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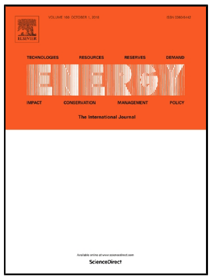

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Impact of climate change on heating and cooling energy demand in a residential building in a Mediterranean climate

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Abstract

A range of energy improvement measures applied to a typical Mediterranean residential building are modelled under various climate-change scenarios. Global Circulation Models (CNRM-CM5 and MPI-ESM-LR), under two emission scenarios (RCP4.5 and RCP8.5), downscaled by the Spanish Meteorological Agency, are used to generate four temperature projections. Energy simulations are obtained with TRNSYS tools in a Mediterranean climate based on temperature projections in two periods: 2048-2052 and 2096-2100, with the same time span. Various energy measures apply thermal improvements to a conventional residential building model that complies with current regulations for this analysis of best practice in passive construction solutions. Sequential implementation of eight different energy improvements measures are applied to the initial building model: six passives (infiltration, insulation thickness, glazing and frame type, window area, shading devices and natural cross ventilation) and two active (mechanical ventilation and a heat recovery system) measures. The climatic trends that are predicted show a local scenario with a warming climate and the thermal behaviour of the building is shown to differ in each scenario. The demand for indoor heating decreases significantly when the outdoor temperature increases, while the demand for cooling and the risk of overheating increase considerably in all the scenarios. The data for the building conditions that are projected in this study predict that natural and forced ventilation strategies will have the least impact, while increased thermal insulation and reductions in infiltration will have a greater effect on global energy demand.

Keywords: Climate change; Energy demand; Buildings; Mediterranean Climate; TRNSYS

1. Introduction

Climate change and global warming are major concerns in modern-day society. One of the most productive international working groups in this area is the Intergovernmental Panel on Climate Change (IPCC). In its fifth report, under various CO_2 emission scenarios, the IPCC predicted that average global surface temperatures by the end of the 21st century (2081-2100) would be within a range of 1.1 and 4.8K, in relation to 1986-2005 [1]. Recent studies point to climate change as having a major impact on energy demand for both heating and cooling in buildings, because of the changes in ambient outdoor conditions [2,3]. Hence, the need to control the energy consumption of buildings and their Green House Gas (GHG) emissions as part of their adaptation to new climatic conditions through the inclusion of those measures in standards and regulations that will guarantee the comfort of users [4].

In general, the effects of climate change on buildings have yet to be considered. Building projects incorporate typical meteorological data from the recent past compiled from historical climatic data from each site [1]. The normal technical solutions that determine the energy performance of a building are hardly ever adapted to the intensity of climatic changes that might be predicted or come to pass during the useful life of the building.

The authors of this paper are therefore convinced that climate change and its effects on the energy demand of buildings must be considered from an architectural point of view; a view that has likewise found support among numerous governments and international research groups [5]. Previous works can therefore be found that have analysed climate change and its influence on energy demand in buildings. The initial studies in this area date back to the 1990s [3,4]. One of the most closely studied methods [6–18] involves annual variations of climate data when assessing the impact of climate change on building models across a variety of climatic regions (Köppen-Geiger climate classification) [19]. The quality of these studies depends on future data predictions [1] that are determined by combining different global climate models and emission scenarios. There are studies from global or national perspective [9,17]. Isaac & van Vuuren, studied residential heating and cooling demand in the context of climate change for the first time at a global scale. They found a stabilization of global heating energy demand and a considerable increase in global energy demand for cooling up to 2050. All scenarios examined by them point to a net decrease in energy demand, but at regional this pattern differs greatly [17]. Though most of them data are usually projected at a regional scale and climate files are usually prepared in hourly sequences for use with simulation tools. Various authors [10] have also analysed climate change issues that affect the functioning of buildings from different perspectives, some relevant to the design of the trials in this research. The results are highly variable, depending on the projection of climate change, the geographical region, and the building typology [7].

In general, the type of analysis preferred by the authors consists of modifying climate data considering simulated projections of climate change that combine different variables in the study such as geographical areas, building typologies, and both active and passive measures to improve energy efficiency. The list in Table 1 shows the impacts of climate change on the energy behaviour of buildings over the last decade, based upon a survey of published research, but is not intended to be exhaustive. Regional climates, typologies, and other parameters that constitute the design criteria of a building will inevitably vary; nonetheless, the conclusions on methods and results overlap, and are simultaneously applicable to the overall issue and specific to different projections, climate types, and buildings.

Karimpour et al. [10] concluded that climate change in Australia will reverse the predominance in Csb Koppen climates of heating over cooling in residential buildings. In contrast, Wang & Chen [7] determined that in USA there would be a general decrease in heating demand and that the demand for cooling in the different locations of their study could be mitigated by natural measures depending on the regional climate (Dfa, Dfb and Dfc Koppen climates), while in others (Am, BWh, Cfa, and Csb Koppen climates) active measures would be necessary to guarantee comfort. In their study of four climate change scenarios, Nik & Sasic Kalagasidis [11] concluded that in Stockholm heating demand would descend to lower values than in 2011 at the end of the study period, while cooling demand would increase in small amounts and overheating would have to be mitigated by natural ventilation measures. Wang et al. [12] also presented results with increases in cooling demand in Australian cities. They warned that the results of the simulations were conditioned by uncertainties inherent in climate models and GHG emission scenarios and by new behavioural trends in the adaptation of users to climate change. Zhu et al. [13] also pointed to the major impacts of climate change on the energy performance of buildings in Shanghai, because of its direct and significant effects on thermal loads and HVAC systems. Dodoo & Gustavsson [14] studied strategies for reducing cooling demand in Växjö, concluding that overheating will be increasingly important in future scenarios. Rubio-Bellido et al. [6] evaluated the effect of climate change in service sector buildings, varying the shape and compactness of building plans with the goal of optimizing energy efficiency in Chilean cities. They concluded that optimization of the factor ratio (FR) and the window-to-wall ratio (WWR) would be insufficient in themselves and that energy demand would increase. Invidiata and Guisi [15] investigated comfort conditions and heating and cooling energy demand in two different climates in Brazil. It provides a significant reduction in energy consumption combined cooling and heating. However, Hooff et al. [18] by means of dynamic simulations estimate that necessary cooling energy can be limited to approximately 70% when using sun protection or additional natural ventilation, in a terraced house, in Netherland. Similar study has been done by Huang and Hwang [16] in a typical residential building in Taipei proving that a combination of passive strategies is necessary to reduce the effects of climate change on the use of cooling energy. Finally, we have also taken into consideration Pierangioli et al. [8]. In the Mediterranean climate, passive strategies can vary over time, in a medium and long term, according to their calculations.

In this paper, the influence of climate change on energy demand in a residential house is investigated in a Mediterranean climate. Global Circulation Models (CNRM-CM5 and MPI-ESM-LR), under two emission scenarios (RCP4.5 and RCP8.5), downscaled and regionalized by the Spanish Meteorological Agency, are used to generate four temperature projections. It follows a sequenced process in which a total of eight energy improvement measures are modelled: six passives (infiltration, insulation thickness, glazing and frame type, window area, shading devices and natural cross ventilation). In addition, two active ventilation measures (mechanical ventilation and a heat recovery system) are included as a strategy to reach net-zero energy building (NZEB) standards in the most extreme climate projections. Based on the outcomes of Global Circulation Models, energy simulations obtained by means of TRNSYS tools in each climate change scenario are considered.

A further theme of this work concerns energy consumption in buildings over recent decades [20]; an issue of global concern reflected in European directives that have been established to achieve nearly-zero energy building through reductions in the energy consumption of buildings [21]. So, the effects of climate change on a house that complies with current building standards in Spain are analysed in the context of improvements introduced to convert the house into a low-energy consumption dwelling. The different improvements are proposed to analyse how they affect changes in energy demand and to assess their effectiveness over the years.

Ref.	Target	Year	Typology	Location	Koppen Climate	GCMs (Scenarios)	Conversion method	Simulation tool
[6]	Reduce energy demand	2020 2050 2080	Office building	Chilean cities	BWk; Cfb Csb; ET	HadCM3 (A2a; A2b; A2c)	Morphing	MS Excel Visual basic
[7]	Energy consumption	2080	Hotel; mall; residential; hospital	US cities	Am; BWh; Cfa; Csb; Dfa; Dfb; Dfc	HadCM3 (A1F1; A2; B1)	Morphing	Energy Plus
[8]	Passive adaptation	2036-2065 2066-2095	Detached house Flat in apartment block Office building	Firenze (Italy)	Csa	COSMO CLM (RCP8.5)	Morphing	Design Builder
[9]	Energy use at sub-national level	2005 2020 2035 2050 2065 2080 2095	50 representative state buildings	USA	Bwh, BSh, BWk, BSk, Csa, Csb, Cfa, Cfb, Dfa, Dfb, Dfc, Dwa, Dwb, Dwc, Dsa, Dsb, ET	GCAM USGS CASCaDE A1, A2	GCAM system	HDD-CDDs
[10]	Passive measures	2070	Residential	Adelaide; Australia	Csb	CSIRO (A1B(90p) B1(90p))	Morphing	AccuRate
[11]	Energy demand	1961 to 2100	Residential	Stockholm (Sweden)	Dfb	ECHAM5; CCSM3; CNRM; HadCM3; IPSL (A1B; A2; B1)	Not specified	Simulink (Matlab) DesignBuilder
[12]	Energy demand	2050 2100	Residential	Australian cities	Aw; BWh; Cfa; Cfb	CSIRO (A1B; A1F1; A1T)	Morphing	AccuRate
[13]	Regional future weather	2000 to 2089	High-rise office building; hotel; shopping mall	Shanghai (China)	Cfa	HadGEM2-CC (S1; S2; S3)	Morphing	Energy Plus
[14]	Primary energy demand	2050 2090	Apartment buildings blocks	Växjö (Sweden)	Dbf	HadGEM2 (RCP4.5; RCP8.5)	Morphing	VIP+ StruSoft software
[15]	Energy demand Passive strategies	2020, 2050, 2080	Single-story social dwelling	Brasilian cities	Csc Csb Af	HadCM3 A2	Morphing	Energy Plus
[16]	Energy demand Passive strategies	2020, 2050, 2080	Top floor Apartament	Taipei (Taiwan)	Csc	MICO3.2-MED A2, A1B, B1	Morphing	EneryPlus
[17]	Heating and cooling demand	2000-2100	Residential sector	Global scale	26 regions	TIMER global energy model	not applicable	HDD-CDDs
[18]	Insigh in th energy demand for cooling and effects when passive strategies	2006	Terraced House	De Bilt (Netherland)	Cfa	Not applicable	2006 Warmer year than normal as a future summer	EnergyPlus

Table 1. Summary of climate-change impacts on building heating and cooling energy demand in the literature. This table is based upon a survey of published research but is not intended to be exhaustive.

2. Methodology

2.1. Generation of weather data through the modelling of scenarios

The climate in Valencia according to the Köppen-Geiger classification is Csa (Warm temperate climate with dry and hot summers), known as a Mediterranean climate [19]. For the referenced location, weather data files were obtained from the Meteonorm® Database exported into TM2 format. This file was used to model the so-called "Base Scenario", the data file that contains average climatic readings over the period 1961-1990; from which data were extracted on Global Horizontal Solar Radiation (GHR, Wh/ sqm), Relative Humidity (RH,%), Dry Bulb Temperature (DBT, ^{o}C), wind velocity (m/s) and wind direction.

Global Circulation Models (GCM), under two emission scenarios (RCP4.5 and RCP8.5), as proposed in the Fifth IPCC Assessment Report (AR5) were used. These models were downscaled and regionalized by the Spanish Meteorological Agency (© AEMET), obtaining four temperature projections. Temperature series were supplied by the CNRM-CM5 and MPI-ESM-LR models.

The existence of historical climatic data for the location has allowed to use techniques of analog statistical downscaling models (SDMs) relating the large-scale data of global climatic models with climatic data at local or regional scale. This method has made it possible to simplify the calculations in relation to the use of dynamic regionalization projection procedures [22].

Climate models on a continental scale are based on physical principles and are spatially projected to predict future climate trends [12] under different hypotheses or emission scenarios. Selecting a GCM model is no easy task, given the variety of those available. Moreover, the IPCC is yet to establish a single model when considering the strengths and weaknesses of various GCMs. Hence, multiple GCM models were considered:

- CNRM-CM5: this model was used to perform experiments in the framework of the Coupled Model Intercomparison Project (CMIP5), Centre National de Recherches Météorologiques [11,12].

- MPI-ESM-LR, Max-Planck-Institute Earth System Model developed at the Max-Planck Institute for Meteorology in Hamburg, Germany, with different resolutions of MPIOM (MPI-ESM-LR, -MR); the low-resolution (LR) version of MPI-ESM (MPI-ESM-LR) was used over a wide range of CMIP5 simulations to allow for inferences across the whole experimental design of CMIP5 [23].

Simulation studies that calculate the trends of the CIMP5 models, individually and jointly have been considered for the selection of these global climate models used [24,25]. These studies check different values and trend, for the estimation of global warming. Ensemble modelling established a warming of 0.64 ° C / century, very close to the value 0.61 ° C / century calculated with observation data of GISTEMP and HadCRUT4 for the period 1901-2000 [24].

Analysing these studies, it is verified that the models CNMR-CM5 and MPI-ESM-LR are valid for their use in Mediterranean climates and present contrary tendencies in the prediction of temperature values for global warming. Also, the first model tends to soften the heating effects and the second overestimates it. Together, they represent an average trend of 0.68 ° C / century, very close to 0.64 ° C / century, which means the average trend of the 24 models that have been compared in these studies.

Considering these characteristics, the selection of global climate models for the realization of our study has been focused on earth system models CNMR-CM5 and MPI-ESM-LR, among the models that have been the subject of CIMP5 in the process of the Fifth IPCC Evaluation Report (AR5).

The IPCC has developed new climate path series – Representative Concentration Pathways (RCPs) for the preparation of AR5 [26]. The number after the “RCP” refers to the intensity of radiative forcing (cumulative measure of human emissions of GHGs from all sources expressed in Watts per square meter in the tropopause due to human activity in 2100) recorded in the available literature, i.e. from 2.6 to 8.5 W/ m^2 [27], as listed in Table 2. The four selected RCPs were considered representative of the literature and included one mitigation scenario leading to a very low forcing level (RCP2.6), two medium stabilization scenarios (RCP4.5/RCP6) and one very high baseline emission scenario (RCP8.5) [27]. RCP4.5 is regarded as the most likely scenario among researchers [13]. Radiative forcing stabilizes at 4.5 W/m^2 with no overshoot after 2100 as strategies are deployed to reduce greenhouse gases [14].

Name	Radiative forcing	Path shape
RCP8.5	>8.5 W/m^2 in 2100	Rising
RCP4.5	~4.5 W/ m^2 at stabilization after 2100	Stabilization without overshoot

Table 2. Description of Representative Concentration Pathways (RCPs).

Having selected two emission scenarios, the projections of the climate models were used to estimate the energy requirements of a conventional detached house. Typical Meteorological Year (TMY) weather files for the location of the city were composed using the weather data from 1961 to around 1990. The 'morphing' approach was employed, in order to obtain future weather data files (monthly-mean local ambient temperature, relative humidity and solar radiation). Projected changes in the weather data from 1990 to 2100, in relation to two GCMs, were then described in Eqs. (1) and (2). The 'morphing' approach involves three generic operations: a shift; a linear stretch; and the combination of a shift and a stretch. A combination of the shift and the stretch may be used for ambient temperature to reflect changes in the daily mean as well as the maximum and minimum daily temperatures [12].

$$x = x_0 + \Delta x_m + \alpha_m \times \left(x_0 - \langle x_0 \rangle_m\right) \quad (1)$$

$$x = \langle x_0 \rangle_m + \Delta x_m + \left(1 + \alpha_m\right) \times \left(x_0 - \langle x_0 \rangle_m\right) \quad (2)$$

where Δx_m is the absolute change in the monthly-mean value of the variable for month *m*, and, α_m is the fractional change in the monthly-mean value for month *m* [28].

The 'morphing' approach is based on the studies of Belcher et al. [28] that constitute the TM2 files for the Base Scenarios. They were morphed with scenarios CNRM-CM5 and MPI-ESM-LR and two RCPs (RCP4.5 and RCP 8.5) to obtain data sets for the in two periods: 2048-2052 and 2096-2100, with the same time span. Thus, eight future climatic scenarios were in total produced and altogether the database held nine climatic scenarios for the purposes of this research.

2.2. Test Models

A typical model of a detached house is used in this study for the estimation of energy demand. The initial model (Model 1) was developed in compliance with Spanish constructive standards [29].

Several strategies and models were developed in the process of reducing energy demand. All the chosen energy strategies were efficiency measures for optimization of the Base Scenario. A historical climate dataset of the zone was used in the optimization of energy gains and losses. In addition, all the models were developed in a sequenced process, gradually introducing the energy efficiency measure into each model, as shown in (Figure 1).

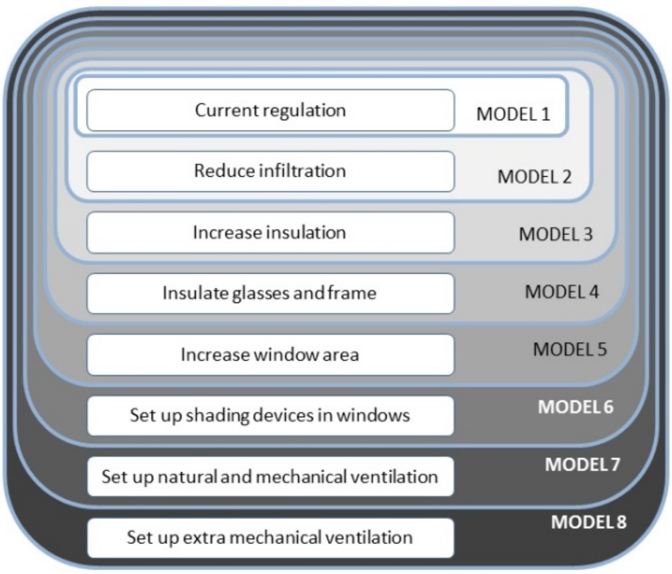

Figure 1. House models and sequences used in this work.

The energy efficiency measures under study were classified into eight different models (Figure 1): both passive measures, such as, infiltration (Model 2), insulation thickness (Model 3), glazing and frame type (Model 4), window area (Model 5), shading devices (Model 6) and natural cross ventilation (Model 7), and active measures, such as extra mechanical ventilation and heat recovery systems (Model 8).

The optimization strategy firstly consisted of reducing heating demand as far as possible using the following measures: infiltration, insulation thickness, glazing and frame type, window area, and heating recovery control.

Once the lowest possible heating demand was achieved, the same process was followed for cooling demand, studying the implementation of the following measures: shading devices, natural cross ventilation and control of extra mechanical ventilation. Hence, the choices at this stage lead to as many reductions in cooling demand as possible, with no considerable increases in heating demand.

2.2.1. Building Type

The energy demand of a conventional detached house is usually greater than a block of apartments. Accordingly, total demand for a single-family house usually doubles the demand of a building dwellings and its heating consumption is up to four times higher. So these buildings, which represent only 33% of the total number of houses in Spain, determine 46% of consumption in the sector, while apartment blocks determine 53% [30]. Currently these types of houses are in high demand among people wishing to live in peripheral urbanized areas of a city. Hence, the conventional detached house that is considered in this study.

2.2.2. Location and Climate

The model is located in the city of Valencia (latitude 39.29 N, longitude -0.23 W) on the Mediterranean coast of Spain. Its local Mediterranean climate is characterized by dry and hot summers and warm and wet winters. Average energy demand of the houses in this region is usually lower than the national average [30]. The effects of climate change in in two periods: 2048-2052 and 2096-2100, with the same time span will be obtained in this warm Mediterranean climate (Csa Köppen-Geiger classification) by using different models of a single-family detached house.

2.2.3 Geometry

The house has a square plan on the ground floor and a rectangular plan on first floor and its alignment is North-South (Figure 2). Its total surface area amounts to 101.79 m^2: the ground floor with the communal space (living room and kitchen) and one room measuring 58.79 m^2; and the first floor with two (bedrooms) occupying 43 m^2. The global area of the different façades is 37.93 m^2 to the North, 30.23 m^2 to the South, 30.84 m^2 to the East, and 30.84 m^2 to the West. The initial model has a total window area of 0.75 m^2 to the North, 2.46 m^2 to the South, 3.1 m^2 to the East and 0.7 m^2 to the West. The window area is considered, in order to reduce energy demand. The house has a flat roof of 16.6 m^2, a pitched roof of 43 m^2 and an under-roof floor space of 58.79 m^2. Model geometry and orientation were not changed.

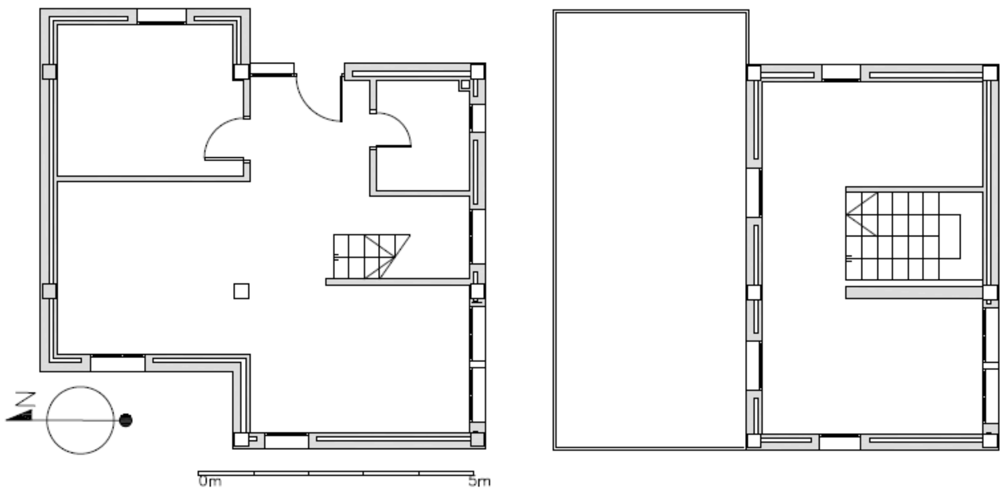

Figure 2. Schematic plan of ground and first floor.

2.2.4 Constructive System

The initial model of the residence (Model 1) and its envelope design complied with Spanish constructive standards [29] and was used to assess the optimum building. This model was optimized until the Zero Energy Demand was reached in the Base Scenario. Table 3 shows the different U-values and infiltrations.

	Analyzed models				
	Envelope	*Model 1*	*Model 2*	*Model 3*	*Models 4 to 8*
U-value W/m²K	*Façade*	1	1	0.232	0.232
	Floor	0.65	0.65	0.185	0.185
	Roof	0.65	0.65	0.185	0.185
	Window-frame	5.7	5.7	5.7	2.2
	Window-glass	3.44	3.44	3.44	2.48
Infiltration h^{-1}		7.75	0.6	0.6	0.6

Table 3. Thermal transmittance U-value (W/m^2K) and infiltration level (50Pa air changes (1/h)) for the building model under consideration.

An element of the building was modified in each model, to analyse a complete range of reductions in energy demand. Firstly, the building parameters were modified for an analysis of enclosure insulation and, thereby, their U-values. Infiltrations in the form of surface openings to the exterior, and solar protection were also considered. Air leaks were calculated with TRNSFlow and several large openings were introduced in the wall. To consider the envelope airtightness in the model affected by weather conditions (wind and temperature), it is necessary to define leakage openings on the walls. In the model have been calculated the equivalent large opening by an equivalent flow through a flat plate orifice [31]. To model that air leakage changes depending on the wind speed and direction, a model was introduced in TRNSYS with TRNSFlow. The model comprises a heavy construction of ceramic brickwork and concrete that are the most commonly used materials in this area. In addition, passive cooling systems such as natural ventilation and bypasses in the air-conditioning system were also analysed.

2.2.5 Internal and External Loads and Operation Schedule

Several internal heat gains were considered in the models according to their use. The same parameter was used in all models, which implies 24 hours of house activity with different loads. The lighting load was 2.25 W/m^2 when the solar radiation was lower than 120 W/m^2 on a horizontal plane. A 12 W refrigerator and a set of kitchen appliances consuming 329 W were used throughout the week for 3 hours a day. The bedrooms were also occupied 7 hours a day and occupancy of the living room changed at weekends. Maximum occupancy from Monday to Friday was considered between 8 pm and 7 am, while 50% occupancy was considered over the rest of the day. In contrast, the maximum occupancy at the weekend was considered to be from 11 pm to 9 am with an occupancy of 25% over the remainder of the day. External heat gains depending on the window area were considered throughout the whole year and 0.6 renovations per hour were considered as infiltrations.

2.3. Energy House Model

Firstly, the energy house model was obtained using TRNSYS 17 simulation software [32], through its multi-zone option standard model (known as Type 56), to calculate the energy demand. The materials and the window glazing were defined in the Type 56 envelope model. Likewise, the necessary characteristics of thermal behaviour in the house were set for performing the analysis; limits on comfort temperatures and internal gains (people, equipment or lights) in thermal zones, and the shading percentages of window. The indoor temperature of the house was set at equal to or above 20° C and equal to or below 26° C throughout the year with heating and cooling systems.

TRNFlow, a TRNSYS tool, was implemented in the Type 56 model, in order to define mechanical ventilation and natural cross ventilation. The air leaks were also considered in the Type 56 model as large openings. There are no constructive standards that refer to air leaks in the model home used in this study, for which reason the figure of 7.75 renovations per hour, as in [31], is a logical estimate of their value. This procedure was previously commented in [33,34]. Type 34 controls the conditions for the shading devices that are also defined. Type 99, which allows the modification of datasets as a text file, was used to introduce the weather data.

The models that used the above-mentioned parameters in this study are described above**:**

- Model 2: Air leaks are reduced to 0.6 renovations per hour. These values are measures of infiltrations at 50Pa pressure difference between the outside and the inside. For improved buildings, the value of infiltrations required by the Passivhaus Standard has been considered, which limits the certification of the building with a Blower Door test result to 50Pa of 0.6 renovations/hour.
- Model 3: The U-value of the envelope is reduced by increasing the insulation thickness. The insulation material under consideration is mineral wool with a thermal conductivity of 0.04 W/m K, the optimal insulation considered in this location is a thickness of 0.16 m for walls and a thickness of 0.20 m for roofs and floors. Table 3 shows the relevant global U-values.
- Model 4: covers the window type; glass and frame. The initial model has clear glass 4/6/4 with a U-value of 3.44 W/m^{2}K that is changed to low emissivity 4/8/4 glass with a

U-value of 2.48 W/m²K. Likewise, aluminium window frames with a U-value of 5.7 W/m²K are switched for Polyvinyl Chloride, PVC, with 5-chamber plastic window profiles with a U-value of 2.2 W/ m²K.

- Model 5. In this model, the window area on the South façade is increased to 6 m², the other facades have the same window area. The areas are summarized in table 4.
- Model 6. Several shading devices are considered on the East, the South, and the West façades using external shading that leaves the windows totally shaded. The shading factor is used at different periods during the year. In summer, from 1st of June to 31st August, the control for the shading devices is implemented from 8 a.m. to 8 p.m. when the outdoor temperature is higher than 22 ºC. In spring and autumn from 1st of March to 31st May and from 1st September to 31st November the control for the shading devices is implemented from 8 a.m. to 8 p.m. when the outdoor temperature is higher than 22 ºC and indoor temperature higher than 23 ºC.
- Model 7. In this model, a high-efficiency heat-recovery ventilation systems with 75% efficiency is considered. The recovery system works in summer and winter. In summer, where cooling demand is connected and when the indoor temperature is higher than 26 ºC, both the doors and the windows are closed, and the indoor temperature is lower than the outdoor temperature. In winter, where heating demand is connected and when the indoor temperature is lower than 21 ºC, doors and windows will be closed, and the indoor temperature is higher than the outdoor temperature. Natural cross ventilation is also considered in this model. In this case, windows and doors are opened when outdoor temperatures are between 21 ºC and 25 ºC. This model only works in spring, summer and autumn. Besides, door and window openings are changed depending on the HVAC requirements.
- Model 8. Extra mechanical ventilation is considered in this model. It is activated in summer, spring, and autumn when doors and windows are closed, and in summer, from

1st of June to 31st August, if outdoor temperature are lower than 25 ºC. In this case ventilation airflow (0.8 renovation/h) increases until the value is doubled. In spring and autumn, from 1st of March to 31st May, and from 1st September to 31st November, the control is activated if the outdoor temperature is lower than 21 ºC, but when cooling requirements exist, then the ventilation airflow (0.8 renovation/h) is increased by 1.6 times its original value.

		Model 1 to 5		Model 6 to 8	
	A_{tot} (m^2)	**A_{wall} (m^2)**	**A_{window} (m^2)**	**A_{wall} (m^2)**	**A_{window} (m^2)**
East	30.84	27.74	3.1	27.74	3.1
South	30.23	27.83	2.4	24.23	6.0
West	30.84	30.14	0.7	30.14	0.7
North	37.92	37.17	0.75	37.17	0.75

Table 4. Wall and window areas considered for different models.

3. Results

3.1. Climate variation

Weather data under the scenarios CNRM-CM5 and MPI-ESM-LR were obtained for the location after applying morphing procedure, in which two emission scenarios (RCP4.5 and RCP 8.5) were considered. Projected changes in the weather data from 1990 were transformed to represent the forecasted average climate conditions in two periods: 2048-2052 and 2096-2100, with the same time span.

So, eight future scenarios (two GCM x two RCPS x two periods) were compared with the Base scenario. For greater clarity, these predictions have been grouped by year (Table 5) and by month (Figure 3). The following tendencies can be outlined in relation to these changes. The average Dry Bulb Temperature (DBT) increased in all scenarios. However, the highest increases are predicted for RCP8.5 in 2096-2100 period: 3.60 °C under the CNRM-CM scenario and 5.33 °C under the MPI-ESM-LR scenario, while for RCP4.5 temperatures would increase by 1.56 °C under the CNRM-CM scenario and by 2.62 °C under the MPI-ESM-LR scenario.

	CNRM-CM5		MPI-ESM-LR	
Year	RCP4.5	RCP 8.5	RCP4.5	RCP 8.5
Base Scenario	16.85		16.85	
2048-2052	17.50	18.18	18.72	19.45
2096-2100	18.26	20.29	19.31	22.02

Table 5. Annual average for dry bulb temperature, “Base Scenario”, in two periods: 2048-2052 and 2096-2100 under scenarios CNRM-CM5 and MPI-ESM-LR and for Representative Concentration Pathways RCP4.5 and RCP 8.5.

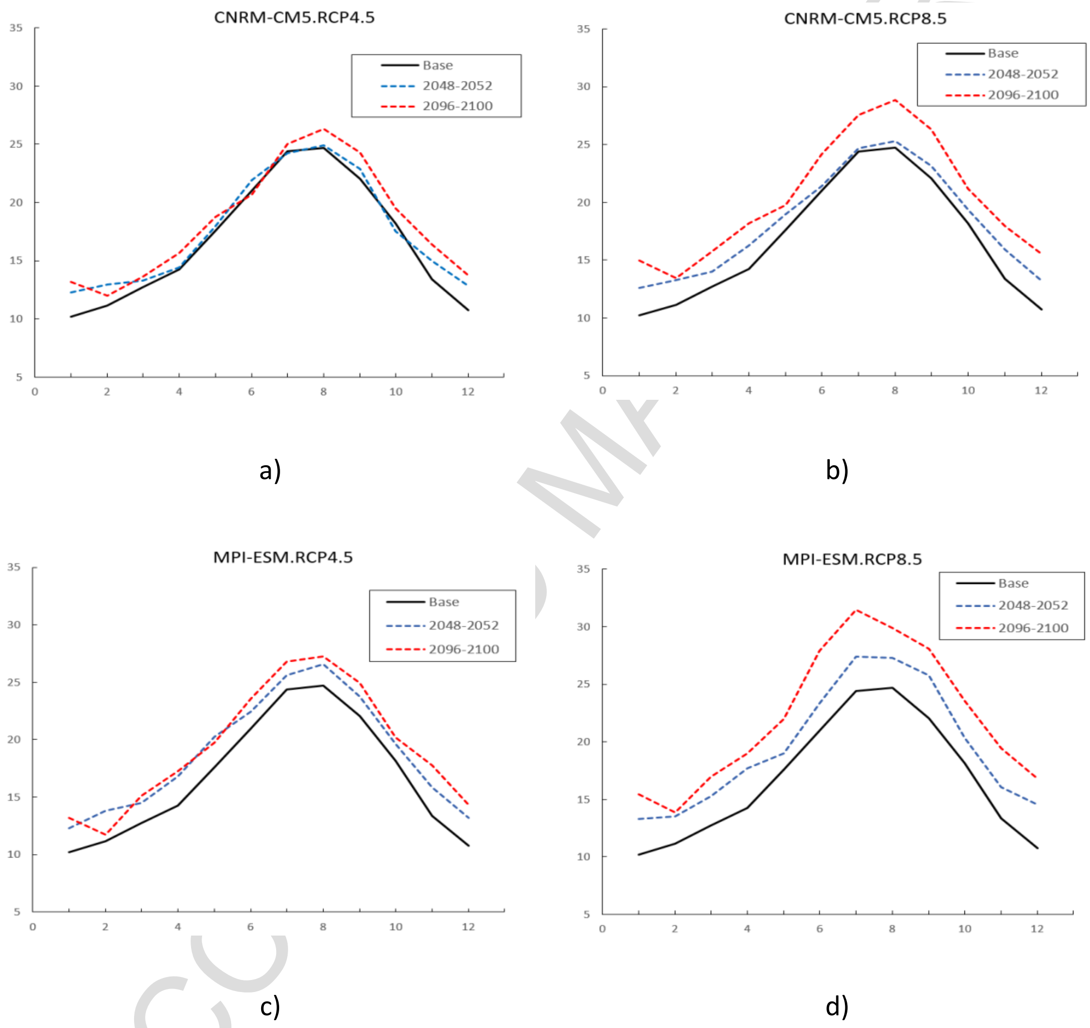

Figure 3. Monthly average dry bulb temperature (DBT) for the Base Scenario, in two periods: 2048-2052 and 2096-2100 under the following scenarios: a) CNRM-CM5 and RCP4.5; b) CNRM-CM5 and RCP8.5; c) MPI-ESM-LR and RCP4.5; d) MPI-ESM-LR scenario and RCP8.5.

Figure 3 shows monthly average temperatures for different scenarios compared to the Base Scenario. In all cases, except for scenario MPI-ESM RCP 8.5 in which the average monthly temperature increases in each month: temperatures rise or fall randomly during the first six months, although the temperature always rises during the last six. Table 6 shows average monthly difference for dry bulb temperature in two periods: 2048-2052 and 2096-2100, with the same time span under scenarios CNRM-CM5 and MPI-ESM-LR and for Representative Concentration Pathways RCP4.5 and RCP8.5 compared to "Base Scenario".

	2048-2052				2096-2100			
	CNRM-CM5		MPI-ESM-LR		CNRM-CM5		MPI-ESM-LR	
Month	RCP4.5	RCP 8.5	RCP4.5	RCP 8.5	RCP4.5	RCP 8.5	RCP4.5	RCP 8.5
1	2.04	2.37	2.09	3.10	2.99	4.74	2.98	5.22
2	1.80	2.14	2.65	2.37	0.83	2.32	0.57	2.70
3	0.59	1.27	1.78	2.53	0.89	3.06	2.37	4.25
4	0.19	2.03	2.57	3.44	1.41	3.91	2.99	4.74
5	0.37	1.41	2.67	1.41	1.15	2.16	2.17	4.38
6	0.91	0.41	1.45	2.36	-0.33	3.15	2.56	6.90
7	-0.15	0.28	1.23	3.03	0.61	3.14	2.41	7.05
8	0.18	0.58	1.89	2.56	1.64	4.14	2.53	5.17
9	0.80	1.10	1.69	3.69	2.24	4.23	2.86	6.02
10	-0.67	1.20	1.45	2.16	1.34	2.98	2.03	5.41
11	1.58	2.55	2.49	2.67	3.01	4.59	4.39	6.06
12	2.10	2.48	2.42	3.79	3.00	4.78	3.60	6.03

Table 6. Monthly average difference for dry bulb temperature, in periods 2048-2052 and 2096-2100 under scenarios CNRM-CM5 and MPI-ESM-LR and for Representative Concentration Pathways RCP4.5 and RCP 8.5 compared to "Base Scenario".

Climate change has been analysed as a function of degree-hours over one year. Figure 4 shows the number of heating and cooling degree-hours for a year (also sum of both), using set point temperatures (20 and 26 °C) as comfort parameters. The number of heating degree-hours shows the heating that is switched on inside the house when the temperature is below 20 °C. In this case, the number of heating degree-hours decreases over the year. The number of cooling degree-hours shows a demand for cooling as outdoor temperatures are above 26° C. It is worth mentioning that the total number of (heating and cooling) degree-hours is quite similar due to the increase in cooling degree-hours that is compensated by a decrease in heating degree-hours.

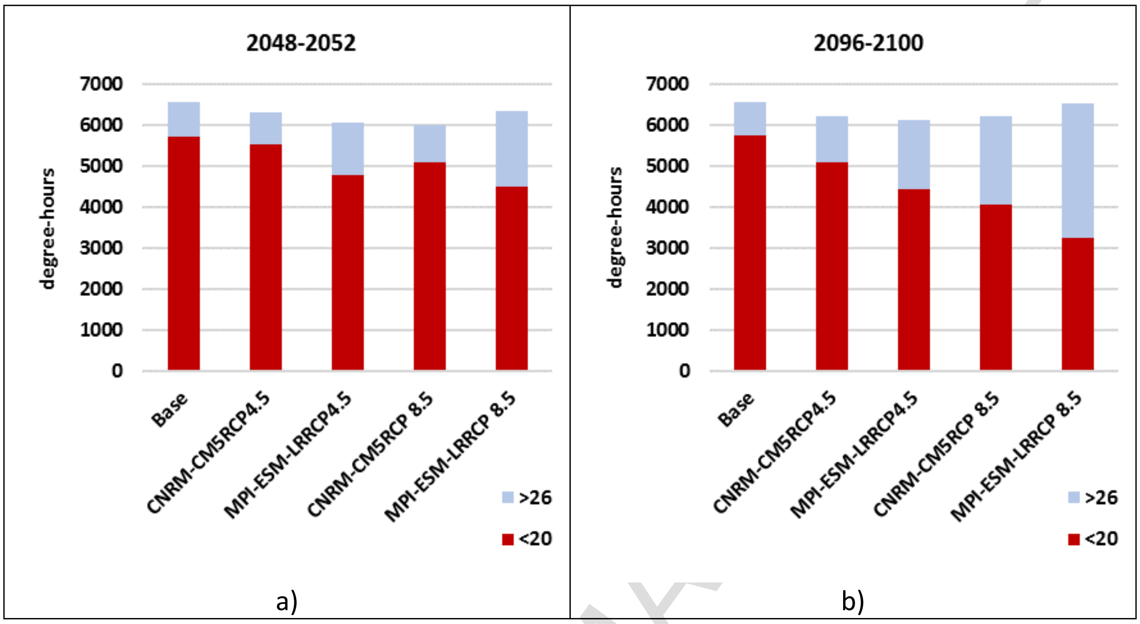

Figure 4. Number of heating (red) and cooling (blue) degree-hours in one year, using set-point temperatures (20 ºC and 26 ºC) for a) 2048-2052 and b) 2096-periods, in accordance with scenarios CNRM-CM5 and MPI-ESM-LR and the Representative Concentration Pathways RCP4.5 and RCP 8.5.

3.2 Effects on annual energy demand

Figure 5 shows annual energy demand according to the Base Scenario for the models under consideration. Energy demand for the Base Scenario and Model 1 means that the building is designed in accordance with Spanish regulations [29]. This model has a total annual energy demand of 111.31 kWh/m^2 year, when 85% of the demand is heating demand; this is characteristic of the mild winters and humid summers of Mediterranean climate. The Base Scenario applied to Model 8 shows the effect of all the passive measures where the total energy demand is 2.83 kWh/m²·per year: 77% of the energy is cooling demand and only 23% is for heating the house.

3.2.1. Models analysed

It is worth noting that heating demand in the first model under consideration, a building design in compliance with Spanish regulations, is much higher than cooling demand. Different passive measures have also to be considered (Models 2, 3, 4 and 5), in order to reduce the cooling demand. Active measures, the opposite of passive measures, are also proposed (Table 7).

			MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5	MODEL 6	MODEL 7	MODEL 8
U-value W/m²K	Wall		1.00	1.00	0.232	0.232	0.232	0.232	0.232	0.232
	Roof		0.65	0.65	0.185	0.185	0.185	0.185	0.185	0.185
	Floor		0.65	0.65	0.185	0.185	0.185	0.185	0.185	0.185
	Window	Frame	5.70	5.70	5.7	2.2	2.2	2.2	2.2	2.2
		Glass	3.44	3.44	3.44	2.48	2.48	2.48	2.48	2.48
Air leaks 50Pa			7.50	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Window área m²	North		0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
	South		2.40	2.40	2.40	2.40	6	6	6	6
	East		3.10	3.10	3.10	3.10	3.10	3.1	3.1	3.1
	West		0.70	0.70	0.70	0.70	0.70	0.7	0.7	0.7
Shading devices			no	no	no	no	no	yes	yes	yes
Recovery system 75%			no	no	no	no	no	no	yes	yes
Extra mechanical ventilation			no	no	no	no	no	no	no	yes

Table 7. Parameters used in models analysed in this study.

3.2.2. Passive measures

It is worth noting that heating demand in the first model under consideration, a building design in compliance with Spanish regulations, is much higher than cooling demand. Different passive measures have also to be considered (Models 2, 3, 4 and 5), in order to reduce the cooling demand.

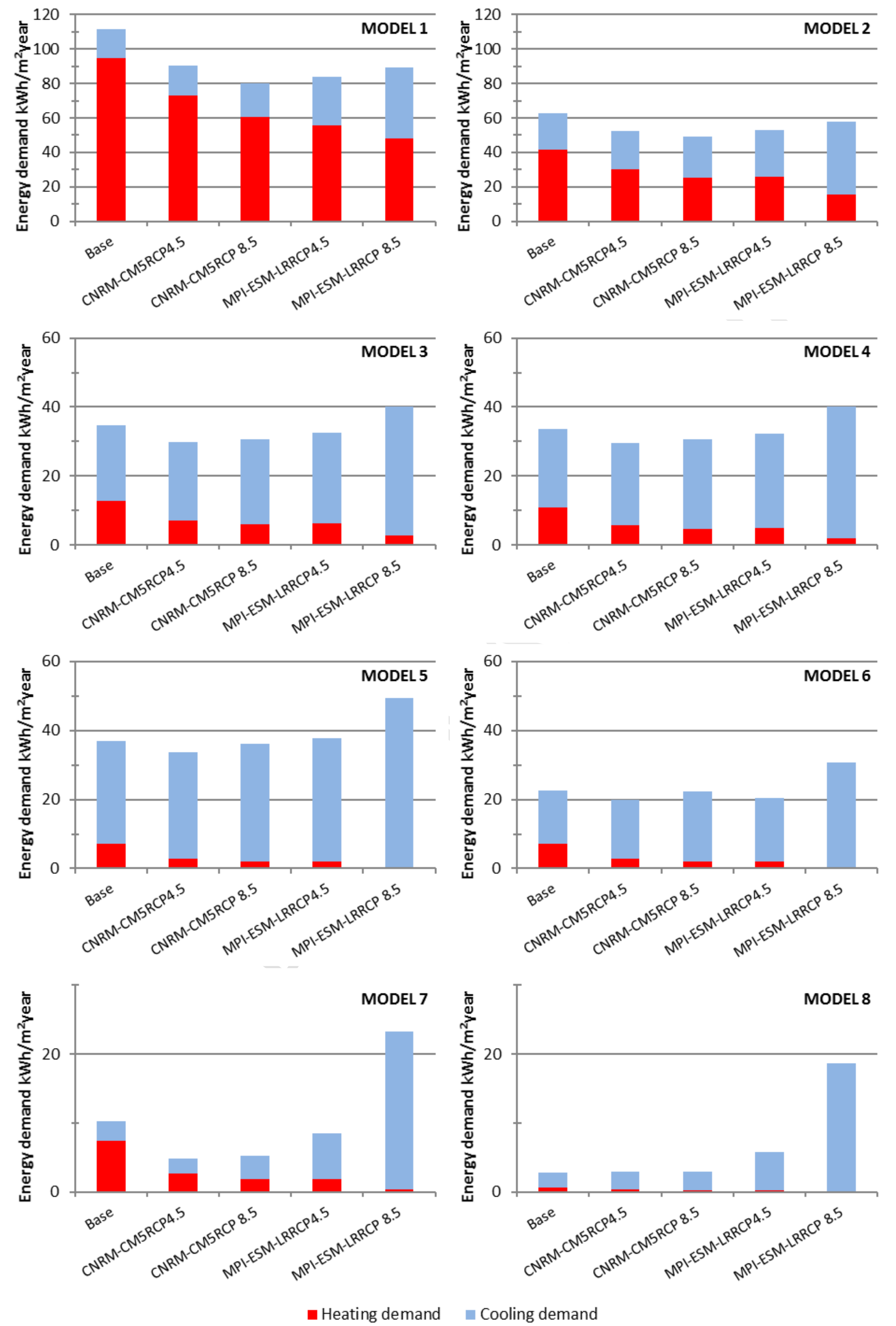

Figure 5. Annual energy demand for the Base Scenario and different models in a window of 2048 to 2052 in accordance with the following scenarios: CNRM-CM5 and RCP4.5; CNRM-CM5 and RCP8.5; MPI-ESM-LR and RCP4.5; and MPI-ESM-LR and RCP8.5.

Climate change in 2048-2052 period decreases energy demand for the Model 1 (Figure 5), as the total number of hours (heating and cooling) degree-hours is very constant (Figure 4). In addition, it can be seen that cooling demand increases and heating demand decreases, which is directly related to the increase in cooling degree-hours and the reduction in heating degree-hours.

In Model 2 (Figure 5), an infiltration level of 0.6 ren/h at 50 Pa was established using the standard PassiveHaus (PH), a construction standard that aims to reduce energy consumption by 90% within dwellings. Compared with the previous model (Table 8), the model 2 reduced energy demand by 44% in the Base scenario (Figure 5), by at least 32% in scenario MPI-ESM-LR RCP 8.5 in 2096-2100 period, and by 42% in scenario CNRM-CM5 RCP4.5 in 2048-2052 period.

Model	Base	2048-2052				2096-2100			
		CNRM-CM5		MPI-ESM-LR		CNRM-CM5		MPI-ESM-LR	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Model 2	44%	53%	56%	52%	48%	52%	48%	48%	33%
Model 3	69%	73%	73%	71%	64%	69%	66%	66%	52%
Model 4	70%	74%	73%	71%	64%	69%	66%	66%	52%
Model 5	67%	70%	67%	66%	56%	63%	59%	59%	41%
Model 6	80%	82%	80%	82%	72%	78%	75%	75%	61%
Model 7	91%	96%	95%	92%	79%	91%	83%	86%	56%
Model 8	97%	97%	97%	95%	83%	94%	86%	89%	65%

Table 8. Percent energy savings compared to the Base Scenario (in periods 2048-2052 and 2096-2100) for scenarios CNRM-CM5 and MPI-ESM-LR and for Representative Concentration Pathways RCP4.5 and RCP 8.5.

In Model 3 the insulation thickness was changed. Compared with the model previous (model 2), this model reduced energy demand by 45% in the Base scenario, by at least 28 % in scenario MPI-ESM-LR RCP 8.5 in 2096-2100 period, and by 43 % in scenario CNRM-CM5 RCP4.5 in in 2048-2052 period (Table 8).

Moreover in Model 4 (Figure 5), the cooling demand is reduced, the heating demand is increased, and there is no significant reduction in annual energy demand. Similar results are obtained in model 5, where the cooling demand is reduced, but the heating demand is increased and energy demand is increased by 10% compared to model 4 in the Base Scenario (Table 8). With regard to model 5, the heating demand (80%) is much higher than the cooling demand (Figure 5). Consequently, Models 6 (shading devices) and 7 (natural cross ventilation) were also developed, in an attempt to reduce the heating demand.

Model 6 compared with the previous model (model 5), reduces energy demand by 39% in the Base Scenario, and there is a reduction of energy demand by at least 34% in accordance with scenario MPI-ESM-LR RCP 8.5 in 2096-2100 period, and a reduction of 46% in accordance with scenario CNRM-CM5 RCP 8.5 in 2048-2052. (Table 8). Heating demand is quite similar to previous model and cooling demand is considerably reduced (50%) (Figure 5).

3.2.3. Active measures

Active measures, the opposite of passive measures, are also proposed. In comparison with model 6, model 7 reduces energy demand in the Base Scenario by 55%, however it is not reduced significantly in scenario MPI-ESM-LR RCP 8.5 in 2096-2100 period, and it is reduced by 59% in scenario CNRM-CM5 RCP 4.5 in 2096-2100 period (Table 8). In this model, heating demand is quite similar to previous model and cooling demand is drastically reduced.

Model 8 uses extra mechanical ventilation with a heat recovery system. Compared with the previous model (model 7), model 8 reduces energy demand in the Base Scenario by 72%, and there is at least a 19% reduction in scenario MPI-ESM-LR RCP 8.5 in 2096-2100 period, and a 30% reduction in scenario CNRM-CM5 RCP 4.5 in 2096-2100 period. In this model, both heating and cooling demand are reduced and heating demand is drastically reduced (90%).

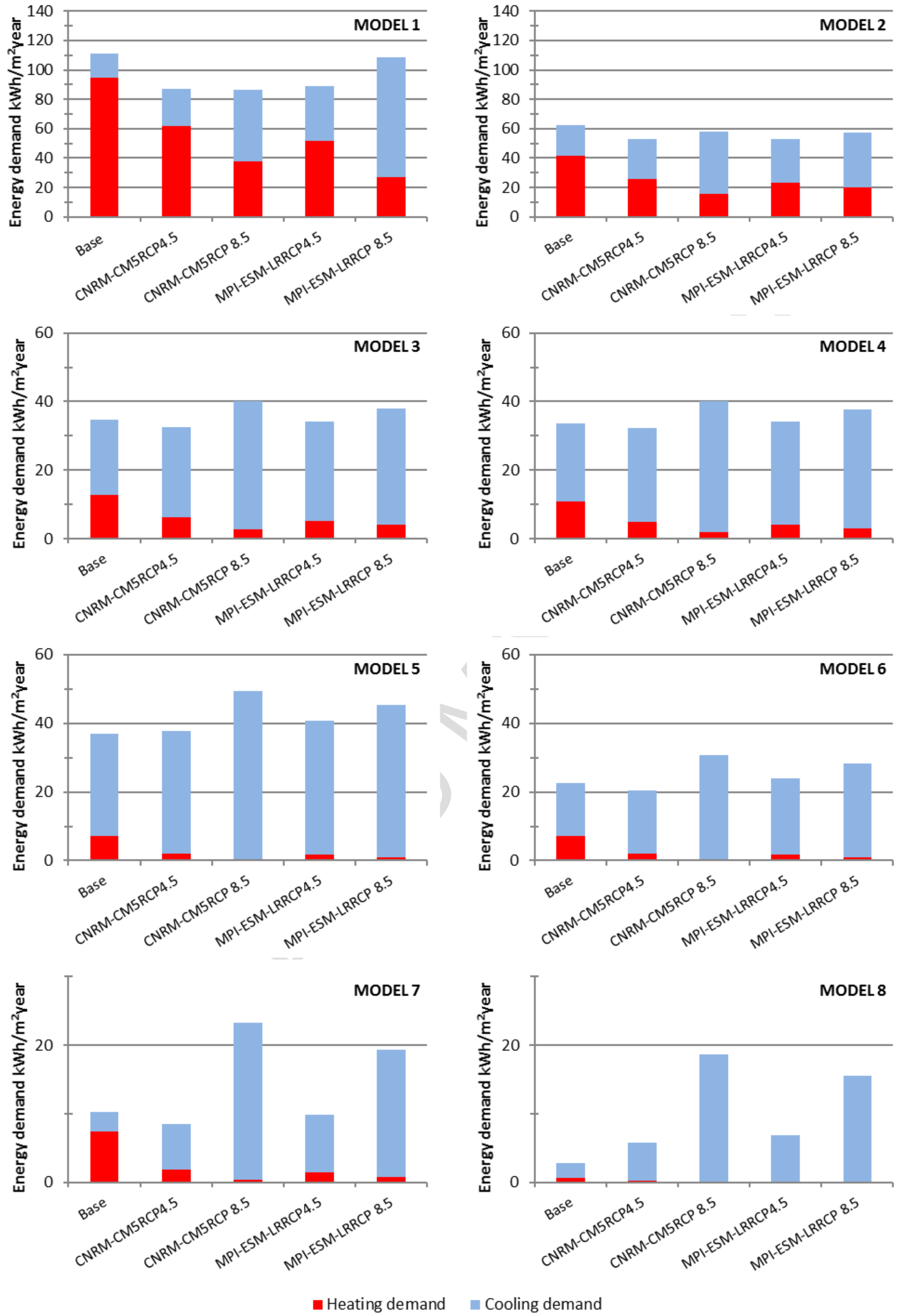

Figure 6. Annual energy demand for the different models in 2096-2100 period, for the Base Scenario and for the following scenarios: CNRM-CM5 and RCP4.5; CNRM-CM5 and RCP8.5; MPI-ESM-LR and RCP4.5; and MPI-ESM-LR and RCP8.5.

3.2.4. Summary for all models

In this section, energy savings due to reductions in energy demand compared to model 1 for each model are shown. Figure 5 shows energy savings for the 2048-2052 period under four scenarios (CNRM-CM5 RCP4.5, CNRM-CM5 RCP8.5, MPI-ESM-LR RCP4.5, and MPI-ESM-LR RCP8.5). In model 8, all the measures are implemented and energy savings of at least 80% are obtained, regardless of the climate scenario for 2048-2052 period, and even energy savings of 95% in the following scenarios: CNRM-CM5 and RCP4.5, CNRM-CM5 and RCP8.5, and MPI-ESM-LR, and RCP4.5.

Figure 6 shows energy savings for 2096-2100 period under four scenarios (CNRM-CM5 RCP4.5, CNRM-CM5 RCP8.5, MPI-ESM-LR RCP4.5, and MPI-ESM-LR RCP8.5). In model 8, all the measures are implemented and energy savings of at least 65% are obtained regardless of the climate scenario in 2096-2100 period, with reductions in energy demand of 89% in scenario CNRM-CM5.

Conclusions

With regard to climate change scenarios, different climatic results have been obtained, according to the scenario under analysis and the variations in the models. In addition, the predicted tendencies in 2048-2052 and 2096-2100 periods have predicted rising temperatures in the climate for Valencia. So, eight future scenarios (two GCM x two RCPS x two periods) were compared with the Base scenario. The average Dry Bulb Temperature (DBT) increased in all scenarios. In all cases, except for some months in scenario CNRM-CM5 and RCP4.5 in which average monthly temperature fail, in general temperatures rise randomly during the year. We can conclude that modelled temperature in future has fluctuations and we cannot assume a constant increment for the whole year.

In this study, the thermal behaviour of a house with different architectural and constructive solutions has been analysed under different climate-change scenarios. The initial model (Model 1) has been explored with a “Base Scenario” taken from TMY2 data. With these values the house has been optimized to obtain the minimum energy demand over one year, to achieve a nearly-zero energy demand building. The different models led us to compare their performance in accordance with the various scenarios under study. The “Model 1” house was developed in accordance with current constructive standards in Spain [29], after which the model was optimized to achieve a house with a very low energy demand in the “Base Scenario”, under the same circumstances as a house that is designed today. Different steps were followed for this optimization process: first, reductions in heating demand and then reductions in cooling demand. All the measures under analysis were passive, except for the extra mechanical ventilation with a fan.

Eight different models for an enhanced house have been analysed in different scenarios. A comparison of the different characteristics of the building under analysis has been completed with passive actions in the various climate scenarios. This thorough analysis has characterized climate change and its influence on the thermal performance of different buildings in a Mediterranean climate. It has contributed to existing knowledge on passive strategies for the performance of the building. Our analysis has shown significant changes in the thermal performance of the building in future climate scenarios and recent climatic conditions. The results have shown that the thermal behaviour of the building differs in each scenario. In all the models, when the external temperature increases, the heating demand decreases significantly while cooling demand and overheating risks increase considerably in future climate scenarios. However, the changes in weather conditions modified global energy demand for all models.

The predicted behaviour of the building was completely different for heating and cooling demand. Cooling demand increased in the future scenario while it decreased completely in scenario 2096-2100 period for Model 8 when there is a nearly-zero energy demand building. The heating demand of Model 5 is zero in the MPI-ESM-LR and CPR8.5 scenarios, when the window area is increased. In these scenarios, the natural ventilation of Model 8 fails to function properly, because of the high outdoor temperatures.

Climate change has therefore been shown to have a direct effect on energy demand in homes. The datasets of projected climate readings have clearly predicted that natural and forced ventilation are the most sensitive to the effects of climate change in these future scenarios. Analysed in models 7 and 8, ventilation has the highest effect of all the increases and decreases in the models under analysis. Measures affecting natural ventilation will have the lowest effect in the future. Specifically, the extra mechanical (fan) ventilation (Model 8) will have almost no effect on nearly-zero demand houses.

Each housing model offers different answers in each scenario, although window shades, increased thermal insulation, and reductions in infiltration have a greater effect in terms of global energy demand. So, if nearly-zero houses are to be obtained in the future scenarios, sound construction that reduces infiltration must always be guaranteed. It can also be said that good isolation is a guarantee of comfort and less energy consumption. In this sense, the effect of sunlight and solar energy, evident in the modifications to window frames and glazing in Model 4 that had the least effect on global demand, is an essential aspect to analyse for any reduction in global energy demand.

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References

[1] IPCC. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 2014. doi:10.1017/CBO9781107415324.004.

[2] Radhi H. Evaluating the potential impact of global warming on the UAE residential buildings - A contribution to reduce the CO2 emissions. Build Environ 2009;44:2451–62. doi:10.1016/j.buildenv.2009.04.006.

[3] Rosenthal DH, Gruenspecht HK, Moran E. Effects of global warming on energy use for space heating and cooling in the United States. vol. 16. 1994.

[4] SCOTT MJ, WRENCH LE, HADLEY DL. Effects of Climate Change on Commercial Building Energy Demand. Energy Sources 1994;16:317–32. doi:10.1080/00908319408909081.

[5] Li DHW, Yang L, Lam JC. Impact of climate change on energy use in the built environment in different climate zones - A review. Energy 2012;42:103–12. doi:10.1016/j.energy.2012.03.044.

[6] Rubio-Bellido C, Pérez-Fargallo A, Pulido-Arcas JA. Optimization of annual energy demand in office buildings under the influence of climate change in Chile. Energy 2016;114:569–85. doi:10.1016/j.energy.2016.08.021.

[7] Wang H, Chen Q. Impact of climate change heating and cooling energy use in buildings in the United States. Energy Build 2014;82:428–36. doi:10.1016/j.enbuild.2014.07.034.

[8] Pierangioli L, Cellai G, Ferrise R, Trombi G, Bindi M. Effectiveness of passive measures against climate change: Case studies in Central Italy. Build Simul 2017;10:459–79. doi:10.1007/s12273-016-0346-8.

[9] Zhou Y, Clarke L, Eom J, Kyle P, Patel P, Kim SH, et al. Modeling the effect of climate change on U.S. state-level buildings energy demands in an integrated assessment framework. Appl Energy 2014;113:1077–88. doi:10.1016/j.apenergy.2013.08.034.

[10] Karimpour M, Belusko M, Xing K, Boland J, Bruno F. Impact of climate change on the design of energy efficient residential building envelopes. Energy Build 2015;87:142–54. doi:10.1016/j.enbuild.2014.10.064.

[11] Nik VM, Sasic Kalagasidis A. Impact study of the climate change on the energy performance of the building stock in Stockholm considering four climate uncertainties. Build Environ 2013;60:291–304. doi:10.1016/j.buildenv.2012.11.005.

[12] Wang X, Chen D, Ren Z. Assessment of climate change impact on residential building heating and cooling energy requirement in Australia. Build Environ 2010;45:1663–82. doi:10.1016/j.buildenv.2010.01.022.

[13] Zhu M, Pan Y, Huang Z, Xu P. An alternative method to predict future weather data for building energy demand simulation under global climate change. Energy Build 2016;113:74–86. doi:10.1016/j.enbuild.2015.12.020.

[14] Dodoo A, Gustavsson L. Energy use and overheating risk of Swedish multi-storey residential buildings under different climate scenarios. Energy 2016;97:534–48. doi:10.1016/j.energy.2015.12.086.

[15] Invidiata A, Ghisi E. Impact of climate change on heating and cooling energy demand in houses in Brazil. Energy Build 2016;130:20–32. doi:10.1016/j.enbuild.2016.07.067.

[16] Huang KT, Hwang RL. Future trends of residential building cooling energy and passive adaptation measures to counteract climate change: The case of Taiwan. Appl Energy 2016;184:1230–40. doi:10.1016/j.apenergy.2015.11.008.

[17] Isaac M, van Vuuren DP. Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. Energy Policy 2009;37:507–21. doi:10.1016/j.enpol.2008.09.051.

[18] van Hooff T, Blocken B, Timmermans HJP, Hensen JLM. Analysis of the predicted effect of passive climate adaptation measures on energy demand for cooling and heating in a residential building. Energy 2016;94:811–20. doi:10.1016/j.energy.2015.11.036.

[19] Kottek M, Grieser J, Beck C, Rudolf B, Rubel F. World map of the Köppen-Geiger climate classification updated. Meteorol Zeitschrift 2006;15:259–63. doi:10.1127/0941-

2948/2006/0130.

[20] IEA. World Energy Outlook 2013. 2013. doi:10.1787/20725302.

[21] EU. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Off J Eur Union 2010:13–35. doi:doi:10.3000/17252555.L_2010.153.eng.

[22] Amblar Francés P, Casado Calle MJ, Pastor Saavedra A, Ramos Calzado P, Rodríguez E. Guía de escenarios regionalizados de cambio climático sobre España a partir de los resultados del IPCC-AR5. Madrid: 2017.

[23] Giorgetta MA, Jungclaus J, Reick CH, Legutke S, Bader J, Böttinger M, et al. Climate and carbon cycle changes from 1850 to 2100 in MPI-ESM simulations for the Coupled Model Intercomparison Project phase 5. J Adv Model Earth Syst 2013;5:572–97. doi:10.1002/jame.20038.

[24] Feng X-L, Zhi H, Lin P-F, Liu H-L. Assessment of Historical Climate Trends of Surface Air Temperature in CMIP5 Models. Atmos Ocean Sci Lett 2015;7:137–42. doi:10.3878/j.issn.1674-2834.13.0081.

[25] Cattiaux J, Douville H, Peings Y. European temperatures in CMIP5 : origins of present-day biases and future uncertainties. Clim Dyn 2013;41:2889–907. doi:10.1007/s00382-013-1731-y.

[26] Moss RH, Edmonds JA, Hibbard KA, Manning MR, Rose SK, van Vuuren DP, et al. The next generation of scenarios for climate change research and assessment. Nature 2010;463:747–56. doi:10.1038/nature08823.

[27] van Vuuren DP, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K, et al. The representative concentration pathways: An overview. Clim Change 2011;109:5–31. doi:10.1007/s10584-011-0148-z.

[28] Belcher S, Hacker J, Powell D. Constructing design weather data for future climates. Build Serv Eng Res Technol 2005;26:49–61. doi:10.1191/0143624405bt112oa.

[29] Documento Básico DB-HE Ahorro de Energía. Código Técnico de la Edificación. Ministerio de la Vivienda, Gobierno de España; 2017.

[30] Institute for Energy Diversification and Saving - IDAE. Project Sech-Spahousec, Analysis of the Energetic Consumption of the Residential Sector in Spain (Proyecto Sech-Spahousec, Análisis del consumo energético del sector residencial en España). 2011.

[31] Orme M, Liddament MW, Wilson A. Numerical Data for Air Infiltration and Natural Ventilation Calculations. Internatio. Coventry, Great Britain: Air Infiltration and Ventilation Centre; 1998.

[32] Klein SA. TRNSYS 17: A Transient System Simulation Program. 2010.

[33] Aparicio-Fernández C, Vivancos J, Ferrer-Gisbert P, Royo-Pastor R. Energy performance of a ventilated façade by simulation with experimental validation. Appl Therm Eng 2014;66:563–70. doi:10.1016/j.applthermaleng.2014.02.041.

[34] Martínez-Ibernón A, Aparicio-Fernández C, Royo-Pastor R, Vivancos J-L. Temperature and humidity transient simulation and validation in a measured house without a HVAC system. Energy Build 2016;131:54–62. doi:10.1016/j.enbuild.2016.08.079.

Highlights

1. Temperatures are projected under two Global Circulation Models for 2050 and 2100.
2. Eight energy measures are modelled under Mediterranean climate-change scenarios.
3. Passive and active improvements are modelled in a residential building.
4. Heating energy demand decreases significantly and cooling energy demand increases.
5. Thermal insulation and infiltration have the greatest effect on total energy demand.