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The performance of Mediterranean low-income housing in scenarios involving climate change.

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Abstract

Social housing dating from the period between the Second World War and the end of the oil crisis is one of the major stores of residential stock of European cities. This housing stock is a major target for retrofitting given its characteristic poor thermal performance and inefficient control of energy consumption. This article proposes a method for analysing the dynamic capacity of thermal enclosures on moderate energy flows in building stock in climate change scenarios, estimating the potential for adaptation and strengths and weaknesses of several building categories exposed to different present and future climate scenarios. A pilot study applying the procedure is carried out in the city of Seville, one of the largest in southern Europe, with a representative northern Mediterranean climate. The approach designed is equally applicable to other urban centres in southern Europe. Although indoor comfort in cold weather must be addressed even in the least favourable future scenarios, the predominant concern for this stock is controlling heat gain. This study shows how, regardless of individual situations, thermal insulation alone does not guarantee an optimal response for the stock as a whole. Different categories can be identified within a given stock, where some buildings display significant resilience and potential for adaptation to new scenarios, while others have less scope for improvement. These conclusions can provide guidelines for the design of future intervention policies in southern Europe.

Keywords: social housing; climatic change; southern Europe; energy demand; monitoring; simulation.

1. Introduction

Social housing, in its collective building form, is central to the configuration of current cities in southern Europe. The considerable volume of housing built in Europe after World War II [1], [2] and in Spain after the Civil War greatly affects the current energy behaviour of urban housing, and must be taken into account when assessing the energy performance expected from these cities. In Seville over 48 % of multi-family residential buildings - the most common type - were built between 1939 and 1979 [3], [4]. Together with the buildings constructed in the early twentieth century, this figure adds up to over 51 % of present housing stock. Consequently, over half of the city's homes are to some extent obsolete. Of this 51%, 60% qualifies as 'social housing' and accounts for over 30 % of Seville's total housing stock, which is at serious risk of underperformance. As a result, social housing and its capacity to continue to accommodate a large part of the population when faced with future changes is called into question, given the effects of climate change on consumption and indoor comfort conditions.

Social housing is usually occupied by medium to low-income families with limited resources to invest in the control of the indoor environment. These conditions lead to situations affecting the health, comfort, and quality of life of residents and should not be approached from the standpoint of energy consumption alone. These factors must therefore all be taken into consideration both when designing global policies to improve the performance of building stock in general and when planning specific interventions.

Given current energy and emissions requirements [5] [6] and the sub-standard habitability deriving from shortcomings in the building stock [7], suitable solutions are needed to lower energy demands - and in turn energy consumption - in order to substantially improve indoor environmental conditions. The most pressing concerns are the envelopes, particularly the façades of multi-family buildings [8], given their crucial importance in ensuring the quality of the indoor environment (thermal, acoustic control and air quality), and building aesthetics in terms of the image of the city [9].

This research aims primarily to present a wide-ranging study on the energy performance of social housing in the city of Seville, one of the largest in Spain, with a characteristic climate highly representative of southern Europe [10]–[12]. In cities with mild winters and warm summers (even extreme ones), indoor thermal conditions, particularly in social housing, are usually conditioned by economic considerations as well as a widespread lack of cooling and heating systems in homes and poor building performance [7]. This analysis aims to establish probable bands for the potential modification of the energy behaviour of building stock, rather than to establish specific values for buildings which should be the subject of specific studies.

One of the main innovations of this study, in the context of urban buildings, is that local weather is constantly changing, both through its natural variability and the effect of anthropogenic factors such as the different processes of climate change (CC). The climate which affects buildings has undergone – and will continue to undergo – changes which will have a direct effect on buildings' energy performance [13], [14] and comfort [15], [16]. The characteristics of this evolution and the main interactions with these buildings are analysed, generating a future evaluation scenario in order to establish a correlation between current and potential future scenarios in terms of factors driving building energy performance and energy use in indoor climate control.

Although this analysis focuses on the evolution of housing stock in the city of Seville, the work methodology and classification procedures followed are equally applicable to other cities and urban areas in southern Europe.

As mentioned above, current environmental conditions, coupled with the effects of climate change, affect energy balances. This is especially noticeable among social groups of lower economic status, often affected by increased demands on energy supply systems for the improvement of indoor conditions [17]. As the energy demand for the thermal control of the buildings is directly related to climatic conditions, modifying these will lead to new energy scenarios for cities and urban areas [14], [17]–[19].

Retrofitting actions to reduce CO_2 emissions from residential buildings and enhance energy savings are usually evaluated considering the conditions of the current climate (and on occasion historical data). This is particularly useful when establishing the performance of present-day buildings in future climate conditions, as well as the potential performance of the energy improvement measures currently under development for residential buildings, and their effectiveness in a future iteration of the current climate. This issue is examined by Hooff [20], Gupta [21] and Roders [22] although focusing fundamentally on colder areas in Europe.

A comprehensive review of the literature on the impact of climate change on building performance can be found in [23]–[25] for the fundamental concepts and methods and a global review in [26]–[29], covering the most recent trends. In general, it is emphasized that in predominantly warm conditions or in areas with a balance between heating and cooling needs, the potential for reduction of energy (or emissions) is strongly altered by the effects of climate change [23] [30]. In the Mediterranean area, the increase in the cooling needs of homes, especially those of lower constructive quality, is especially significant, as in [31] for Greece, where a significant increase in cooling degree days and maximum indoor temperatures (naturally ventilated homes) is forecast.

2. Methodology

This paper proposes a method for the analysis at housing stock-scale of the dynamic and evolutive capacity of the thermal envelopes trading energy flows within climate change scenarios. A probability assessment has been developed to establish the performance expected for city housing stock by 2050. This short to medium timeline will provide the key points for effective and economic actions in cities, calculating the potential for adaptation as well as the strengths and weaknesses of various building categories when exposed to different present and future climate scenarios.

In order to evaluate the potential impact of a climate change scenario on a multi-family social housing block in southern Spain, this study simulates a representative sample for housing units from the current social housing stock in 6 different scenarios. For the first scenario complying

with the current demand stipulations of Spanish CTE-DB-HE1 regulation [32] an alternative scenario is introduced to provide a realistic assessment of the current energy use in the dwellings, and the same model is subsequently used to evaluate energy variables for climate conditions predicted for the year 2050.

This study is made up of the phases of:

- characterisation of social housing
- selection of case studies
- monitoring

- climate model development
- simulations under six scenarios.

2.1. Characterisation of social housing

Given the lack of a database for social housing in Seville, this study required an exhaustive data collection process to identify the developments built between 1939 and 1979. A thorough review was carried out of original documents in national, regional and local historic and government archives, as well as in the records of engineering firms. Documentary analysis was followed by the on-site inspection of several buildings for the comparison of as-built and planned or design data, identifying any changes made since their construction.

The information and documentation compiled was entered into a database with historic, geometric and technical data in numerical and graph formats. This information was supplemented with new drawings and the inspection of construction systems. The data compiled and the specific characterisation is developed in [9] for performance and construction characteristics of envelopes and in [33] where the cataloguing process and data set is discussed. This database features information from 99,437 social dwellings built in the period under study.

2.2. Selection of case studies

The buildings studied were selected after a comprehensive process to faithfully represent the building stock. The first phase consisted of the identification and characterisation of the social housing developments built within the city limits in the period studied (1940-1979), 250 developments totalling 99,437 dwellings of an expected total of 100,510 were identified, and those which were especially small or far too unique to have representation in the stock were discarded [4]: in other words 98.93 %, which for all practical purposes can be considered as the entire population. Exhaustive data collection was carried out, identifying affordable and social-type housing units in the city, including location, typological characterisation and the cataloguing of units. National, regional and local archives from historical, governmental and technical organisations were consulted in the data collection process, while information and documentation from press, technical journals from the period studied and a scientific literature review were also analysed. Further fieldwork was carried out to inspect buildings on site, collecting data for the comparison of construction plans and existing buildings, allowing further evolution and transformations experienced since their construction to be identified. This procedure has resulted in an extensive database of historical and descriptive data: geometric, typological and constructive parameters and other technical aspects, both numerical and graphical. Data set and catalogue details are included in [33]

Analysis led to the identification of the characteristics common to each time frame (walls, roofs and other constructive element types, size of dwellings, windows and wall areas, etc.), with decades selected as sub-periods to guarantee an improved practical approach. A sample group of the stock (covering 83 developments and 46,476 units or 47 % of the population) was used to establish the essential morpho-constructive features of these developments [9], represented by the buildings selected (Tables 1 and 2, Figure 1).This group was selected for Stratified sampling and used to analyse energy demand performance in the different present and future climate scenarios. This group includes a representation (typical buildings) of each decade based on the differences revealed between time periods in earlier analysis, and mostly resulting from the implementation of housing construction programmes and ordinances [9]. Sampling precision was improved through stratification with variable strata sizes [34]. The sample size of each stratum was adapted depending on standard deviation to ensure the minimum variance in the mean of the sample [35]. This resulted in a sample covering 14 developments (13,898 housing units in total) with a sampling fraction (f_h) of 0.056. The buildings were defined using non-probabilistic, directed selection, making up a modelling sample for exploratory research design built using the 'typical cases' method [36]. The data sourced from an earlier study (matrix) included quotas to ensure that all the usual types present in each sub-period were represented and that clear in-depth information was provided on the performance of these characteristic types. The development component was used as it was considered the minimum grouping for multi-family buildings within the housing stock. When the number of units is used as a parameter it does not allow suitable discrimination, given that it is a discrete variable (units are grouped in buildings forming part of developments). Nonetheless, for the fit resulting from applying an f_h factor = 0.138, the approximation is suitable and compatible with the developments selected and assignment error is therefore minimised. The major geometrical envelope parameters are given in Table 1, while a comprehensive data analysis of the stock can be found in [33].

Table 1: Sample selected for energy modelling: main quantitative parameters

Model			**Building**				**Development**			
	Year	**Decade**	**ND**	**S_F**	**S_W**	**S_R**	**ND**	**S_F**	**S_W**	**S_R**
A	1952	50	20	878	171	273	1,180	51,802	10,061	16,107
B	1955	50	60	5,672	1,387	689	300	28,358	6,933	3,445
C	1959	50	8	248	44	89	1,611	49,975	8,848	17,922
D	1961	60	8	309	66	115	1,013	39,107	8,302	14,562
E	1963	60	20	1,009	157	324	554	27,940	4,347	8,975
F	1964	60	8	322	65	138	1,680	67,620	13,650	28,980
G	1964	60	30	2,071	252	358	300	20,712	2,520	3,580
H	1966	60	20	822	290	230	840	34,524	12,180	9,660
I	1971	70	24	1,520	242	470	2,768	178,164	28,365	55,090
J	1974	70	45	2,480	511	330	540	29,765	6,132	3,960
K	1976	70	40	5,302	866	710	640	84,832	13,856	11,354
L	1977	70	8	329	56	149	1,048	42,954	7,311	19,453
M	1979	70	32	2,603	304	359	800	65,075	7,600	8,975
N	1979	70	16	1,106	162	378	624	43,134	6,318	14,723
			(dwellings)	*(sqm)*			*(dwellings)*	*(sqm)*		

This analysis aims to establish distributions and patterns to define and classify the actions based on:

- Patterns and aggregation by time period of developments.
- Aggregation by basic magnitude: construction type and general dimensions.

- Morphological parameters related to energy performances of the building envelope: wall or roof surfaces, wall to window ratio or wall to indoor area, compactness and other parameters.
- Construction systems and temporary distribution.

The energy and morphological parameters for the models are listed in Table 2. Developments with the lowest % of openings on the façade (approximately 12 %) are models M and G. The models with the highest percentage of openings on the façade are B and H (24% and 35 % respectively). Models A, D and E are composed of single-brick façades. The housing units of models M and N are representative of developments with thermal insulation in the envelope, both on the roof and the façade. The 1970s saw an increase in the number of sloping roofs in multi-family housing (models I, M and N).

Table 2. Energy and morphological parameters

Model		Morphological parameters (m^2)				Energy parameters (W/m^2K)		
Model	**Year**	**ND**	**S_F**	**S_W**	**S_R**	**U_F**	**U_R**	**U_G**
A	1952	20	878	171	273	1.83	2.40	2.45
B	1955	60	5 672	1 387	689	1.53	1.23	2.25
C	1959	8	248	44	89	1.28	1.23	1.66
D	1961	8	309	66	115	1.83	1.23	2.07
E	1963	20	1 009	157	324	1.97	1.57	2.17
F	1964	8	322	65	138	1.28	1.23	1.81
G	1964	30	2 071	252	358	1.68	1.57	2.04
H	1966	20	822	290	230	1.53	1.23	1.91
I	1971	24	1 520	242	470	2.17	2.40	2.49
J	1974	45	2 480	511	330	1.53	1.84	2.20
K	1976	40	5 302	866	710	1.53	1.23	2.06
L	1977	8	329	56	149	1.53	1.54	1.97
M	1979	32	2 603	304	359	0.72	0.67	1.18
N	1979	16	1 106	162	378	0.75	0.67	1.22

Where:

- S_F Area of opaque façade (m^2)
- S_W Window area (m^2)
- S_R Roof area (m^2)
- ND No. of dwelling
- U_F Thermal transmittance, opaque façade enclosure (W/m^2K)
- U_R Thermal transmittance, roof (W/m^2K)
- U_G Thermal transmittance, building as a whole (W/m^2K)

In Seville, the smaller housing units associated with social programmes for population with limited means, have mostly been built in medium-height or tall buildings (models A, C, D, E, F, H, I ,L,N). The housing units in taller tower blocks, approximately 27 % of the total (models B, G, J, K), have larger surfaces than medium-height buildings. There is also a correlation between the size of the housing unit and the block type, as housing units tend to be smaller in linear than in H-type blocks [9].

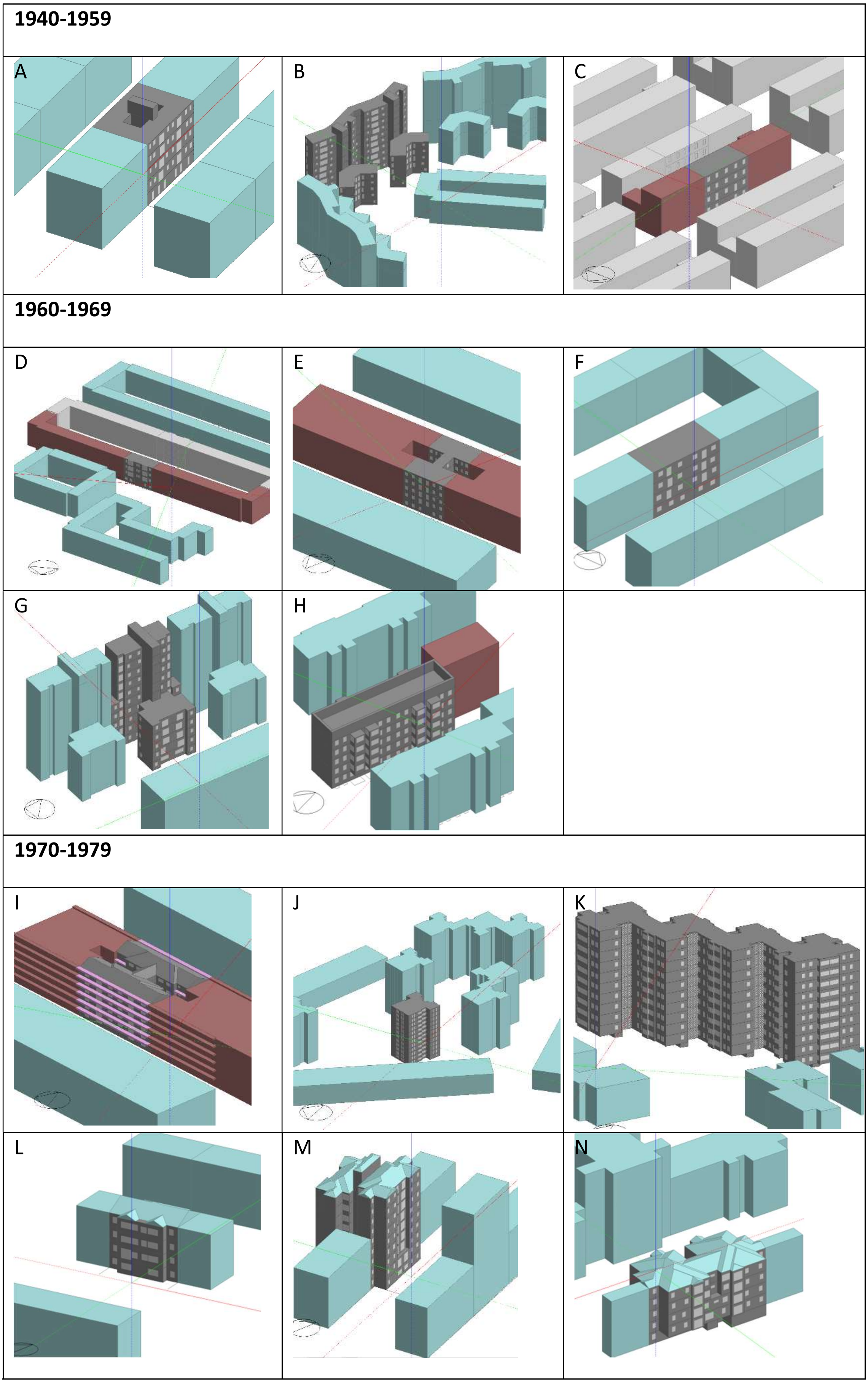


Figure 1: Building energy modelling by main time period (DesignBuilder).

2.3. Actual performance data gathering

One of the main aims of this study is to identify the difference between real use patterns and those proposed by the National Standards [10] (Table 3) . The actual intensity of use and conditions within the buildings tend to differ, leading to a distortion when evaluating demand. This is reflected mostly in the variations in energy flow due to the different indoor temperatures. In some cases, a monitoring process was carried out to identify the most frequent indoor temperatures, and in turn, to establish new comparison scenarios. Indoor environmental parameters (temperature, relative humidity and CO_2 levels) were monitored continuously for a full year in the selected housing units using a Wöhler CDL 210 multi-parametric monitoring system (one control -housing unit in each development). Outdoor humidity, temperature, and wind velocity were provided by the Spanish meteorological agency (AEMET). These measurements were used to establish a pattern of use closer to that normally expected in this type of housing unit rather than the standard patterns defined by national regulation for energy-demand compliance simulations. The starting conditions for the construction of the models are based on the operational patterns established by the Spanish Standards for energy in buildings: the National Energy Labelling procedure [37] and the national requirement for energy conservation (CTE DB-HE) [38], regulations which implement the European Energy Performance Building Directive (EPBD) at national level [39]. (Table 3):

Table 3. Heating/AC temperature set-point schedule as in Spanish national Standards [37] [38].

Target temperature (˚C)	**1:00-7:00**	**8:00**	**9:00-15:00**	**16:00-23:00**	**24:00**
January to May (lowest)	17	20	20	20	17
June to September (highest)	27	free running	free running	25	27
October to December (lowest)	17	20	20	20	17

*free running = mechanical thermal control off

This operational definition can be defined as the Normative Scenario. It should be noted that this pattern assumes an almost continuous use of heating in winter, which is not the usual situation in social housing stock [40], [41]. For the purposes of comparison assessment, an alternative and complementary scenario was proposed as part of the discussion of the results from the environmental variables and the analysis of user surveys monitored (Table 4), and is developed in [10].

This scenario is introduced to provide a more consistent model for the actual energy-use of housing (especially in social housing), occupational profile, and heating and air conditioning operation. The statistical development for the definition of the schedule and the analysis of the indoor environmental data are covered in [10].

Table 4. Alternative Heating/AC temperature set-point schedule for social housing.

Target temperature (˚C)	1:00-7:00	8:00	9:00-15:00	16:00-23:00	24:00
January to May (lowest)	15	19	19	19	15
June to September (highest)	free running	free running	free running	27	free running
October to December (lowest)	15	19	19	19	15

*free running = mechanical thermal control off

In general, it can be established that the use of normative scenarios in the energy assessment of the housing units results in an overestimation of the energy linked to the thermal exchanges in these buildings. This especially affects the effect of energy-conservation measures (such as retrofitting insulation), increasing the weight of the energy contribution in cold periods.
The envelope airtightness of the housing units was measured using the standard blower door test (as defined by EN 13829:2000 [42]) and a complementary methodology developed for this type of multifamily buildings, which define specific techniques for measuring the contribution of the components of the dwellings to air-infiltration through five additional tests where the sequential increase in sealing elements makes it possible to allocate infiltration responsibility for the envelope [43]. The 'Minneapolis Blower Door Model 4' kit used was connected to an automated performance testing system (flow range at 50 Pa, 25–7800 $m^3 h^{-1}$; accuracy, ± 3%).Measurements were taken at pressures ranging from 20 Pa to 70 Pa at 5 Pa intervals following the procedures described in Spanish and European standard UNE EN 13829:2002 [44]. Mean value for the stock is 7.51 h^{-1} (+/- 2.74 h^{-1} STD). Broad results were published in [11], [43], [45].

Indoor and outdoor environmental parameters and airtightness were also used to calibrate the energy demand simulation model.

2.4. Climate model development

Therefore, the use of dynamic simulation techniques for energy behaviour on meteorological predictions will be necessary in order to evaluate the impact of climate change on buildings and their indoor ambient. These techniques must establish a representative dataset for the future conditions which these buildings must face. The use of meteorological data with at least hourly details - and representative of the future scenarios for evaluation - is necessary to ensure precise dynamic analysis of thermal and energy responses of buildings [46].

The climate fluctuations in the city of Seville for the period between the construction of this housing stock and the present were studied to understand the changes undergone by these buildings to date and to establish the base-line for the climate evolution trend. The second step was the development of a 'typical year' weather-data set for a future period under the evolution driven by climate change processes. This procedure was borrowed from Jentsch et al. [47] from the University of Southampton's Sustainable Energy Research Group: a methodology and process algorithms to develop future standard weather years, factoring in the effects of climate change. This procedure draws from the morphing methodology established by Belcher et al. [48]. and the work by Chan et al. [46] for the development of hourly weather files. This approach drives the transformation of current local daily data, a mathematical transformation referred to as morphing [47], through regional (RCM, Regional Climate Models) or global (GCM, Global Climate Models) climate change forecast models. This ensures a set of future local data with hourly information. In this research the EPW (Energy Plus Weather) format was selected to represent typical yearly weather, where the data for Seville were adapted from the SWEC (Spanish Weather for Energy Calculations) type-year. A displacement and stretch calculation technique was applied, imposing the foreseeable modifications derived from global models to current data [47]. This probabilistic approach introduces climate variability and uncertainty factors, allowing the adaptation of present weather data to new conditions [49]. This method is one of the most commonly used for future performance simulations, especially within the United Kingdom where it has been adopted by CIBSE [50] and validated by [30].

The difference with other probabilistic methods is the reduction of scenarios in comparison with other more extensive ones, such as that developed for the program UKCP09 [51], which generates 100 sequences of 30 years. Although this method allows very detailed probability distributions to be established, the vast amount of data generated makes it unsuitable for work with building stocks [47]. Equally, although models based on RCM (Regional Climatic Models) are preferable for the generation of regional scenarios, given their higher geographical resolution [52], they are less efficient as driving forces for current weather morphing procedures as they have fewer consistent parameters [53]. The use of GCM (Global Climatic Models) for data transformation is considered a suitable estimation, especially for the periods close in time and for the assessment of building performance [47]. The dataset generated by [54] for Europe, includes five climate models (CGCM2, CSIRO-Mk2, ECHAM4, HadCM3, NCARPCM) and four emission scenarios (B1, B2, A2, A1FI) [55] [56]. Although this method may have limitations when working with time-extended scenarios such as those through to 2080, [47] it is not a conditioning factor for this work given its focus. In practical terms it does not seem useful to extend the analysis beyond the middle of the century as the assessment of the energy potential of the current housing stock beyond this time would provide no additional information, as the level of renewal of the current stock beyond this period of reference is expected to be very high as well as the uncertainty of the climate forecasts. The HadCM3 (Hadley Centre Coupled Model, version 3) model [57], [58] was selected as it presents the higher number of parameters to feed the morphing process suitably. Scenario A2, representing the most probable unfavourable scenario, was selected to develop future weather models. It can be assumed that this represents the expected evolution of our current society without major changes and can therefore be adopted as the upper threshold for change in relation to the current situation (some scenarios have greater impact but are highly improbable)

Climate change data from general climatic models, in this case monthly predictions from HAdRM3 type models [15], are regionalised ('spatial downscaling') with the application of the starting conditions referring to the city location (data included in the typical meteorological year for the city —in this case EPW). This type of model has been shown to be meteorologically consistent [48]. The city- future weather profiles developed for the years 2020 and 2050 (HadCM3-A2 scenario) are represented with monthly average values against the current weather for Seville (EPW format) as accepted for regulatory energy simulations (Figure 2).

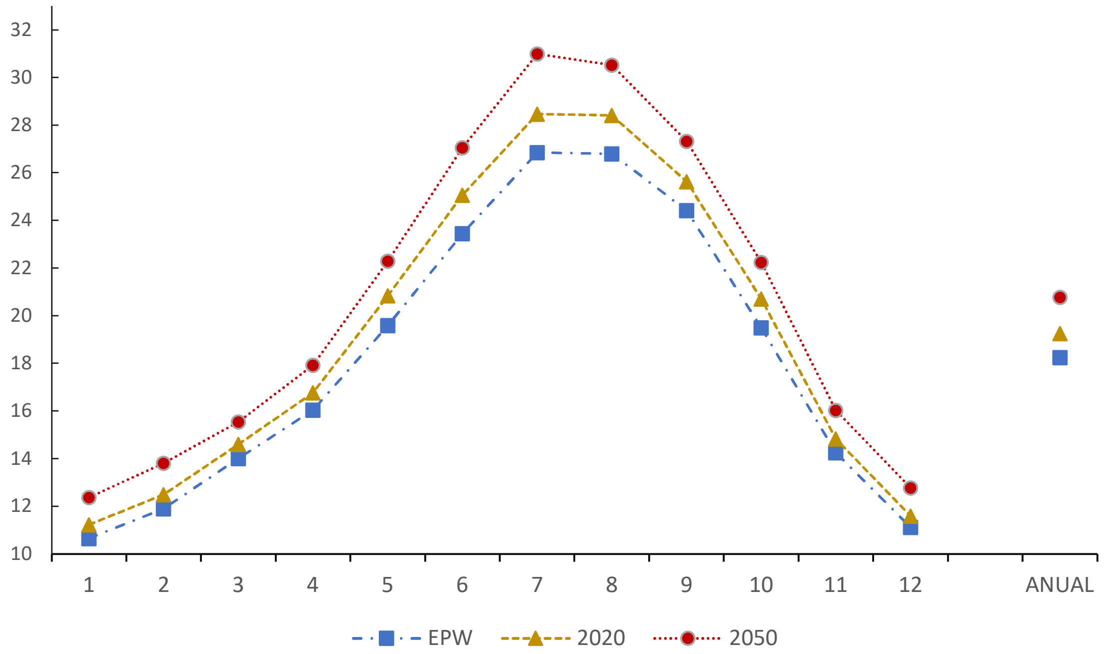


Figure 2: Comparison of average monthly air temperatures (° C) and annual average for the current meteorological year (EPW), and models showing evolution for 2020 and 2050.

2.5. Energy modelling

The building sample-group is modelled to recreate geometric, morphological and typological characteristics, construction systems, urban environment and operational conditions. The models include urban boundary conditions and solar horizon surroundings (Figure 1).

The building energy simulation tool EnergyPlus v8.2 was chosen for this purpose, through the energy analysis package DesignBuilder (v4.2.0.054), whose validity can be considered adequately proven [59] [60]. The building modelling of simulation sets followed the methodology detailed in ANSI/ASHRAE/IES Standard 90.1-2013 [61], with initial operational protocols established according to Spanish official Energy Labelling procedures and adapted to a more realistic approach in the second step.

A calibration procedure was then carried out between models and real housing units to check the accuracy of the model compared to actual performance. Control homes were used both as a source for the identification of thermal behaviour and for the calibration of the nodal model. Thermal and operational real profiles for calibration were created by extracting hourly values for indoor parameters as in [62] and using real weather data to feed the climate file. the mean bias error (MBE) and the coefficient of variation of the root mean square error (CV/RMSE) (3) were used to assess the differences between the simulated and hourly data observed.

$$MBE = \frac{\sum_{i=1}^{N_S}(y_i - \hat{y}_i)}{\sum_{i=1}^{N_S} y_i} \quad (1)$$

$$\hat{Y}_S = \frac{\sum_{i=1}^{N_S} y_i}{N_S} \quad (2)$$

$$CVRMSE_{(S)} = \frac{\sqrt{\sum_{i=1}^{N_S} \frac{(y_i - \hat{y}_i)^2}{N_S}}}{\hat{Y}_S} \quad (3)$$

where:

- y_i: recorded data
- $\hat{y}_i$: simulated data
- N_S: sample size
- $\hat{Y}_S$: sample mean for recorded data

Different parameters were adjusted to reach convergence (airtightness, material density and thermal resistance, floor temperature…) through a GOF (*Goodness-Of-Fit*) method as explained by Coakley et al. where for each model it is based on a weighted combination of CVRMSE and the NMBE, comparing the simulation models with lower results they represent parameter sets showing a higher goodness of fit in relation to the measured data, thus allowing the selection of better fits [63]. The calibration process was conducted following ASHRAE 14-2002, establishing that the simulation model calibrated must have 10% accuracy range for NBME and 30% for CV (RMSE) in relation to the hourly data measured [64].

Figure 3 shows an example of calibration process output for models E and H (Figure 1) during one winter week. Figure 3 shows actual indoor temperature with measurement error (±0.5 ^{O}C) in contrast with simulated indoor temperature. In both examples, MBE and CV/RMSE values were well within the limits established in ASHRAE 14-2002 (E: 0.54/6.69% and 0.93/11.48%; H:1.94/23.88 and 1.68/20.62%).

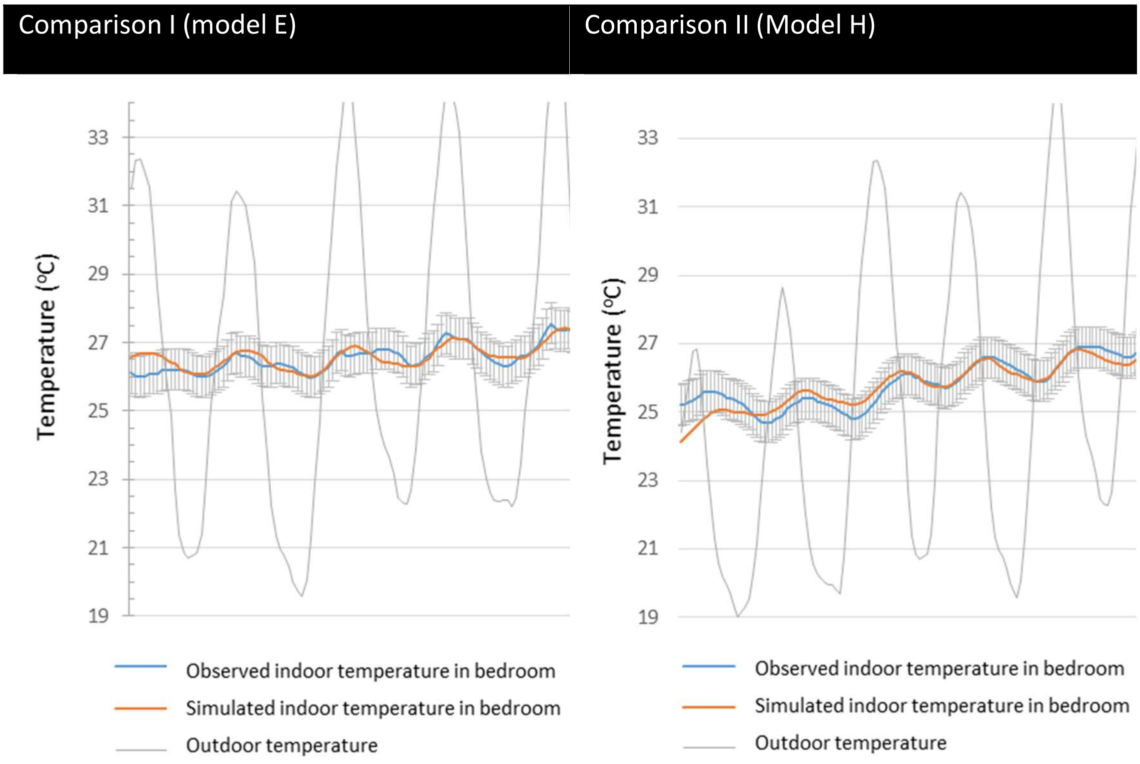


Figure 3: Comparison of observed and simulated indoor air temperatures (˚C) for models E and H using outdoor air temperature (˚C) as a reference for a summer reference week.

2.6. Assessment scenarios

The different analysis scenarios used are derived from the combination of the different states: current standard (national regulation) and alternative low energy intensity scenario; basic envelope and envelope retrofitting (insulation); current climate and future weather.

Table 5 shows the state-combinations to draw up the different scenarios where six are chosen to develop the comparative assessment. They are used in the simulations where 339 dwellings grouped into 14 different buildings (Table 1) are simulated for each scenario

Table 5. Scenarios used in simulations.

Scenario		OA	OB	RA	RB	FOB	FRB
Envelope	Original	X	X			X	
	Retrofitted			X	X		X
Climate	Present	X	X	X	X		
	Future					X	X
Temperature set	CTE	X		X			
	Alternative		X		X	X	X

Where:

- OA original building and Spanish standard set temperature
- OB original building and alternative set temperature
- RA retrofitted building and Spanish standard set temperature
- RB retrofitted building and alternative set temperature
- FOB future climate, original building and alternative set temperature
- FRB future climate, retrofitted building and alternative set temperature

Operational schedules, shown in Table 6, are based on those from the national EPDB implementation procedures, with percentages representing the partial application of the schedule during this time frame [65].

Table 6: Dwelling Operational Profiles

Activity	Value	Schedule			
		Winter		Summer	
Occupation	0.056 pers/m^2	00:00 to 07:00	100%	00:00 to 07:00	100%
		07:00 to 16:00	25%	07:00 to 16:00	25%
		16:00 to 23:00	50%	16:00 to 23:00	50%
		Weekends & holidays:		Weekends 00:00 to 24:00	100
		00:00 to 24:00	50%	Holidays 00:00 to 24:00	0%
Equipment & Lighting	0.44 W/m^2	00:00 to 08:00	10%	00:00 to 08:00	10%
		08:00 to 19:00	30%	08:00 to 19:00	30%
		19:00 to 20:00	50%	19:00 to 20:00	50%
		20:00 to 23:00	100%	20:00 to 23:00	100%
		23:00 to 24:00	50%	23:00 to 24:00	50%
Supplementary ventilation	3 ACH	*not applicable*		00:00 to 08:00	100%
				08:00 to 24:00	0%

Winter: from November to March
Summer: from April to October

2.6.1. Envelope

Constructions were considered to be as originally built, an assumption compatible with the normal state of affairs since most of the past interventions on façades of the stock were only repairs. Windows are considered second-generation upgrades, with steel frames and single glazing, and with little to no thermal effect compared to the original windows [9].

In the retrofitted stage the façade was assumed to have been improved by the external addition of an insulation layer, a 5 cm *External Thermal Insulation Composite System* (ETICS) EPS panel, as defined by EOTA-ETAG 004 [66]. This solution was chosen for its current national widespread use in the energy improvement of buildings [9], [67], [68].

2.6.2. Temperature set

a) CTE

The set temperature described in Table 2 was used.

b) Alternative

The set temperature described in Table 3 was used.

2.6.3. Climate

a) Present

This scenario, based on the present weather situation, was represented by the standard year defined in the document *Spanish Weather for Energy Calculations* (EPW format- SWEC).

b) Future assuming climate change

A weather profile for the year 2050 was created to assess the behaviour of the building stock exposed to climate change, based on HadCM3 and A2 emission conditions.

2.6.4. Combined scenarios

The comparison of different energy models is especially interesting, based on those derived from the monitoring of protocols proposed in national standards, seeking alternatives resembling this behaviour more closely and proposing alternatives for aspects where the biggest differences have been detected (for example, use of heating). Occupant actions affecting envelope performance were modelled following the National Energy Labelling procedure [38]:The use of blinds and solar devices in summer was emulated in the models, considering that in warm periods the aperture level of windows is reduced by 33% as a result of outer blinds - the most frequent - [69], [70], in keeping with the findings of research on solar shading carried out in the area [71].The impact of window aperture was standardised according to this procedure, assuming that windows remain closed during winter, with very short and barely noticeable operation, and in warm periods during the hours in the middle of the day, also with a very short ventilation period. During late evening and night-time hours complete window aperture is expected. This natural ventilation action, with a mean of 4 ACH [69], is within the range identified for the area in the literature [72]–[74]. Although these values can vary greatly and depend on the climate conditions at each point, this study aims to represent the common values of the housing stock in order to ensure the suitable comparison of the complex based on individual behaviour.

The modelling incorporates the effect of the presence of neighbouring buildings and its impact on the solar horizon of the model for the different orientations and façades and roofs surfaces. As these buildings are within an urban layout this aspect is crucial to ascertaining the real performance of the building and its enclosures as well as its correlation to solar radiation. The main effect occurs in winter (given the lower solar trajectory), where obstructions prevent solar gains from entering through windows or being stored in walls, while in the summer greater protection is provided to the roofs (in the case of lower buildings) and façades, especially those with SW-NW and NE-SE orientation. This allows the model to closely simulate the real conditions of use and to assess the different urban layouts.

3. Results and discussion

This section discusses and analyses the findings for the energy models of the individual scenarios defined. The data were normalised for inter-model comparison, using the parameter of the building's environmentally controlled gross floor area (routinely applied in residential energy labelling and standard compliance). The energy performance indicators (EnPIs) defined were total thermal energy demand (TD) and cooling (CD)/heating demand (HD) per year.

3.1. Energy demand per model

The behaviour of the different models was studied through the comparison and evolution of the different variables —heating, cooling and yearly total demand for individual building models— in each of the scenarios introduced in order to analyse the degree of response and variation of each of these models. Each building model was represented based on the average energy demand of all the housing units within, comparing the mean value for each scenario (intra-scenario analysis) and between scenarios (inter-scenario analysis), as well as the use of lineal and multiple regression analyses to identify the influence of parameters when needed. Multivariate visualisation is used for pattern recognition.

Z-score was used to apply standardised demand result values in order to compare the behaviours of each of the models included below each set of conditions (with very different demand values in each case). , The difference between the result and the sample mean of the set analysed was established and expressed in standard separation deviations (σ). Thanks to this adjustment the models with the most extreme behaviours in each of the parameters analysed (demands) are identified. In general, no models with extreme behaviours (outliers >3σ) were identified and the different models are within the range of +/- 1.96σ in most situations. These values have been represented with a multivariate Star Plot [75] (Figure 4), which is most useful when the scales are comparable. Each ray represents individual study variables (in this case upper vertex: annual demand; lower left vertex: cooling demand; lower right vertex: heating demand).

In the original scenario (OA) (Figure 4a) annual energy forecasting performance varies by up to 1.5 times within the group. There is some relation between figures and age, with higher demand in older buildings and lower demand in more modern ones (an R-square value of 62.3915% and a correlation factor of 0.789883 show a moderately strong relationship between the variables —p value: 0.0008—). Nonetheless, some of the older buildings have demand figures close to the sample mean (D type), while some modern examples show higher results (model L). It should be noted that the M and N building types date from the final period when insulation was introduced into the construction and, despite the minimal energy-demand sample-minimum values, total figures are very similar to those in non-insulated buildings of a similar age. The building with the highest annual energy demand (A) had mass single-wythe construction, while the non-insulated building with the lowest demand (J) had ceramic brick cavity-walls. However, this does not appear to be a determining factor, since demand in the same sample buildings with ceramic brick single-layer construction shows figures around central values.

In this initial scenario for the heating needs the correlation between the most demanding and least demanding models is over double the energy (excluding insulated models), where model E (building with single-wythe enclosures) displays the highest demand compared to L and F (both also have single-wythe enclosures). Given that in this instance all three types had single-wythe façades, the difference is due mostly to a combination of morphological and boundary factors rather than to the specific construction system alone. In this case the different behaviours are probably the result of the joint intervention of additional factors, rather than of the sole influence of the constructive system. In this instance the most influential factors are the aperture of the dwellings and solar obstruction, with the lowest demands found in the buildings with a higher solar capture (orientation, aperture degree and no obstructions).. In heating demand insulated buildings M and N display the highest difference in relation to the sample group. Excluding models with thermal insulation which alters behaviour in some way, regression model analysis establishes that the best explanation for the sample corresponds to the variables linked to the envelope, especially global transmittance and the ratio of envelope per square metre (with the lower Mallows Cp of 3.9692 and a r-square: 58.5182). However, variability is very high as most variables show major correlations and most importantly, this is in keeping with the high intensity of use and prolonged heating periods for this scenario.

Cooling behaviour in this scenario was almost a mirror image of heating performance, as the models with the lowest heating demand exhibit the highest cooling demand. The same occurs with variability, with the maximum value almost doubling the minimum. The best annual overall performance was found for model I - with mean heating values and low cooling demand figures for a fabric of single layer concrete-block walls and a rather high wall U-value (2.17 W/m^{2}K)- which appeared to strike the best balance. Figures for this building type are extremely low, with a z-score of -2 σ. This performance can be associated with the presence of continuous balconies across the entire façade, providing horizontal solar protection thus regulating solar capture in winter and preventing it in summer, as a result of orientation and morphology rather than specific wall solutions. Attention should be drawn to the relative high cooling demand in buildings with originally insulated façades (models M and N) compared to non-insulated buildings with a similar configuration (J and K). Insulation during warm periods has limited effect when the morphology is not optimal.

In the present weather alternative low-energy intensity scenario (OB) (Figure 4c) types with insulated façades (M and N) show greater differences compared to the sample as opposed to scenario OA, with much lower yearly energy demands. Without this specific type of buildings, demand differentials display similar relative values to those of the OA scenario (around one and a half times higher), although absolute values are lower (50% less). Building performance distribution reflects that from OA, albeit with some differences. In scenario OB the highest total demands are again found in models A and E (close to model D), while models F to H and L represent central values, and the minimum is for I to K types —excluding fabric-insulated M and N. Parameters such as U global and U wall, connected with envelope thermal resistance, are less noticeable in this scenario (linear regression models have no significance over annual energy-demand with p-values over 0.05 in both cases). The seasonal patterns show similar relative-profiles although heating requirements are around 30% lower and 40% for cooling.

From the above it is deduced that in an alternative energy-use laxer profile the energy demand profile is moderate in buildings with dense, single-layer fabrics in which the effects of other strategies such as solar control and thermal storage and buffering carry greater weight. The buildings with cavity walls and lower envelope thermal mass were less sensitive to this change of scenario (in relative values). In general there is less scattering of extreme values in distribution. This suggests an important correlation with intermittent use - change in use patterns - which is detrimental to buildings with lower thermal accumulation capacity and a greater exposed surface, provoking the opposite effect in more compact cases with higher thermal masses.

Following retrofitting (scenario RA) (Figure 4b), as expected, total demand declined significantly with a roughly homogeneous façade thermal resistance for all types (thermal resistance converges between 0.50 and 0.57 W/m^2K due to the addition of insulation), with a substantial reduction in the effect of heating and an increase in the relative weight of cooling in the annual figures. Demand distribution also varied, with a change in the clustering identified in the two preceding scenarios. Somewhat extreme figures were found in type C for annual demand (2.1σ) and in L-Type for cooling (2.2σ). The lesser impact of façades heightened that of other parameters such as the roof or WWR. Under an alternative indoor control pattern (RB) (Figure 4d) demand is lowered substantially, particularly for cooling, following much the same pattern as that observed in scenarios OA and OB. As in scenario RA, the highest total and heating demands were associated with model C, although the absolute values are 20% lower. The combination of low (but not the lowest) fabric thermal resistance, low WWR and small housing unit size makes this type of building highly sensitive to envelope losses.

Scenarios RA and RB (Figures 4b and 4d) show similar distribution of means for the models with attenuated values related to OA and OB. However, as they are clearly differentiated sample sets, specific distributions show major changes in the behaviour of the scenario (Kolmogorov-Smirnov tests show a statistically significant difference between both distributions with a level of trust of 95.0% and a DN-value of 0.7857 and 0.7142 and p-value of 0.000352 and 0.0015 for OA-RA and OB-RB respectively). The differences between maximum and minimum were mostly attenuated in RB with respect to RA, as is the case in the original scenarios (OA and OB).

When climate change was assumed in the scenarios, heating accounted for far less of the total demand (23% for the mean values) than cooling.

Comparing both climate situations, it is worth highlighting the significant reduction in heating and increase in cooling for future forecast. There is also a reduction in efficiency of insulation measures between the original envelope and the improved one in scenario FOB/FRB. The B scenario was selected for its closer representation of the operation of actual buildings, and consequently greater capacity for evaluating the potential for energy change among the different scenarios.

In the future scenario with buildings in original conditions the effect of heating is far less noticeable in the overall requirements (23% of total mean values), whereas behaviour in cooling conditions is far more significant. The lowest total demand is observed in the insulated buildings (models M and N), albeit with very similar values to those of non-insulated buildings I and J, which show the lowest demand in the group without insulation. Models M and N present medium cooling demand, with low total values due to the reduced heating demand resulting from the façade insulation. However, this does not appear to be particularly effective for heating demand control. In contrast, the demand values for the most balanced non-insulated models within the sample (I and J) are slightly higher (close to the mean), in keeping with an envelope without insulation. Nevertheless, their morphology benefits cooling control. Model E displays the highest heating demand, with behaviour in keeping with prior analyses. However, models A, C and D also present high heating demand values, which can be linked to a lower thermal resistance of these enclosures compared to the rest of the group. Although heating demand values are relatively low compared to the current scenarios (with a 35% reduction between scenarios), maximum and minimum values vary greatly, exceeding double the value without taking into account freestanding buildings. There is a high incidence of the parameter associated to the thermal resistance of façades (U-value) in the distribution of heating demand values, albeit with great variations(linear correlation r-square: 46.2407% indicates a moderately strong relationship between variables with a standard deviation of the residuals of 2.4105 with p-value of 0.0075). Variability is reduced in the case of cooling, with an approximate minimum-maximum ratio of 1.6, despite the much higher absolute values and the significant increase when compared to the current situation, doubling the mean cooling demand of scenario OA, although in this case there are no predominant parameters in the distribution process and B-type and I-Type are found in extreme positions, with z-scores over +/-2 (2.1; -2.1)

For the situation of future climate (2050) and improved envelope, - and ahead of M and N, which could be considered to have excessive insulation - models I and J display the lowest total energy demand and jointly the lowest cooling demand. Heating demand is also reduced in both cases. Models C and F display the highest total energy demand, with the highest cooling demand also observed in model F. The features noted above are confirmed as the poor behaviour of model C cannot be linked to the thermal resistance of its enclosures —wall R-value— (in this case with equal values throughout the sample) or Global transmittance value, with no actual correlations as R-square only reaches 12.2233% for FOB and a very low 0.8720 % for FRB both with p-value over 0.005 (0.22 and 0.7508). This model also shows the highest heating demand, followed by model E. Although the maximum overall value of model F is also due to its high cooling demand, it presents one of the lowest heating demands in the group. This can be attributed to high solar radiation capture throughout the year (high ratio of openings to surface area and effect of the roof), which allows control of the need for heating but is especially problematic in the warm period, despite the presence of insulation.

When observing the symmetry and scope of the behaviour in relation to the group mean (Figure 4) in general the models displaying the most balanced behaviour and lowest demands are J and N, whereas models C, F and L show the least balance and the highest demands.

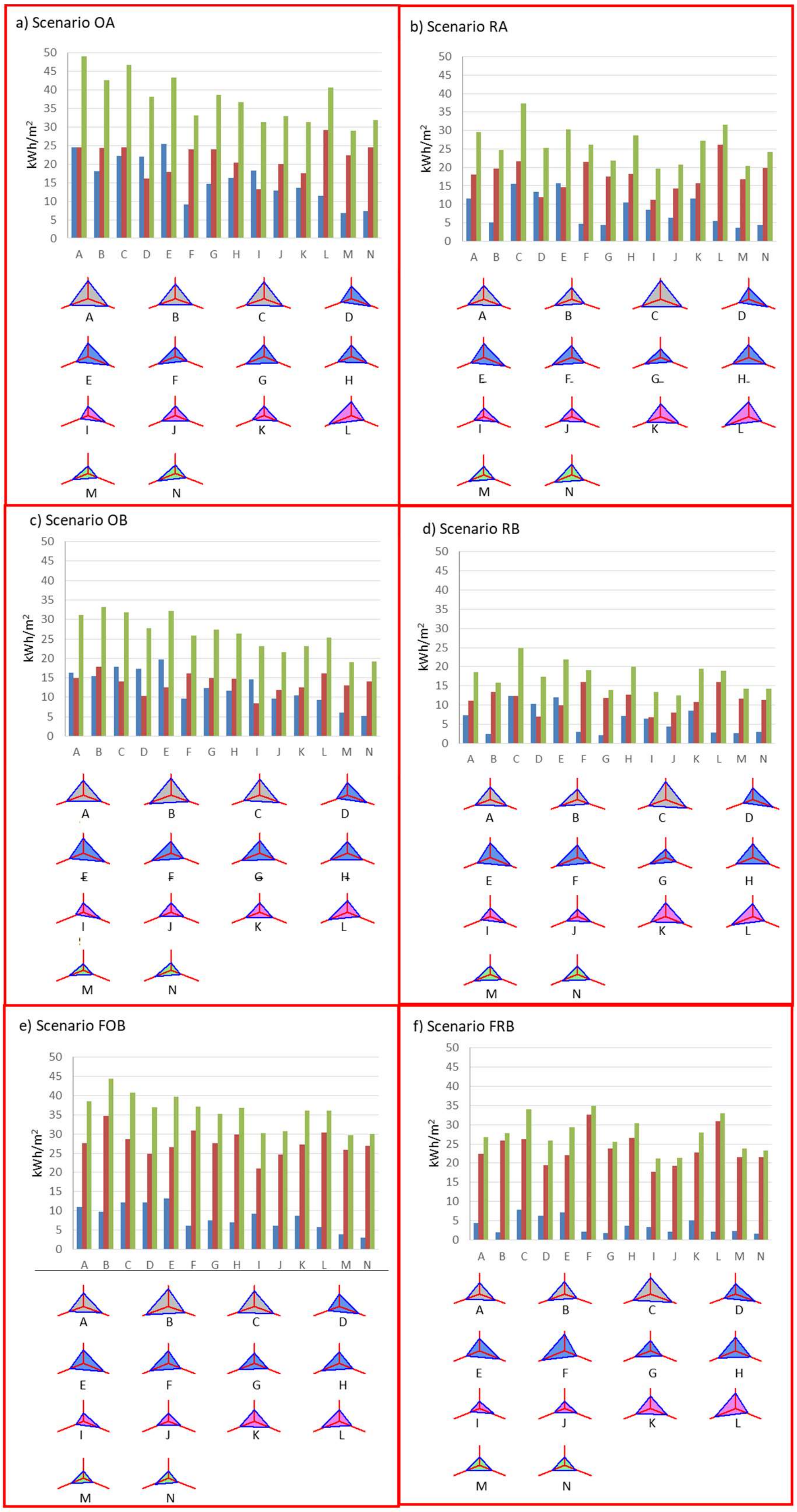
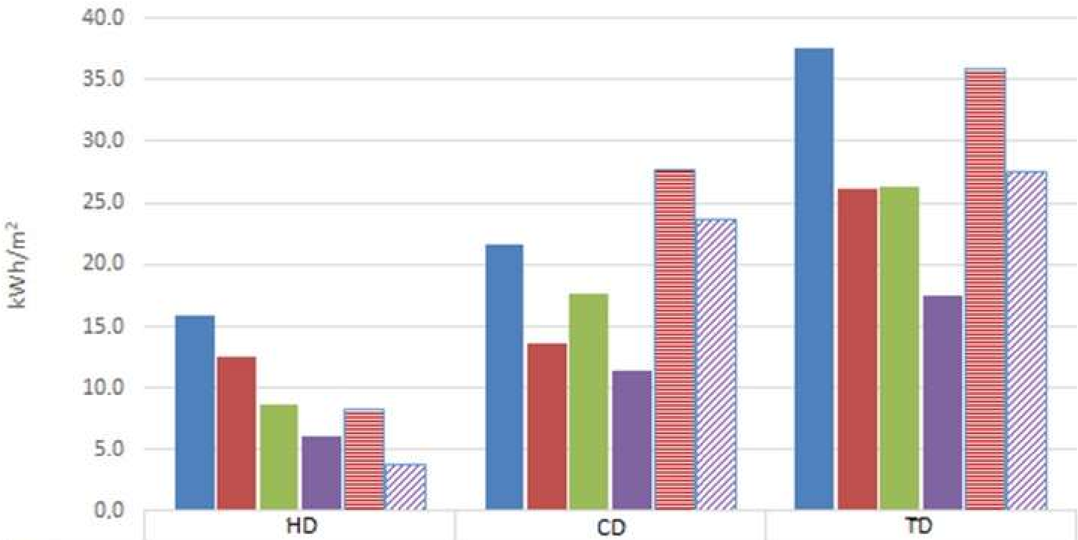


Figure 4: Mean total, heating and cooling demands for each model in the sample and star plot multivariate visualisation of model energy demands under six scenarios (bar graph: blue=cooling demand; red=heating demand; green=total demand; Chambers graph: top vertex=yearly demand; lower left vertex=cooling demand; lower right vertex=heating demand)

3.2. General energy demands for the sample studied: inter-scenario comparison

Partial and total energy demands are shown in Figure 5, comparing the results for the six scenarios: present, retrofitted and for the year 2050 assuming climate change, each with and without retrofitting. The average values for all the scenarios and the differentials between the non-retrofitted and retrofitted versions in each group (expressed in relative and absolute values) are listed in Figure 6 for heating and in Figure 7 for cooling demand.



	HD	CD	TD
0A	15.9	21.6	37.5
OB	12.5	13.7	26.2
RA	8.6	17.6	26.3
RB	6.1	11.4	17.5
FOB 2050	8.2	27.6	35.9
FRB 2050	3.7	23.7	27.5

Figure 5: Mean HVAC energy demand (kWh/m^2) in six scenarios.

	A		B		FB
O	15.9	-21.38%	12.5	-34.40%	8.2
	-45.91%		-51.20%		-54.88%
R	8.6	-29.07%	6.1	-39.34%	3.7

	A		B		FB
O	15.9	-3.4	12.5	-4.3	8.2
	-7.3		-6.4		-4.5
R	8.6	-2.5	6.1	-2.4	3.7

Figure 6: Comparison of average heating demand (kWh/m2) for all models by scenario (left: relative variation (%) with and without retrofitting; right: absolute variation (kWh/m2) with and without retrofitting)

	A		B		FB		A		B		FB
O	21.6	-36.57%	13.7	101.46%	27.6	O	21.6	-7.9	13.7	13.9	27.6
	-18.52%		-16.79%		-14.13%		-4		-2.3		-3.9
R	17.6	-35.23%	11.4	107.89%	23.7	R	17.6	-6.2	11.4	12.3	23.7

Figure 7: Comparison of average cooling demand (kWh/m2) for all models by scenario (left: relative variation (%) with and without retrofitting; right: absolute variation in kWh/m2) with and without retrofitting).

Where:

- A Spanish standard set temperature
- B alternative set temperature
- O original
- R retrofitted
- F Future climate.
- HD Heating demand (kWh/m^2)
- CD Cooling demand (kWh/m^2)
- TD Total demand (kWh/m^2)

A comparison of the type O (original) scenarios showed the significant effect of the intensity of use of HVAC systems and the adoption of different set-points. The implementation of an alternative schedule, closer to common practice, and the strict application of the analysis to the areas of housing units that are currently conditioned (OB) lowered yearly demand to approximately 70 % of the initial value (OA).

The distribution of seasonal demand also varied. In scenario B heating and cooling tended to be more balanced (heating: 47.7% / cooling: 52.3%), whereas cooling carried greater weight in scenario A (heating: 42.4% / cooling: 57.6%). A seasonal analysis showed that modifying the indoor conditions greatly affected summer values, as the heating demand from OA to OB decreased by 21.4%, compared to a 36.6% reduction in cooling.

Type R scenarios reflected the effect of improving the vertical opaque envelope (façade enclosures) through energy retrofitting. Improving thermal insulation lowered yearly demand in both cases (RA, RB), although the reduction was more noticeable in the lower intensity scenario than in the higher one: RB=33.2%; RA=29.9%. Lower demand was observed primarily in winter, with a greater decrease in heating (RA: 45.9%; RB: 51.2%) than in cooling demand (RA: 18.5%; RB: 16.8%) as a result of façade insulation. As stated, façade improvements greatly impacted heating, reducing the energy needs to around half the initial requirement. Although demand for cooling was also reduced, this decrease was less than one-fifth of the initial value.

The climate change (CC) scenarios assumed an intensity use of type B or lower, considered to best represent the predominant conditions in this housing stock. The assessment for the year 2050 indicated a significant change in energy performance, even under moderate use. In the future scenario, climate change with higher mean temperatures and longer summers made the winters much less severe, thereby raising the weight of summer time demand in the total. The net result was a considerable reduction in heating demand, even with the original envelopes, with an equally considerable rise in cooling demand, even under less strict summertime temperature targets (compared to current standards for premises with mechanical HVAC systems).

In the future scenario, façade improvements (FRB) improved the control of yearly demand, reduced by 23.3%, attenuating the effects of CC and delivering yearly values similar to those recorded for the original situation (OB). However, this effect was not balanced as the relative weights of seasonal performance were highly impacted and both scenarios (OB and FRB) were rendered unsuitable for comparison. In FRB, cooling (86%) clearly prevailed over heating (13.4%).

In this scenario, heating demand was marginal, dipping to values below half those of the scenario without façade improvements (FOB) and to less than one-third of the current values assuming low intensity use (OB). These observations reinforce the idea that thermal resistance of the enclosure is a primary factor in preventing energy loss. In contrast, the difference in present and future cooling demand assuming CC is under 15%.

While the relative values would appear to indicate much more significant reductions in heating than in cooling demand, the absolute values revealed a more balanced situation. Insulating the façade lowered heating demand by 54.9% and cooling demand by just 14.1%, whereas the overall reduction was actually 4.5 kWh/m^2 for heating and 3.9 kWh/m^2 for cooling. This can be explained by the relatively low heating and high cooling demand in this scenario. The differentials in absolute terms given in Table 7 show that façade insulation had a greater effect on heating; the greater the indoor-outdoor temperature difference, the higher the impact. The same pattern was observed in connection with the overall reduction in cooling demand between FOB and FRB, compared to the more moderate findings for OB and RB.

3.3. Application to general stock models

After analysing the variability and dispersion of energy demand for each regime under the different study scenarios (Annex 1) together with the density traces, behavioural models can be established to represent the population, providing an image of possible evolution under the different scenarios of the set of residential buildings.

Therefore, the proposed models should be applied to the information of the entire housing stock, returning to previous analyses for the study of specific cases, or to behaviour groups to avoid possible deviation of the data when modifying the scale.

Distribution models were selected for the best fit. A Kolmogorov-Smirnov non-parametric test was applied to verify the fit to the proposed distributions, with the best fit within 70.11% of the population (95% significance) and non-rejection of the null-hypothesis (K-S p-value>0.05). The results and complementary tests are shown in Annex 2.

Analysis of the data obtained allows representative probabilistic distributions to be incorporated in order to forecast a performance model to be exported to the general case set, providing a general prediction model based on probability (assuming the approximation). Normal distribution or related types of distribution (i.e. inverse Gaussian) were selected to ensure better applicability and commonality. The prediction models of the annual energy demand for thermal conditioning of the OB, RA, R and FOB scenarios can be adjusted to a normal probabilistic distribution. At the same time, the OA and FRB scenarios are better represented by an inverse Gaussian distribution (Figure 8). Table 7 shows the defining statistical parameters of the different distributions.

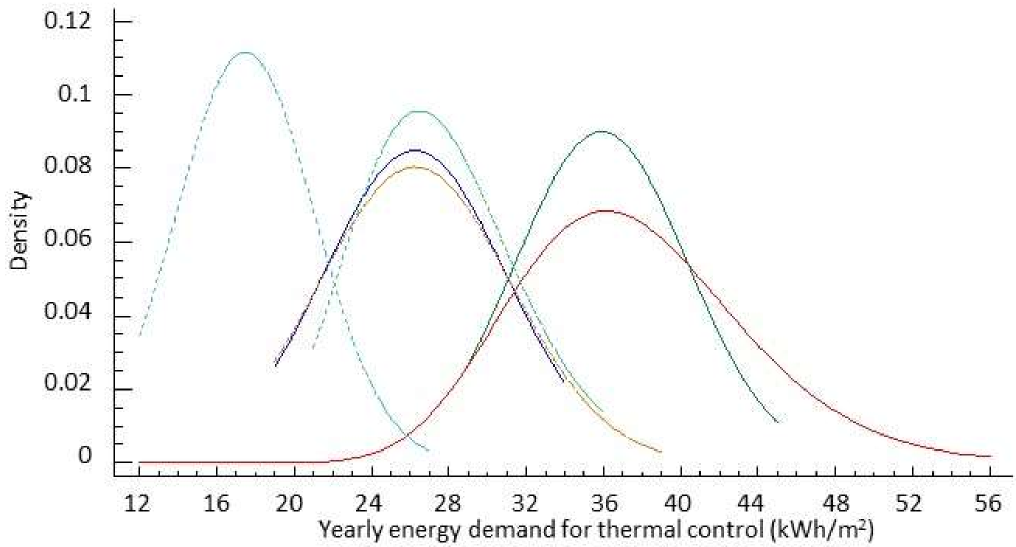


Figure 8: Probability distribution for overall energy demand per unit of gross floor area (kWh/m^2) in six scenarios. OA: Red; OB: Blue; RA: dot-Orange; RB: dot-Cyan; FOB: Green; FRB: dot-green

Table 7. Statistical parameters for the distributions in Figure 8.

Scenario	Mode	Scale	Tolerance intervals	
			Upper limit (kWh/m^2)	Lower limit (kWh/m^2)
OA	34.67	4.92	49.01	29.00
FRB	27.48	41.2	24.88	12.52
	27.4643	41.0988	34.8	21.2
Scenario	Mean	Standard deviation	Tolerance intervals	
			Upper limit (kWh/m^2)	Lower limit (kWh/m^2)
OB	26.22	4.7	47.8693	4.6020
RA	26.25	4.93	49.01	3.42
RB	17.48	3.57	33.92	1.03
FOB	35.88	4.42	33.17	18.98

The results obtained are in keeping with other research, which establishes that total energy needs in mild and warm zones will increase despite the significant reduction in the influence of the heating. This is the case of the USA [30], mild Australian climate zones [76], and especially

Mediterranean areas such as Greece, with a significant reduction in heating needs and a substantial increase in cooling demands [31]. Mild zones may be the most sensitive to change, given the predominance of lower performance buildings, as has also been pointed out by [76] and [77] in relation to social housing in Brazil.

4. Conclusions

The collection of stock-representative samples did not exhibit uniform performance values, as was expected. The distribution was characterised by a wide base with broad scattering and around 50% differences between maximum and minimum values for most of the scenarios. Although many of the models share construction definitions (particularly in façades), the forecast values were not clustered or directly associated with such factors. In fact, demand was the result of the combined effect of the many complex factors defining each model.

Strategies based on the improvement of the envelope insulation, particularly its opaque components, improve building-stock performance. This is mainly noticed during cold periods, providing the occupants practise thermal control close to the standards, which currently differ from real behaviour. This effect weakens as the climate evolves.

The choice of the energy intensity model plays a fundamental role in predicting the performance of improvement measures. When more realistic indoor control schemes and reliable set-points are used, the energy saving potential of the insulation-based actions is noticeably reduced, decreasing the actual weight of winter in the energy balance, especially in the case of future scenarios. Façade improvements were less effective in reducing consumption in scenarios characterised by lower energy-intensity with fewer temperature requirements or considering future climate change actions (where the cold season is not as influential). In these cases, although the decrease observed was proportionally significant (around 50% for heating demand in the scenarios analysed), the absolute figures were less so. These results directly impact the cost-effectiveness of intervention.

Retrofitting by adding thermal insulation to the envelope had less impact on cooling demand, which decreased by less than 20% in these scenarios. The impact of this insulation was less noticeable in the future climate change scenario than in the current one. The reduction in demand was lower, decreasing from over 30% to under 24%, while the absolute values were particularly small in the current scenario and distribution was inverted: the decrease was lower in winter than in summer. Nevertheless, we should bear in mind that heating demands are more likely to translate into actual energy consumption, primarily because dwellings are occupied for more hours in winter than in summer, so that the analysis of heating demands should not be ruled out.

Although the effect of climate change on the area is quite mild in comparison to other European locations [21], [31], [78], [79], this process shows the potential disruption to the energy performance of the oldest housing stock. There is a need for a transition towards a building energy performance model that is less dependent on the thermal resistance of the envelope and thus more dependent on the building type and solar radiation management. The expected rise of the cooling demand (with higher loads and longer warm periods), along with shorter periods with heating needs will result in a change of the energy profile of the buildings, possibly leading in turn to a significant increase in the annual demand compared with the current situation (around 50%). This demand will result in real consumption depending on the evolution of the use of Air Conditioning in residential buildings and the situation of energy poverty of the population, despite the significant impact foreseen.

Although heating total loads will decrease in this climate process they will still be present, and the comfort and health of inhabitants will be a driving force (due both to exposure time and to the presence of anomalous climate periods such as extreme weather episodes). It should be remembered that this performance does not have a homogeneous distribution but rather displays scattered behaviour. Therefore, the stock includes buildings with high heating demands even under warm scenarios (commonly buildings associated with lower income population where energy poverty usually occurs).

Under future climate change scenarios, incident solar radiation energy-gains would increase their year-round effect due to increased surface irradiation. The longer warm seasons will increase the contribution of façades to the capture of radiation energy, thus widening the gap between buildings that are properly oriented and those that are not. Roofs will become a key envelope element, especially in buildings with a higher roof to gross floor-area ratio (low rise collective homes) unlike the usual situation of the current stock, where the roof envelope is less important in the overall demand of the entire building. Therefore, roofs should be a major focus for improvement actions.

However, there is a key factor in energy performance which cannot be modified for existing stock layout, as it is inherent in its construction. The solar orientation and the sun blockades of the buildings and their surroundings will play an increasing role in energy demand values, with buildings with similar features presenting higher divergences depending on boundary conditions.

While the building type and boundary factors of built heritage cannot easily be modified, these can be used as design rules for future development in the region, both in terms of city planning and future construction. The key role of the orientation and proper design of the surroundings in the future Mediterranean city should be understood and tackled.

The most balanced performances (annual figures) —under all scenarios— are found in medium to high- rise buildings with façades with multiple orientations and limited vertical solar obstructions. Suitable performances are also found in buildings with two predominant façades (mainly NW-SE orientations) but with good solar protection, displaying low cooling demands at the expense of higher heating needs. Buildings with SW-NE orientation are the most common and usually present overall mean performances which vary in accordance with their degree of solar obstruction. In contrast, façades with E-W orientation are the least favourable for both types of demand, with higher impact in low-rise buildings.

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Annex 1

Table A1.1. Statistical summary of heating energy demands in six scenarios

Scenario	*Mean*	*Standard deviation*	*CV*	*Minimum*	*Maximum*	*Range*	*Standard bias*	*Standardised kurtosis*
OA	15.91	6.16	38.7%	6.72	25.45	18.73	0.097	-0.849
OB	12.53	4.44	35.4%	5.2	19.7	14.5	-0.081	-0.722
RA	8.62	4.33	50.2%	3.62	15.67	12.05	0.717	-1.014
RB	6.08	3.65	60.1%	2.08	12.45	10.37	0.902	-0.811
FOB	8.24	3.15	38.3%	3.06	13.18	10.12	-0.006	-0.760
FRB	3.74	2.13	57.0%	1.61	7.86	6.25	1.356	-0.436
Total	9.19	5.71	62.2%	1.61	25.45	23.84	3.011	0.278

Table A1.2**:** Statistical summary of cooling energy demands in six scenarios

Scenario	*Mean*	*Standard deviation*	*CV*	*Minimum*	*Maximum*	*Range*	*Standard bias*	*Standardised kurtosis*
OA	21.60	4.29	19.8%	13.17	29.22	16.05	-0.575	-0.120
OB	13.68	2.43	17.7%	8.53	17.76	9.23	-0.766	0.257
RA	17.63	4.03	22.8%	11.15	26.11	14.96	0.448	0.155
RB	11.39	2.81	24.7%	6.91	16.06	9.15	0.015	-0.182
FOB	27.64	3.27	11.8%	20.98	34.68	13.70	0.256	0.938
FRB	23.74	4.26	17.9%	17.77	32.60	14.83	1.204	0.147
Total	19.28	6.66	34.5%	6.91	34.68	27.77	0.667	-1.617

Table A1.3**:** Statistical summary of total energy demands in six scenarios

Scenario	*Mean*	*Standard deviation*	*CV*	*Minimum*	*Maximum*	*Range*	*Standard bias*	*Standardised kurtosis*
OA	37.52	6.27	16.7%	29.02	49.06	20.04	0.680	-0.701
OB	26.22	4.70	17.9%	18.98	33.17	14.19	-0.034	-0.823
RA	26.26	4.96	18.9%	19.67	37.32	17.65	0.962	0.232
RB	17.47	3.56	20.4%	12.52	24.88	12.36	0.686	-0.242
FOB	35.88	4.42	12.3%	29.66	44.37	14.71	0.078	-0.376
FRB	27.48	4.41	16.0%	21.23	34.84	13.61	0.396	-0.679
Total	28.47	8.18	28.7%	12.52	49.06	36.54	0.752	-0.753

Annex 2

The distribution characteristics for each case were defined based on their parameters. The Test battery panel performs different approaches designed to determine if the data could reasonably come from the selected distribution or not (most on the case of normality). For each test the hypotheses are:

- Null hypothesis: the data are independent samples of a normal distribution
- Hypothesis Alt .: the data are not independent samples of a normal distribution

Since the smallest P-value of all the tests performed is greater than or equal to 0.05, the selected distribution cannot be rejected with 95% confidence.

The tolerance interval for each distribution was provided, with 95% confidence, and the certainty that at least 70.11% of the population is included (Table 7).

Table A2.1. Statistical summary of models in six scenarios

Distribution		Mean	STD	Scale	
OA	Inverse Gaussian	37.528		39.1797	
OB	Normal	26.2357	4.700		
RA	Normal	26.2571	4.96072		
RB	Normal	17.4786	3.5732		
FOB	Normal	35.8929	4.43577		
FRB	Inverse Gaussian	27.4643		41.0988	
Chi-square	Chi-square	G.1.	p-value	>0.05 (95%)	
OA	2.3710	2	0.3055		
OB	0.77965	2	0.6775		
RA	0.8450	1	0.3579		
RB	1.5786	1	0.2089		
FOB	2.49434	1	0.1142		
FRB	2.23574	2	0.3269		
Kolmogorov-Smirnov	D+	D-	DN	p-value	>0.05 (95%)
OA	0.18366	0.09111	0.18366	0.7324	
OB	0.104798	0.135352	0.135352	0.9596	
RA	0.101252	0.0931152	0.101252	0.9987	
RB	0.16268	0.1231	0.16268	0.8525	
FOB	0.16485	0.16148	0.16485	0.8412	
FRB	0.08639	0.10684	0.10684	0.9972	
Anderson-Darling	A^2	Mod. form	p-value	>0.05 (95%)	
OA	0.338383	0.338383	>=0.10		
OB	0.264951	0.282186	0.637368		
RA	0.2188	0.23312	0.7978		
RB	0.3314	0.3529	0.4655		
FOB	0.452514	0.4819	0.2310		
FRB	0.20117	0.20117	>=0.10		