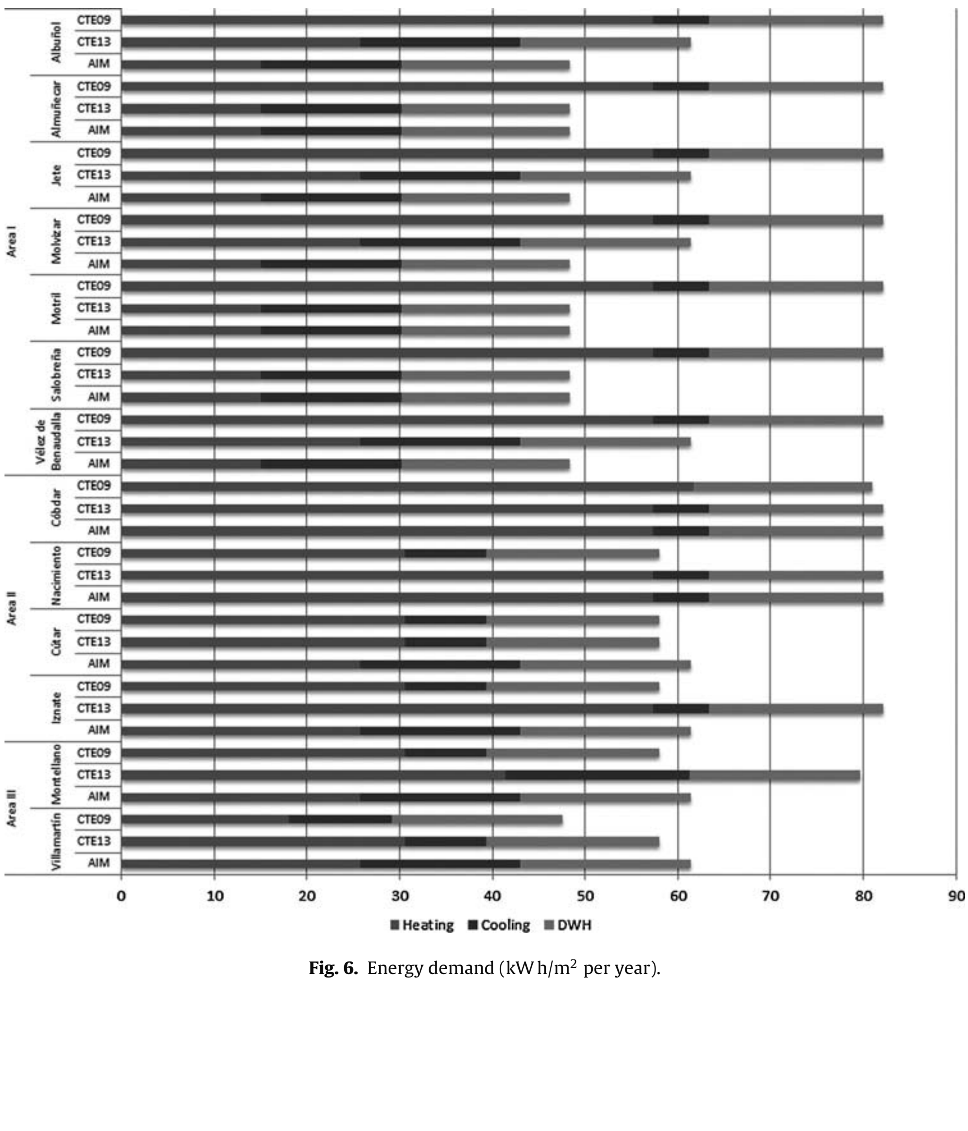

Fig. 6. Energy demand (kW h/m^2 per year).

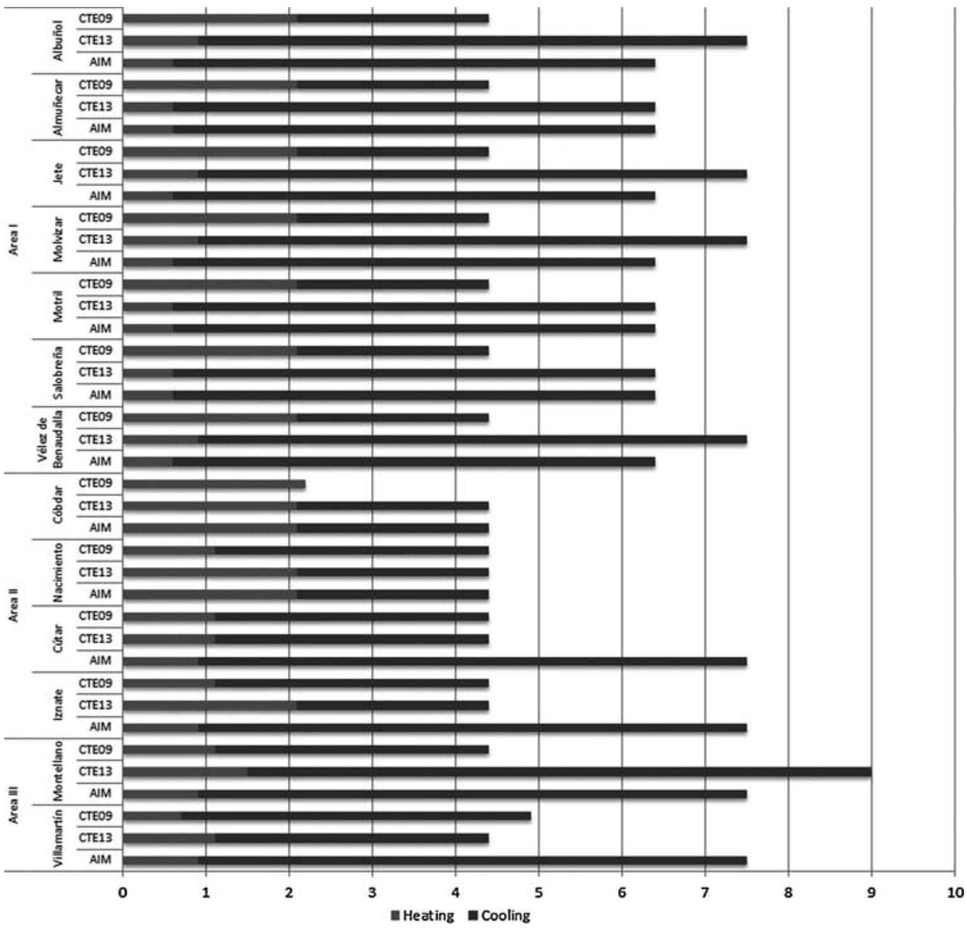

Fig. 7. CO_2 emissions (kg CO_2/m^2 per year).

emissions. However, CTE09 had an erroneous climate zone. In the case of cities located at the limits of the highest thresholds (Area 2) no differences were detected; finally no coincidences were found between energy rating values in localities in different provinces but near between them (Area 3).

The results could be explained by the use of renewable energy (biomass) instead of gasoil or natural gas [28]. This choice usually reaches four classes on a scale of seven levels [28]. Furthermore, a biomass boiler is considered to be better than a conventional boiler in economic [30] and environmental terms [31].

4. Conclusions

The results of the application of three different methods of determining climatic zones for the calculation of buildings' energy efficiency showed that both methodologies proposed by the CTE present important disadvantages since the results did not always reflect the real climate of the cities. However the new proposed AIM method showed a climatic zone classification more in accordance with the real climatic characteristics of Andalusian cities.

Unsuitable climatic zone classifications have resulted in energy demands as well as CO_2 emissions not consistent with areas' real climatic characteristics (maximum increases of 280.13% and 285.71%, respectively, according to the method used have been observed) Although these differences have not resulted in significant differences in energy rating, in the case of using renewable fuels instead of fossil fuels, the differences could imply a previous bad building design because the precision in correctly assigning a climatic zone to a dwelling is essential to design it with correct energy efficiency [28], such as installing thermal insulation or other related building materials [29].

Therefore, the proposed approximation and interpolation method is a suitable way to determine climatic zone in areas without available climate data. The use of latitude, altitude, and longitude data is enough to calculate a good approximation of a climatic zone, so the use of this method could be extrapolated to other areas.

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Appendix A. Annex

$$\mathrm{CS} = a \times \mathrm{Rad} + b \times \mathrm{DG} + c \times \mathrm{Rad} \times \mathrm{DG} + d \times (\mathrm{Rad})^2 + e \times (\mathrm{DG})^2 + f \quad (1)$$

$$CS = a \times \mathrm{Rad} + b \times \frac{n}{N} + c \times \mathrm{DG}^2 + d \times \left(\frac{n}{N}\right)^2 + e \quad (2)$$

$$\Phi(r) = e^{-(\varepsilon r)^2} \quad (3)$$

$$\Phi(r) = \frac{1}{1 + (\varepsilon r)^2} \quad (4)$$

$$\Phi(r) = \sqrt{1+(\varepsilon r)^2} \quad (5)$$

$$\Phi(r) = \max(1-\varepsilon r)^4 \times (4\varepsilon r + 1) \quad (6)$$

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