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Article

Reducing the Energy Demand of Multi-Dwelling Units in a Mediterranean Climate Using Solar Protection Elements

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Abstract: It is known that glazed openings are very important elements in the energetic behavior of buildings, especially in Mediterranean climates where there are many hours of solar radiation. The objective of this study was to determine the influence of solar protection on the energy demand of public housing structures in these climates. To this end, the reduction in energy demand achieved by fixed solar protectors in combination with mobile protectors (blinds) was quantified, including an evaluation of the influence of their geometry, dimensions, degree of openness, and the orientation of the opening. To analyze and quantify energetic demand, a block of public housing units in a neighborhood of Seville (latitude 37°23' N) was used as a model. This block is typical of public housing in the Mediterranean region. Simulated energetic models were created using DesignBuilder, achieving reductions in the annual energy demand from 10% to 27% according to the orientation chosen. The results and conclusions of the study are applicable to new construction, energetic rehabilitation projects, and/or the improvement of existing buildings.

Keywords: solar protection; energy demand; energy efficiency; energy saving; social housing buildings; building design

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1. Introduction

This study is part of the Research, Development and Innovation project known as *Efficacia*, financed by the Andalusian Government and by companies in the construction sector, with an overall objective of reducing the energy consumption and environmental impact of public housing in southern Spain [1]. To achieve this objective, the project has analyzed the incidence of each thermal envelope component in a block of public housing units with an enclosed courtyard. This methodology has involved activities planned in several stages, and the housing block has been the subject of a broader energetic description project. The first phase of this project was to monitor this housing building under real occupation conditions, with the goal of analyzing and creating parameters for energetic consumption and demand over the course of two years. This first phase was accompanied by a series of surveys regarding the consumption habits of the renters [2]. In the second phase, the reduction in energetic demand through modification of the exterior envelope components (passive systems) was evaluated [3]. The third and final phase centered on the control and automation of ventilation using active systems and solar protection elements. This final phase is the subject of this article, in particular, the influence of façade solar protection elements on the energetic demand of the analyzed housing units.

Façade solar protection elements are known to play a relevant role in the energetic demand of buildings because they have a large influence on one of the factors that greatly impacts this demand: solar radiation. There are many published architectural studies on solar protection elements [4–7]. In general, the majority of these studies focused on the influence of façade solar protectors on light regulation, and thus, solar protectors were discussed in the context of natural lighting [8]. However, the study of Jaber *et al.* [9], similar to the present work, is focused on the variation of the energy consumption through the use of different types of orientation of the building, window sizes and thermal insulation thickness, for typical residential buildings located in the Mediterranean region. They concluded that, using best orientation, optimum size of windows and shading devices, and optimum insulation thickness in dwellings, energy annual consumption can be reduced by about 27.59%. There are studies in the field of energy that use simple, generic models of a rectangular parallelepiped enclosure containing only one window. The objective of these is to determine the optimal angle for the slats in a horizontal overhang, using only latitude as a variable [10]. In the case of housing units, the work of Chan *et al.* [11], in which the percentages of total energy savings achieved by a climate control system in a typical Hong Kong dwelling were sampled, is especially important. Using simulation models, Chan studied the energetic consumption of the typical dwelling with and without solar protection elements (balconies) in different orientations. In Mediterranean climates, studies of energy savings using rectangular dwelling models that are 3 × 4 × 3 m (width × length × height) [12] are also worth examining.

Among the studies that have analyzed the influence of certain types of solar protection on the interior thermal environment (operative and radiant temperature), we highlight those of Bessoudo *et al.* [13]. They performed experimental measurements of an office building located in Montreal using two types of solar protection: rolling-type cloth shades and horizontal aluminum blinds. This study, applicable to office enclosures with two thirds of the south-facing façade composed of glass, was later complemented by another study of which the objective was to quantify the capacity of different types of glass, with varying thermal resistance and solar factors, to achieve interior thermal comfort in this type of space [14].

Lee and Tavil [15] studied the total energy demand and peak consumption in office buildings by analyzing the influence of horizontal overhangs. They varied dimensions and position relative to the window for the different ratios of glazing surface to total façade area in Chicago (41°50' N) and Houston (29°46' N).

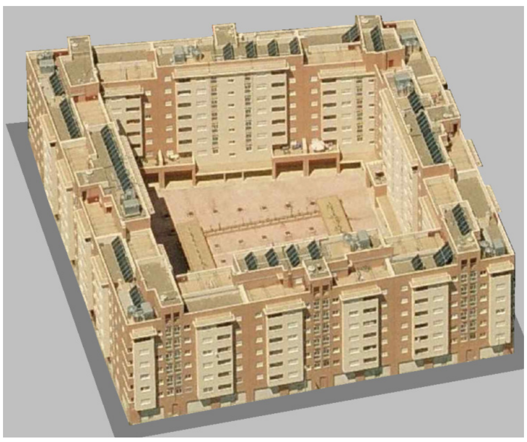
This study uses a real housing unit of which the initial energetic behavior has been contrasted and validated to generate a base model of the behavior and evolution of energy demand. The two most common types of solar protection were used: (a) horizontal overhangs above the openings (HO), simple (Ss) and double (Sd) side fins, and protections combining overhangs and side fins (BX); and (b) fixed and mobile horizontal louvres (L) and mobile exterior blinds (B). Independent of the existence of some type of exterior solar protection, in Mediterranean dwellings, the use of opaque blinds or some other form of external shading (e.g., Roman-type shades or Venetian blinds) is very widespread, therefore, this study examined the potential reduction in energetic demand by combining several types of fixed solar protector elements with the usual mobile ones (blinds), to more closely reflect reality.

Energetic demand is defined as the useful energy required for maintaining the interior of the dwelling within the indicated temperature conditions and hours of use. Based on different theoretical models, the energetic influence and the energy saving potential of solar protection elements were analyzed for facades in the four cardinal directions. The results shown are representative of buildings in housing units with glazed openings that constitute approximately 20% of the total façade surface and with windows that have an average height of 1.2 m (typical parameters in public housing dwellings in the Mediterranean area).

2. Description of the Studied Climate and Building

The building studied, Cros-Pirotecnia, is a multi-dwelling block located in Seville (Spain), with an enclosed courtyard (Figure 1) containing 218 dwellings, retail units, and a garage. This building, developed by the Municipal Housing Company of Seville, was built in 2005. All the dwellings are rental units, with an average usable area of 58 m^2. The total building surface area is 5216 m^2.

Figure 1. Aerial view of the studied building.



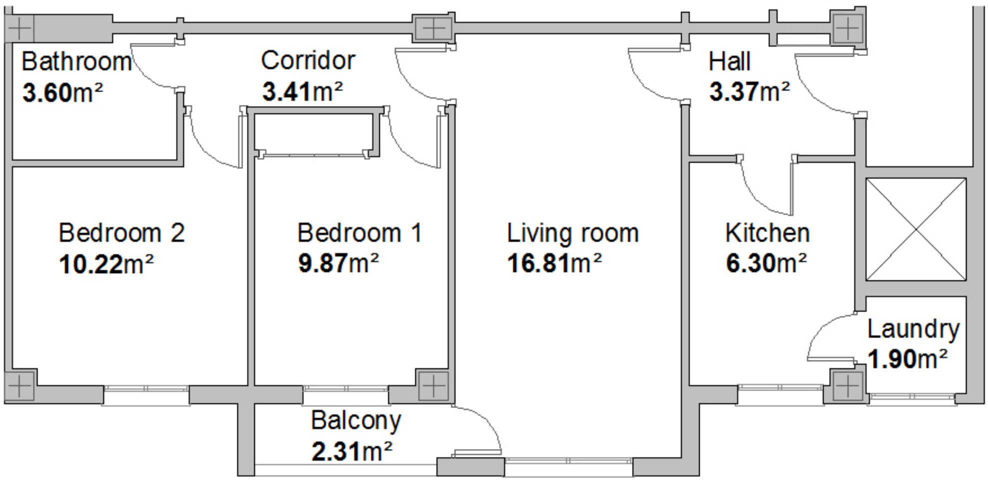
2.1. Weather Data

Seville, located in southern Spain, (37°25' N) (5°54' W), has a Mediterranean climate, corresponding to Csa in a Koppen climate classification, and its altitude is 6–7 msnm above sea level. The climatic profile was obtained from an EnergyPlus weather file (EPW), developed by the U.S. Department of Energy. The file selected for Seville, SEVILLA SWEC (Spanish Weather for Energy Calculations) was created from data originating from Luis Pérez-Lombard at the Spanish National Institute of Meteorology. The climate is characterized as B4 climatic severity (Spanish National Climatic Zonification for Energy Savings, CTE DB-HE1), with mild winters and hot summers [16].

2.2. Study Site

A typical dwelling, consisting of two bedrooms, a living room, a bathroom, and a kitchen, was used as the geometric, functional, and energetic model (Figure 2). The bedrooms each had glazed windows with dimensions of 1.20 m × 1.20 m (width × height), and the dining room had one window measuring 1.80 m × 1.20 m.

Figure 2. Floor plan of the typical dwelling unit studied.



2.3. Structural Conditions

The structural elements of the thermal envelope and interior partitions were typical for this type of building. The surface mass, thermal transmittance (U), and solar factors (in this case, of the windows) are shown in Table 1.

All dwelling unit windows were of the sliding type and were single pane, 6 mm in thickness (Ug = 5.40 W/m^{2}K), with metal aluminum frames without a thermal break (Uf = 5.88 W/m^{2}K). All windows had external blinds that modified the global thermal effects of the opening. As previously shown [17], the use of these elements reduces both thermal transmittance and the solar factor of the window. In the series of simulations for the HO, BX, Sd, Ss, and L solar protectors, both parameters were corrected to obtain the most realistic results for energy demand. When the only solar protection was the blind itself (series B), the original transmittance (U) and solar factor ($g_{\perp}$) for the opening were assumed to not duplicate their reductive effects.

Table 1. Envelope description.

Element	Weight per unit area (kg/m²)	Transmittance U (W/m²K)	Solar factor
Façade	176	0.81	-
Roof	728	0.49	-
Diving wall	189	1.54	-
Partition	25	1.79	-
Floor	519	2.02	-
Glazing	with solar protection: series	4.64	0.66
	HO, BX, Sd, Ss and L with solar protection: series B	5.40	0.82

The thermal transmittance and solar factor modified by the presence of window blinds were obtained adopting the average approximation included in the Spanish Official Energy Demand Limitation procedure (LIDER) [18–20] [Equations (1)–(3)], for an average modification value for the transmittance (U) and solar factor ($g_{\perp}$) due to the partial action of the elements distributed among the various façades (a window coverage of 30% is understood):

$$U_{mod} = U_{orig} \cdot \text{Factor}_U \quad (1)$$

$$\text{Factor}_U = 0.70 + [0.30/(1 + 0.165 \times U_{orig})] \quad (2)$$

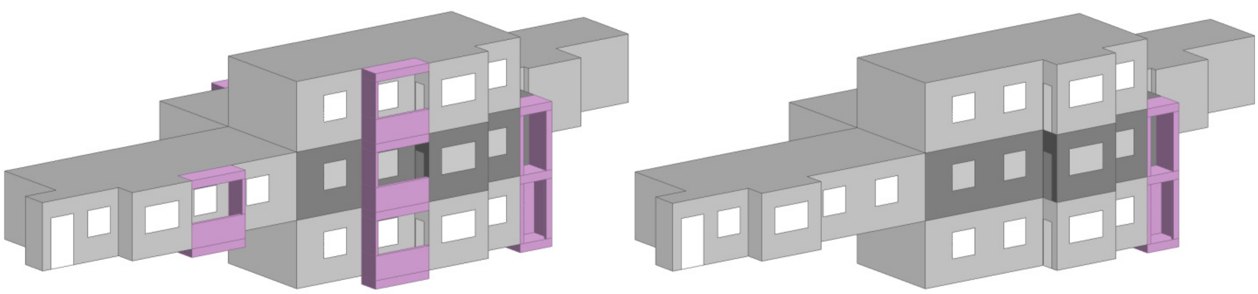
$$g_{\perp mod} = g_{\perp orig} \cdot \text{Factor}_g;\ \text{Factor}_g = 0.8 \quad (3)$$

3. Description of the Methodology

3.1. Energy Models

The energy simulation models were generated and evaluated using DesignBuilder (Version 2.3.6.005). To analyze the influence of balconies, a very typical architectural element in this type of building, two typical dwelling models were used, with and without balconies. In Figure 3, both models are shown, with the dwelling unit studied in this paper highlighted using a darker color.

Figure 3. (**a**) M1: Models with and (**b**) M2: without a balcony.



(**a**) (**b**)

Before continuing with the energy simulation, the energetic base models used in the study were developed after a calibration and validation process. Calibration of the models was done during the

Efficacia project by tuning the energetic simulation models, supported by an 18 months monitoring, energy consumption and inhabitants behavior campaign in the control dwellings, as described in [1–3].

The usage and operation variables for the dwelling were previously described in [3]. The model construction accounted for the units and spaces adjacent to the model dwelling unit. The adjacent habitable spaces had usage and operation conditions similar to the model unit. The non-habitable spaces and community areas had null occupation and standard lighting and ventilation conditions.

The models were considered free of shadows produced by exterior elements (vegetation and/or nearby buildings), as is frequently seen in dwellings situated in the upper stories of these buildings. The shadows projected by parts of the building itself (jutting elements and laundry-terraces) were included in the analysis. For the effects of the energetic demand simulations for each hypothesis, the model unit was considered thermally treated for winter and summer. The influence of natural lighting conditions in the spaces was not considered in the results.

3.2. Solar Protection Series

Six series of solar protection elements (Table 2 and Figure 4) were considered to evaluate their influence on the energetic demand of the model dwelling unit in its two modes (with and without balcony). Each series was coded with letters and numbers according to the dimensions and variables of each protection type. Fixed protections, such as horizontal overhangs (HO), vertical side fins (Ss and Sd), and their combination (BX), were analyzed while varying their primary dimensions. The mobile protection elements (L and B) were studied while varying their dimensions, grade, and opening schedule.

Table 2. Series of solar protectors studied.

Series	Type of Protection (variables parameters)	Variables of the solar protection coding
HO	Overhang (L, W, H)	L = depth of horizontal element (m) W = lateral extension (m) H = height over opening lintel (m) D = depth of vertical element (m) α = louvre angle (degrees over horizontal) I = vertical separation between louvres (cm) % = opening percentage (0:closed; 50:middle; 100:open) T = timing schedule (see Table 3)
BX	Box type protection (L, D, H)	
Sd	Double side fin (D, H)	
Ss	Simple side fin (D, H)	
L	Horizontal louvres (α, I, %, T)	
B	Blinds (%, T)	

The different protection series were available for all of the windows in habitable spaces (living room, bedrooms, and kitchen). When the model dwelling unit was studied with the balcony included for the living room-dining area (model M2), no additional protection for its openings was considered, aside from the effect of the balcony itself. Because all windows were on the same face (single orientation), each simulation analyzed one type of solar protection for all windows. Mobile solar protection elements (series L and B) were studied with automatic opening controls based on incident solar radiation; this function was guided by the schedule indicated in Table 3.

Figure 4. Geometric dimensions of the solar protection elements.

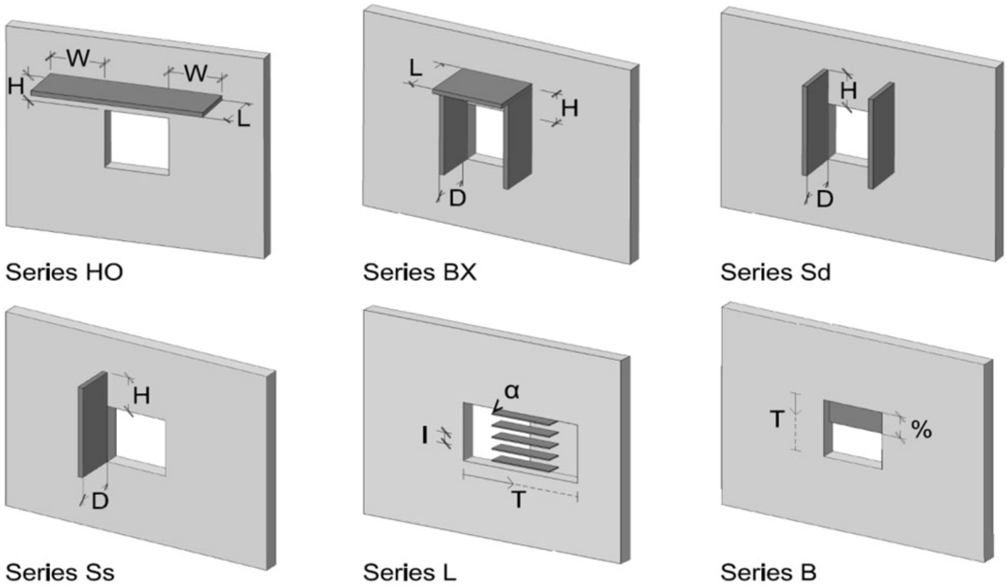


Table 3. Annual timing schedule for louvres and blinds according to orientation.

Facing	Timing schedule							
	Timing 0 Year-round		Timing 1 Summer (May to September)		Timing 2 Summer (May to September)		Timing 1 and 2Winter (October to April)	
North	0:00 to 24:00	% Closed	00:00 to 24:00	% Closed	00:00 to 10:00	Opened	00:00 to 24:00	Opened
					10:00 to 22:00	% Closed		
					22:00 to 24:00	Opened		
South	0:00 to 24:00	% Closed	00:00 to 24:00	% Closed	00:00 to 10:00	Opened	00:00 to 24:00	Opened
					10:00 to 18:00	% Closed		
					18:00 to 24:00	Opened		
East	0:00 to 24:00	% Closed	00:00 to 24:00	% Closed	00:00 to 09:00	Opened	00:00 to 24:00	Opened
					09:00 to 15:00	% Closed		
					15:00 to 24:00	Opened		
West	0:00 to 24:00	% Closed	00:00 to 24:00	% Closed	00:00 to 15:00	Opened	00:00 to 24:00	Opened
					15:00 to 22:00	% Closed		
					22:00 to 24:00	Opened		

3.3. Geometric Optimization of Protections

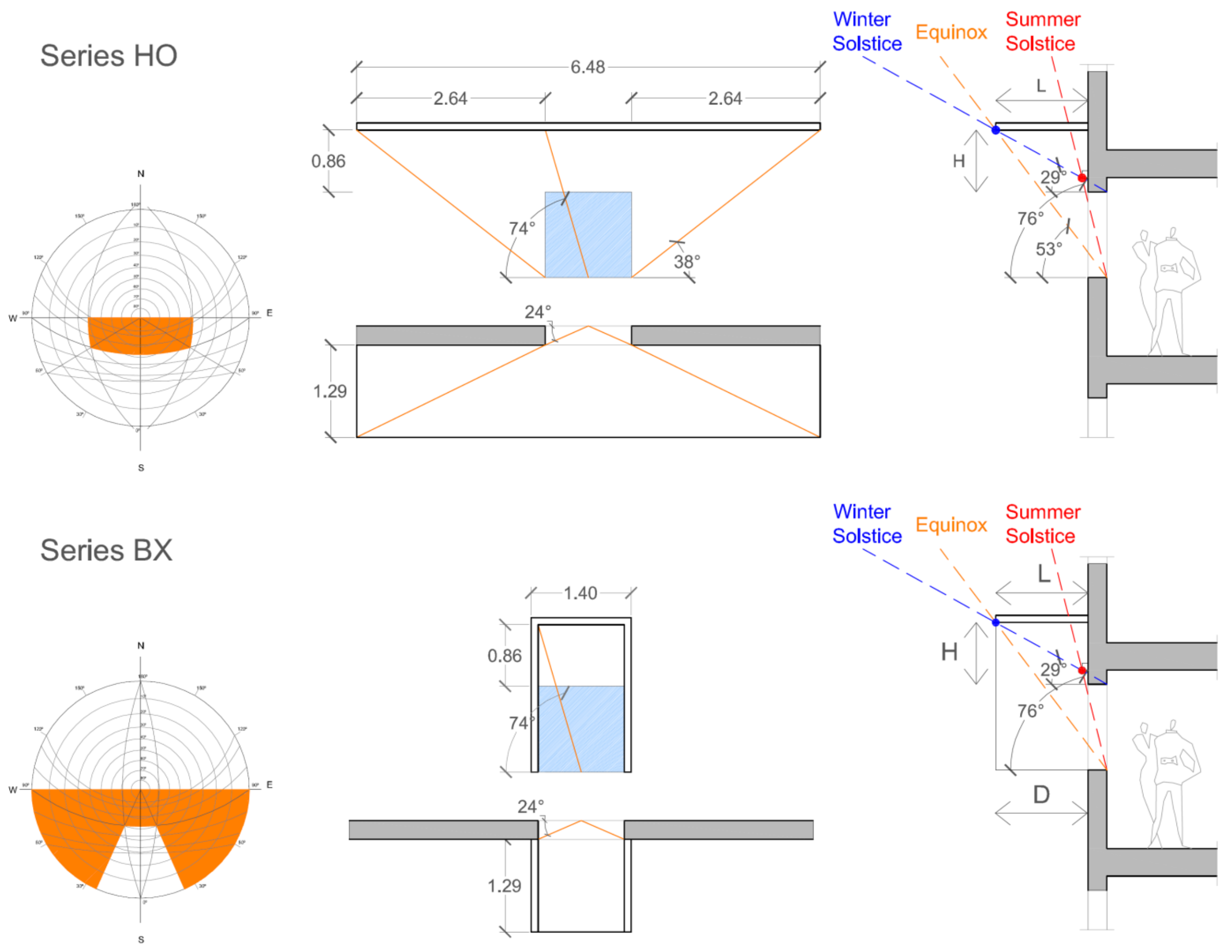
Because of the different seasonal sun elevations for the 12 hours of daylight, the approach shown in Figure 5 was followed to optimize the depth (L) and height (H) of the horizontal protection elements of the HO and BX series. The longest and shortest values for (L) were established through two optimization processes:

(i) Optimization by summer and winter solstice: Lines were drawn at the angle of solar incidence of the summer and winter solstices in relation to the interior face of the opening; the intersection point of both lines provided the optimal height of the protection element with respect to the opening lintel (H) and its minimum length (L) (H = 0.08 m and L = 0.19 m for an opening of 1.2 m in Seville). For

12 hours of daylight, this overhang allowed the complete entry of all solar radiation during the winter solstice and projected complete shade during the summer solstice. For the days in between, the sun entered the opening according to its height relative to the horizon.

(ii) Optimization by winter solstice and equinoxes: To obtain greater solar control of the opening, two lines for the winter solstice and the spring/fall equinoxes were drawn. Their point of intersection denoted the height of the overhang from the window lintel (H) and its maximum length (L) (1.29 m and 0.86 m, respectively). During the 12 hours of daylight, this protection projected shade over the entire opening from the spring equinox until the autumn equinox, impeding increases in thermal gains due to solar radiation during times of demand for cooling. After this moment, the opening began to fall under sunlight till the winter solstice, when solar incidence was at a maximum level.

Figure 5. Determining the maximum and minimum length of the overhangs and lateral fins.



To determine the influence of the (L) and (H) dimensions, three additional positions intermediate to those above were used, as shown in Figure 5. The (W) dimension for the HO protections was fixed to guarantee shade during the least favorable summertime hours. For this, the stereographic solar chart for Seville was used. With the goal of simplification, the (W) dimensions for the solar protections were designed to be symmetrical with respect to the opening and varied according to each half hour of daylight.

4. Analysis of Results

4.1. Energetic Demand of the Model Dwelling in Its Original State

Before analyzing the energetic influence of the different types of solar protection, in Figure 6, the favorable (winter) and unfavorable (summer) impacts of thermal gains from solar radiation through the openings for the model dwelling unit in the two modes (with and without balcony) are shown. The values are shown for a south-facing model unit. In the same manner, in Figure 7, the annual thermal demands (kWh/m^2) for the model dwelling unit based on geographic orientation are shown.

Figure 6. Annual contribution of solar gains in the original dwelling unit (south-facing).

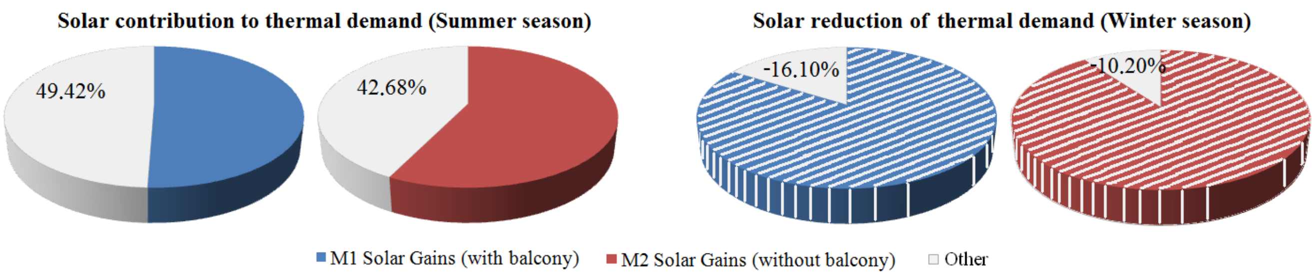
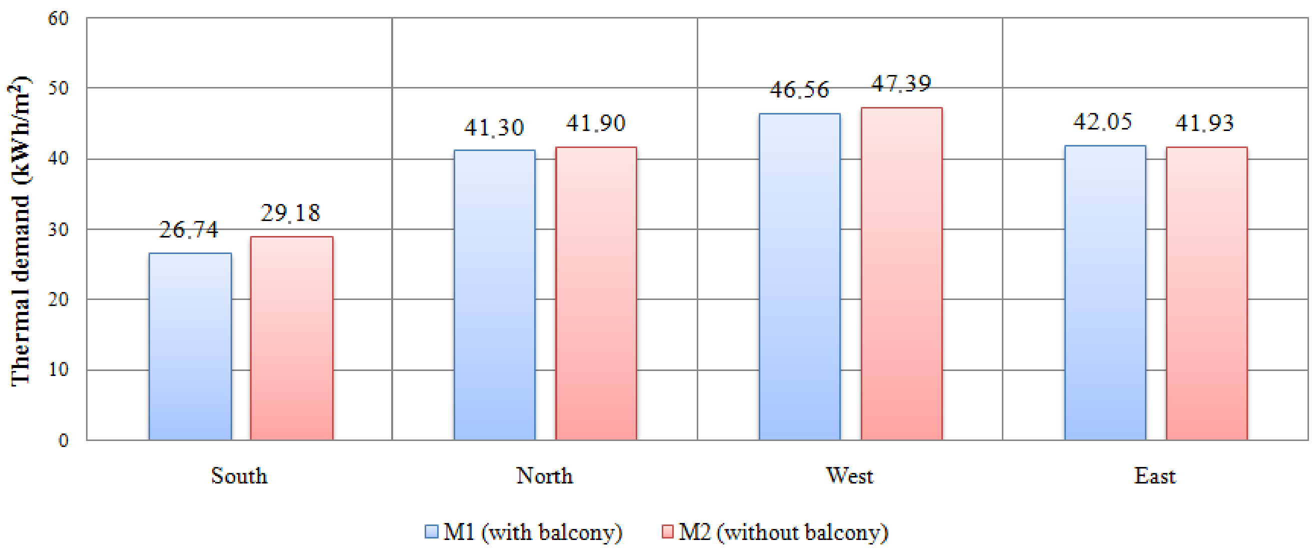


Figure 7. Annual thermal demand by geographic orientation.



The presence of balconies on the façade mostly reduced the demand because the balcony provided optimized solar protection for blocking radiation during the summer, whereas its geometry and dimensions allowed for the benefits of radiation during the cold months. The presence of the balcony created a reduction in demand for the original unit (OU). This reduction was greatest in the south-facing orientation (8.36%) and least when facing west and north (−1.75% and −1.43%), with the eastern façade having a non-significant effect.

4.2. Influence of Each solar Protection Series on the Energetic Demand of the Model Dwelling Unit

In Figures 8 and 9, the results for the annual global energy demand analysis for thermal treatment in the energetic models with different solar protection configurations are shown, according to geographic orientation. These demands were both positive (heating) and negative (cooling), although for the purposes of analysis, they were evaluated in absolute terms, assuming the incorporation of energy into the possible thermal treatment system of the unit. To simplify the results, solar protection is shown in Figures 8–11 only for those series that had the greatest reduction in annual energy demand for each orientation. In the Appendix 2, all of the results from each series of solar protection are shown in detail by geographic orientation and design variables.

Figure 8. Annual thermal demand (South).

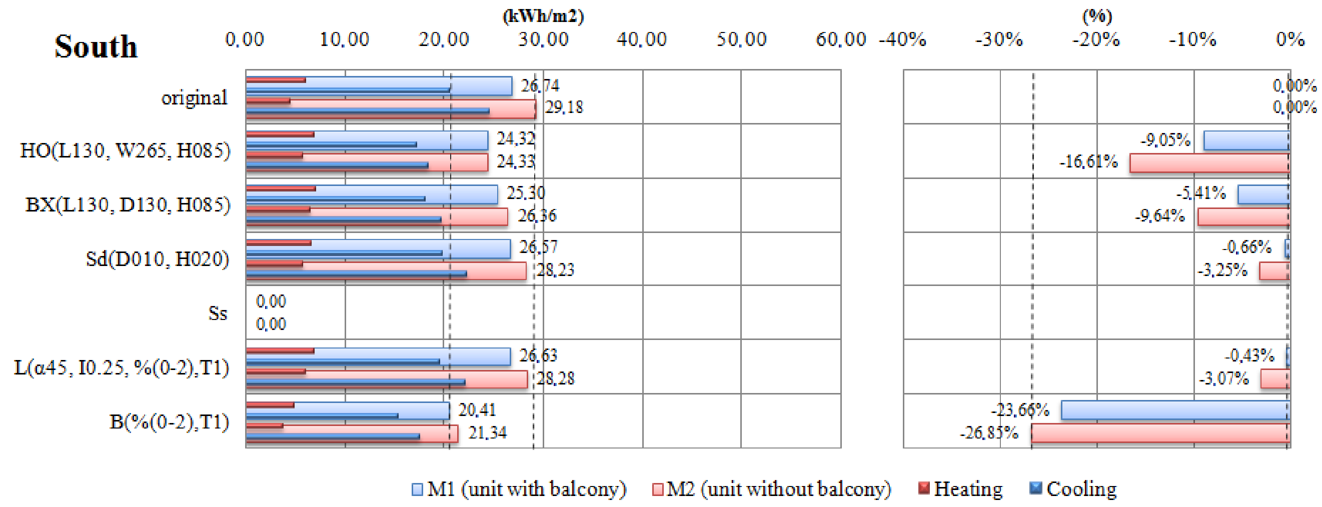


Figure 9. Annual thermal demand (East).

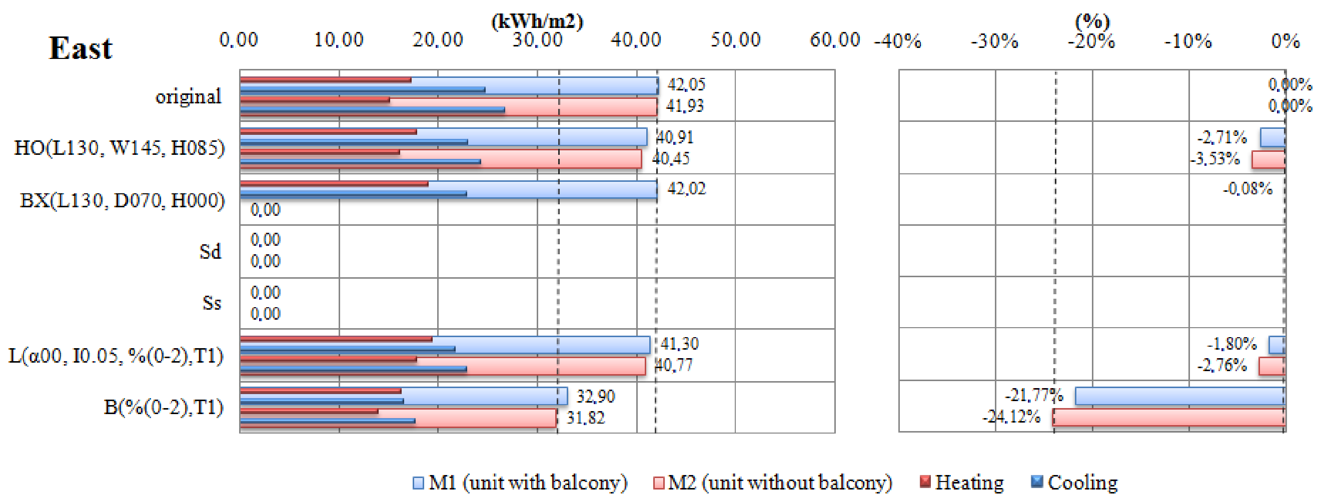


Figure 10. Annual thermal demand (North).

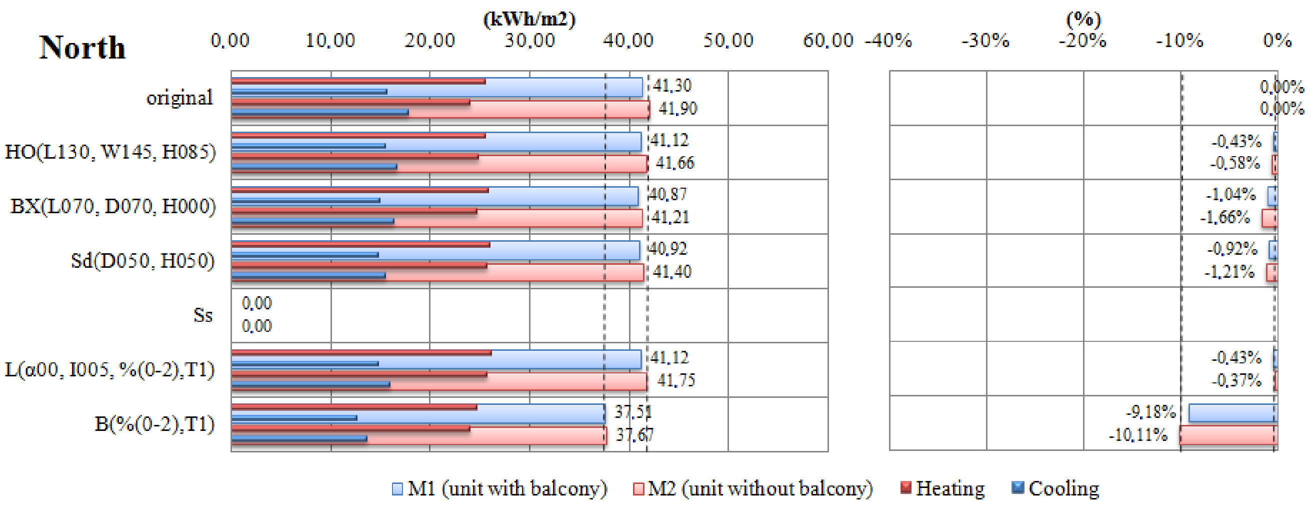
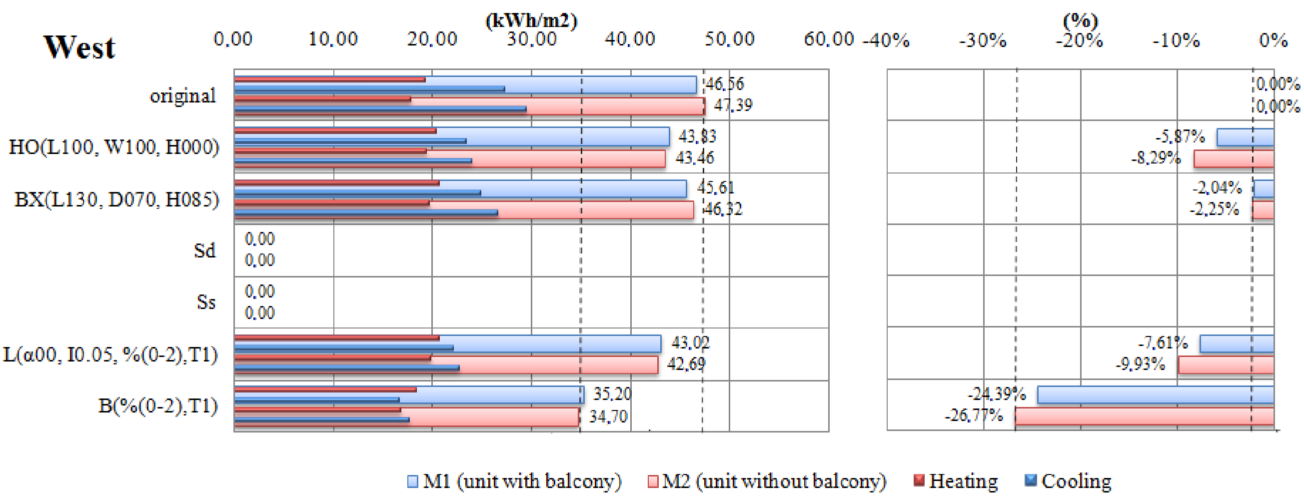


Figure 11. Annual thermal demand (West).

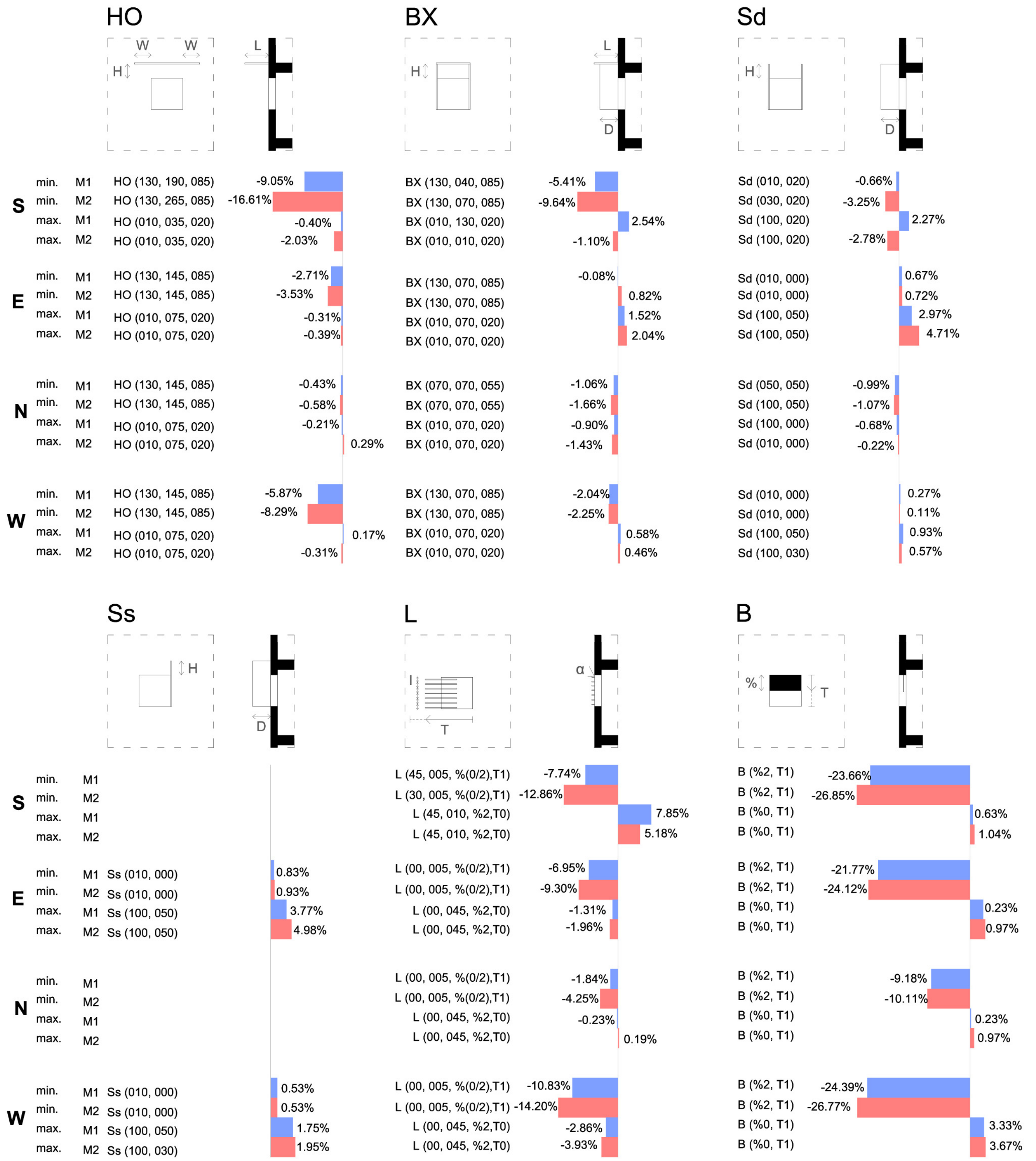


As can be seen, the solar protections that achieved the lowest annual energetic demand are those that maximized favorable solar gains (winter) and reasonably reduced the unfavorable ones (summer solar radiation). In Figure 12, the maximum and minimum annual energetic demands for each solar protection system are shown for the model dwelling unit in its two modes (with and without balcony) for each geographic orientation.

4.2.1. Overhang (HO Series)

The influence of horizontal overhangs (HO series) was most significant for south-facing façades and insignificant for the others, particularly the north. On the south-facing façades, projection beyond the area of the window opening did not have an effect on demand, except at the edge of L between 0.70 and 1.00 m. The greatest influence was obtained by proportions closer to L = 1.30/H = 0.85, primarily because of strong effects during the winter. Good results were also found for L between 0.70 and 1.00 m and H between 0.55 and 0.7 m, increasing with the increasing width of the W element. The presence of balconies barely altered this general behavior, although their presence minimized the protection effect of HO. In the west orientation, significant reductions were only observed with L and W values equal to or greater than 1 m.

Figure 12. Maximum and minimum annual demand for each series.



4.2.2. Box Type Protection (BX Series)

In general, BX series protections did not result in high overall performance, considering that they increased complexity at the design level and in the process of constructing the openings. As with the previous case, the south-facing façades showed noticeable effects, but the blocking of oblique radiation during the winter affected global demand and reduced the effectiveness of BX. For this case, the best results were achieved through greater L and H dimensions, with optimum D values between 40 and 70 cm. In these cases, the improvements increased to approximately 10%. When there were balconies, the effectiveness in the overall results was diluted, and it was not necessary to increase D to more than 40 cm. For the other geographic orientations (N, W, and E), the improvements were minimal and did not provide benefits, even worsening the original situation on the east face.

4.2.3. Simple and Double Side Fins (Series Ss and Sd)

The behavior of the side fin series (Ss and Sd) was quite singular: for the east and west orientations, the traditional locations of vertical protections, Ss and Sd, did not contribute any real reductions in demand. Rather, they worsened it in every situation, increasing demand to 4.7% on the east face. A slight improvement was seen on the north face, which would not justify the incorporation of these elements on the façade.

4.2.4. Horizontal Louvres (L Series)

The use of horizontal louvres created significant reductions in global energetic demand for all geographic orientations except north. The reduction percentages varied between approximately 10% for the east and 14% for the west. In all cases, the best results were produced when the opening and closing program for the protection was set to timing 1. For the south, the optimal separation between louvres (I) was 5 cm, whereas the angle formed by them (α) was not a determining factor. For the east and west, the optimal separation (I) was also 5 cm, but in those cases, the angle (α) noticeably influenced the results.

4.2.5. Blinds (B Series)

The use of adaptable elements such as blinds was shown to be the most efficient method for demand reduction for all of the geographic orientations, while also allowing the benefit of free radiation gains during the winter. The programming of total opening or closing according to timing 1 provided the best results for all combinations. In the non-balcony model, the reduction in demand was approximately 27% for the south and west geographic orientations. In the east orientation, it was slightly lower (24%), and for the north, it was approximately 10%. With the balcony, these improvements were slightly reduced, to approximately 2%–3% (S, W, and E) and 1% (N).

5. Conclusions

From the analysis of the energetic models and the global balance of the demand factors, we can conclude that the reduction in energetic demand for the housing blocks and climate analyzed showed a high potential for reduction in solar protection control beyond the control of the opaque elements in the thermal envelope. In this study, the possibility of a significant reduction in energetic demand using non-fixed or manual-action solar protections that are traditionally used in housing blocks has been verified and quantified. The results varied with geographic orientation, time of day, day of year, building shadows, and/or cast shadows.

In general, fixed protection elements represented an obstruction of free energy gains during the heating period and a reduction of gains during cooling. Solutions with a good overall balance exist because the observed improvements in summer were greater than the drawbacks in winter. In Southern Europe, it is rare to find efficient heating systems, as heating is normally performed by portable Joule Effect systems, and thus, the actual energy consumption of the residence might be multiplied by up to a factor of 3 (based on the type of system used). This alters the usage balance if evaluated in terms of consumption rather than demand. Therefore, solutions offering seasonal adaptability are preferable, including mobile elements (blinds) for all geographic orientations and those optimized by solar geometry (overhangs) on the south faces of buildings.

The suitability of adaptable mobile protections opens the door to the introduction of automatic control systems, which could be managed for optimal behavior independent of the actions or presence of occupants in the building.

Regarding fixed protection elements, for the purposes of housing (minor influence of internal load and use hours that are very distinct from tertiary buildings), the incorporation of other elements beyond south-facing overhangs and generalized blinds or adaptable shutter systems is of relatively little use. The greater constructive complexity that these other solutions entail, their minimal influence on global demand, and their effect in winter cause them to be inadvisable for similar types of housing structures.

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Appendix 1

Table A1. Envelope description.

Element	Composition	Transmittance (W/m^2K)
Façade	½ foot face brick + PUR Insulation + Air chamber + Plasterboard cladding.	0.81
Roof	Gravel + XPS Insulation + Lightweight aggregate concrete + Concrete waffle slab + Plaster coating.	0.49
Diving wall	Plaster coating + Low density ceramic block + Plaster coating.	1.539
Partition	Plaster coating + Ceramic brick + Plaster coating.	1.79
Floor	Plaster coating + Concrete waffle slab + Cement mortar + Artifical stone.	2.024
Glazing	**Thickness**	**Frame**
Single glass	6 mm	Aluminum windows frame without thermal break

Table A2. Protocols used for the demand calculations.

Activity	Value	Schedule			
		Winter		Summer	
Occupation	0.056 pers/m^2	00:00 to 07:00 07:00 to 16:00 16:00 to 23:00	100% 25% 50%	00:00 to 07:00 07:00 to 16:00 16:00 to 23:00	100% 25% 50%
		Weekends & holidays: 00:00 to 24:00	50%	Weekends: 00:00 to 24:00 Holidays: 00:00 to 24:00	100% 0%
Equipment & Lighting	4.44 W/m^2 +4.44 W/m^2	00:00 to 08:00 08:00 to 19:00 19:00 to 20:00 20:00 to 23:00 23:00 to 24:00	10% 30% 50% 100% 50%	00:00 to 08:00 08:00 to 19:00 19:00 to 20:00 20:00 to 23:00 23:00 to 24:00	10% 30% 50% 100% 50%
Infiltration	1 ac/h	00:00 to 24:00	100%	00:00 to 24:00	100%
Ventilation	3 ac/h	00:00 to 24:00	0%	00:00 to 08:00 08:00 to 24:00	100% 0%
Operative set-point temperature		00:00 to 16:00 16:00 to 23:00 23:00 to 24:00	- 20 °C -	00:00 to 08:00 08:00 to 23:00 23:00 to 24:00	- 26 °C -

Notes: Winter: from last Sunday in October to last Saturday in March; Summer: from last Sunday on March to last Saturday on October. Data obtained from CAPALYC document [19].

When building the study model in the program to make the nodal calculation, it is necessary to create the boundary conditions, *i.e.*, the spaces with which the complete dwelling makes contact, they are:

- The dwelling on its left (same floor);
- The dwelling on its left (same floor);
- The dwelling immediately above;
- The dwelling immediately below;
- Access corridor and common areas.

The characteristics of these spaces will be the same as the study location, except the hall, which represents an area without air conditioning and zero occupation and activity. The boundaries of these adjacent areas, which are the exterior and the other dwellings. The latter connection is represented by adiabatic partitions, since the energy exchange with these other rooms is not of great relevance, given the predominance of energy flows to the exterior via the envelope compared to those that occur between the partitions.

Appendix 2

Figure A1. BX Series**:** Annual thermal demand.

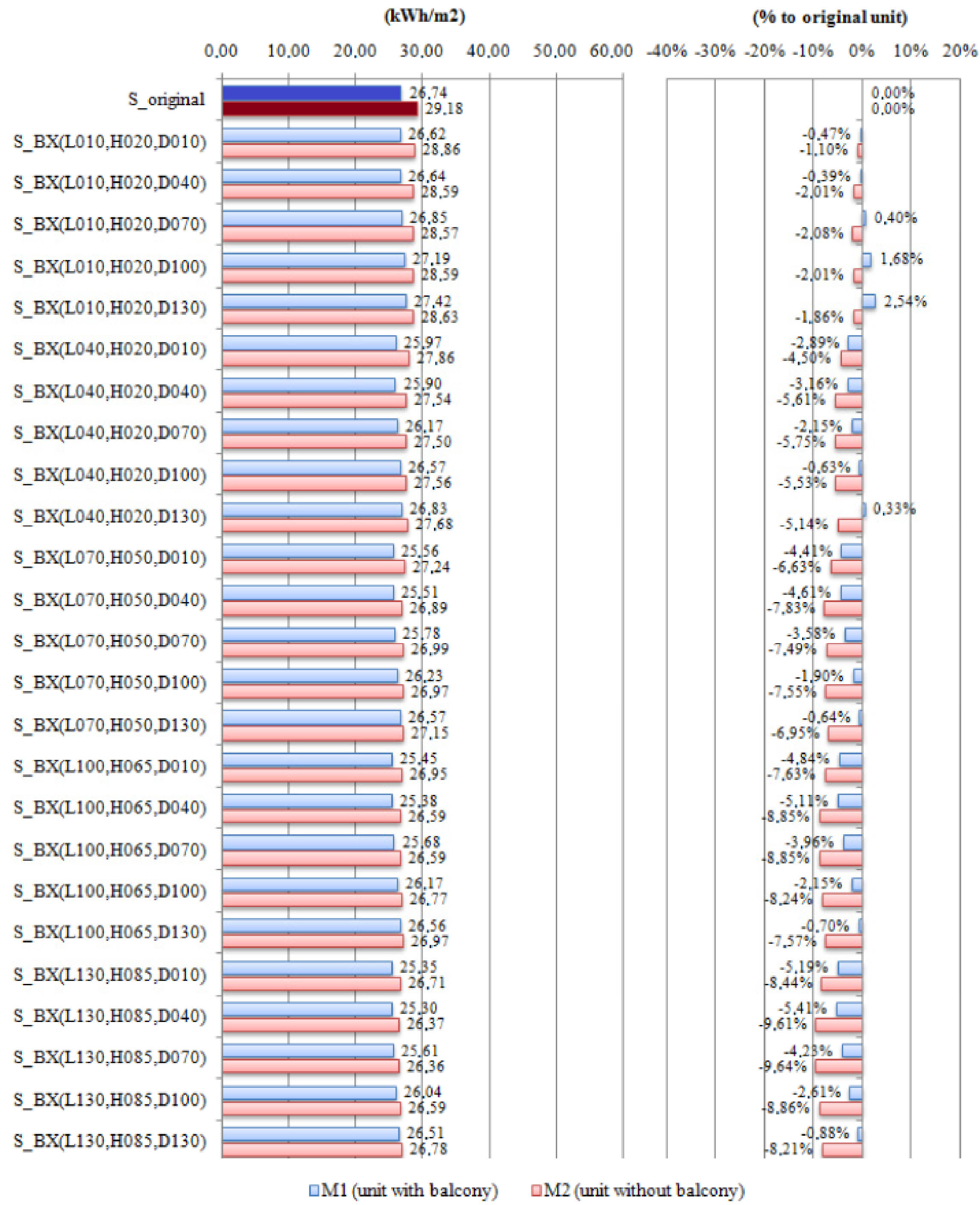

Figure A1. *Cont.*

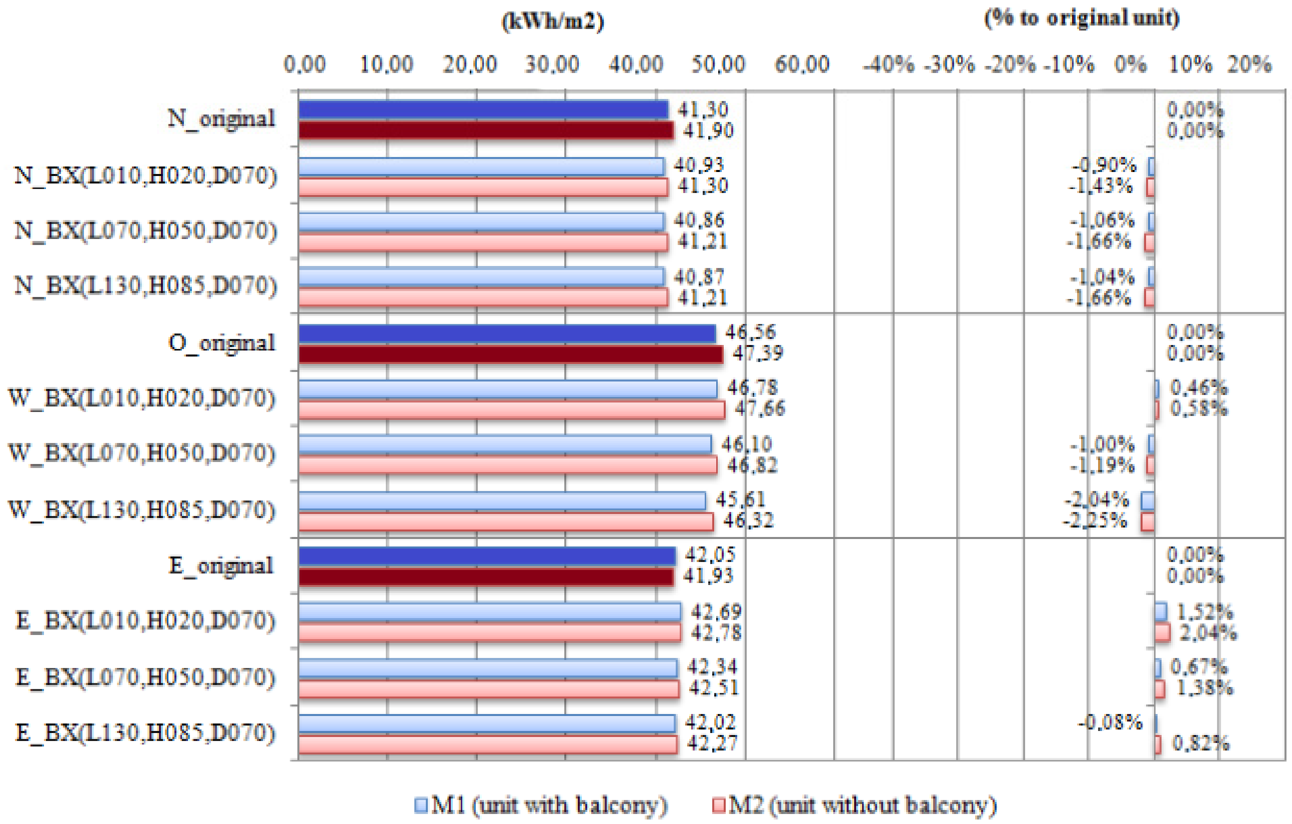

Figure A2. HO Series*:* Annual thermal demand.

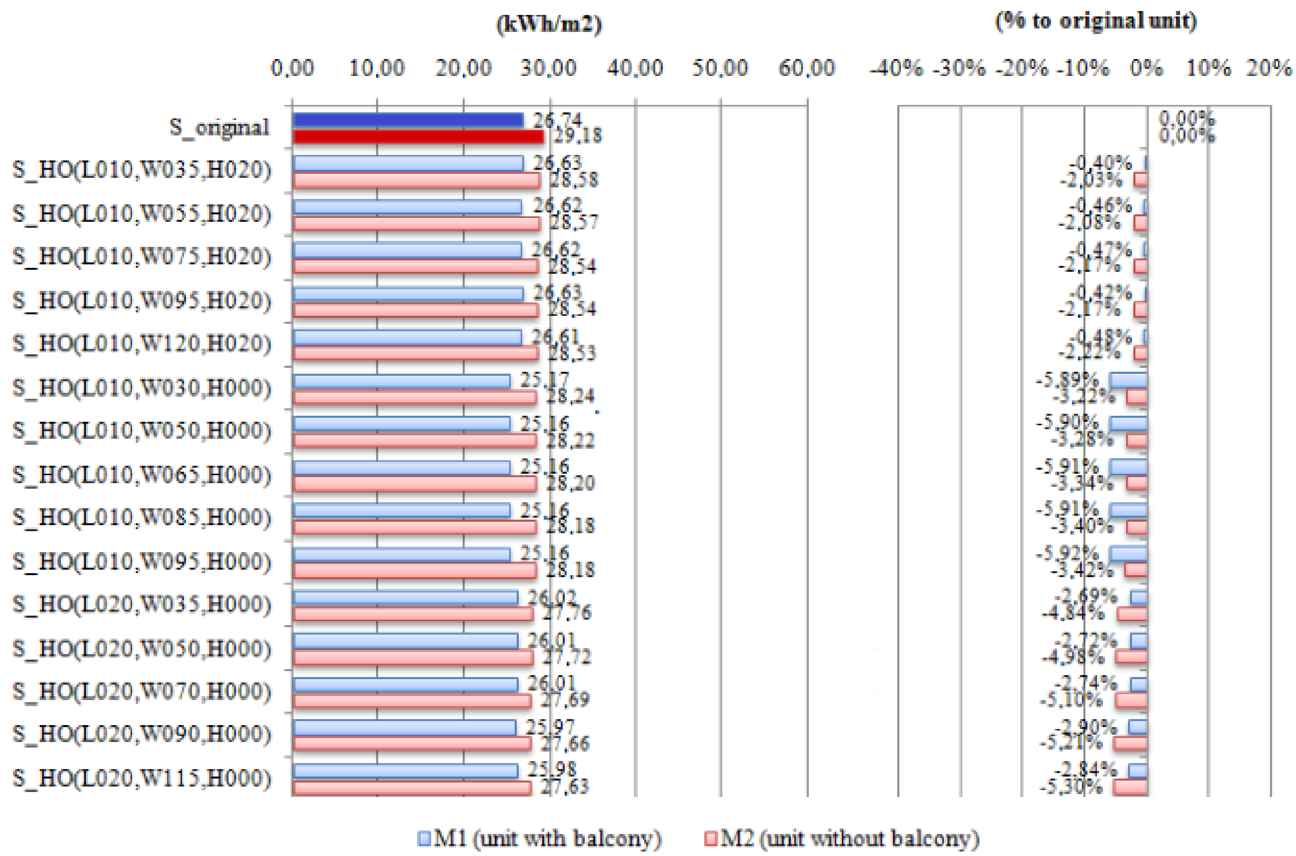

Figure A2. *Cont.*

Figure A2. *Cont.*

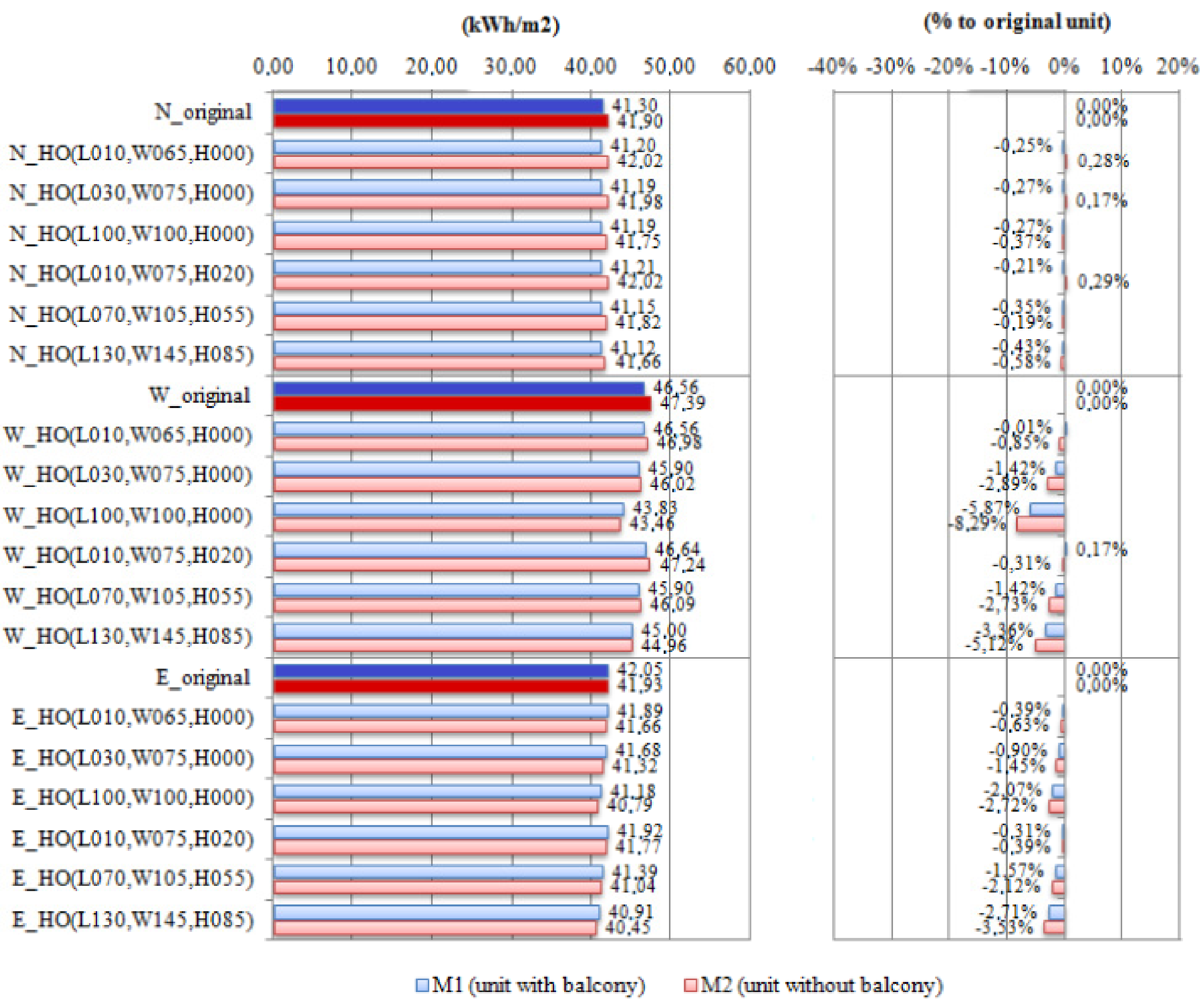

Figure A3. Sd Series: Annual thermal demand.

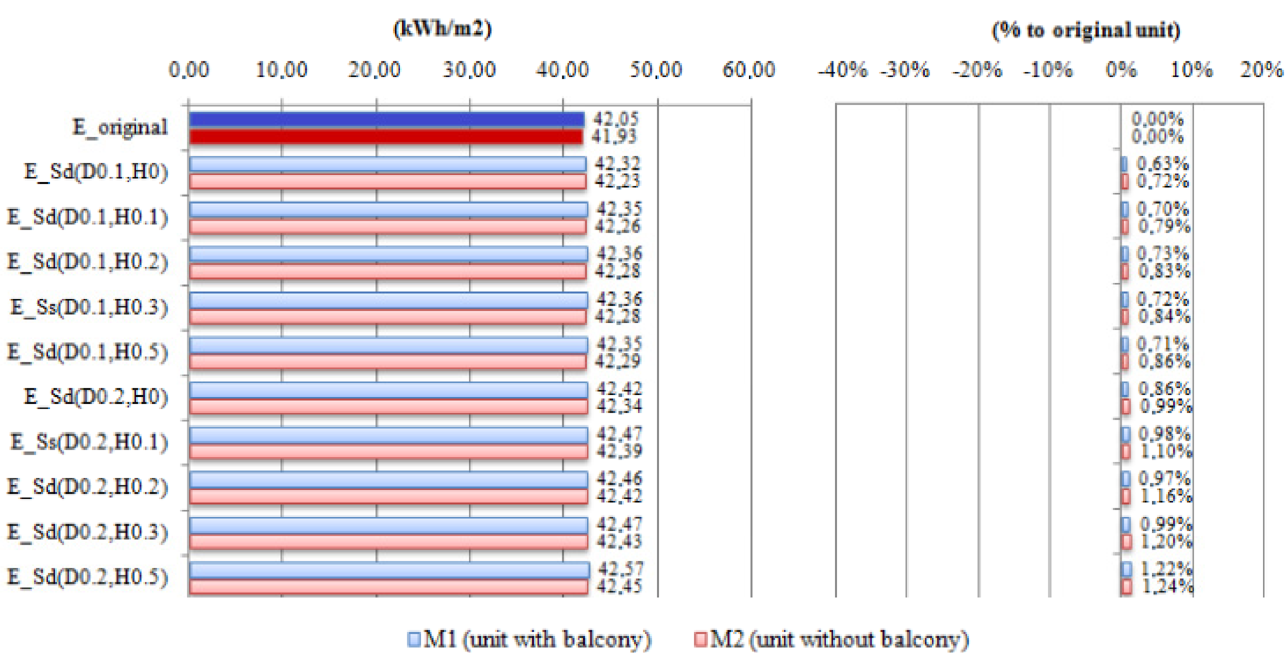

Figure A3. *Cont.*

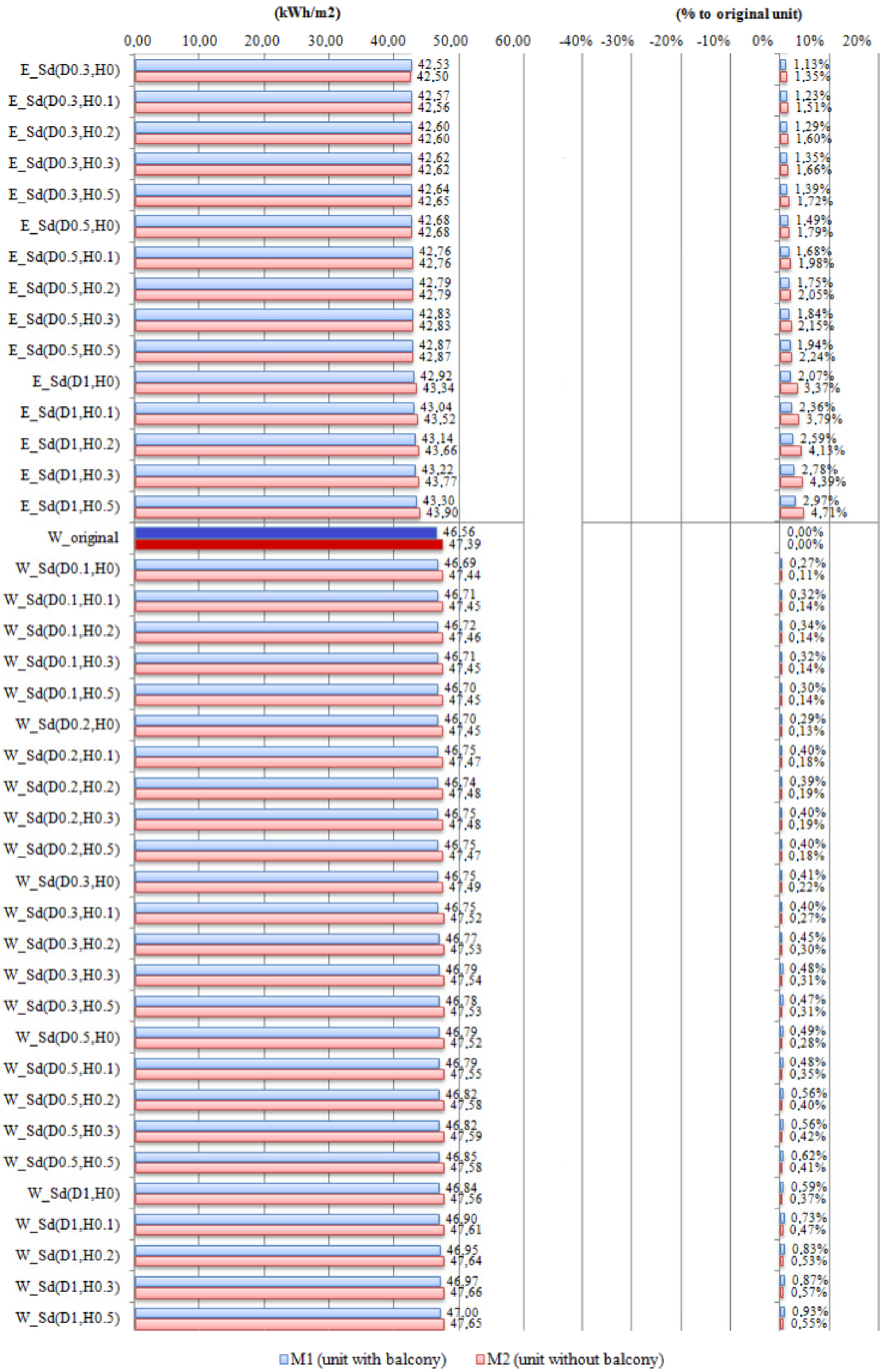

Figure A3. *Cont.*

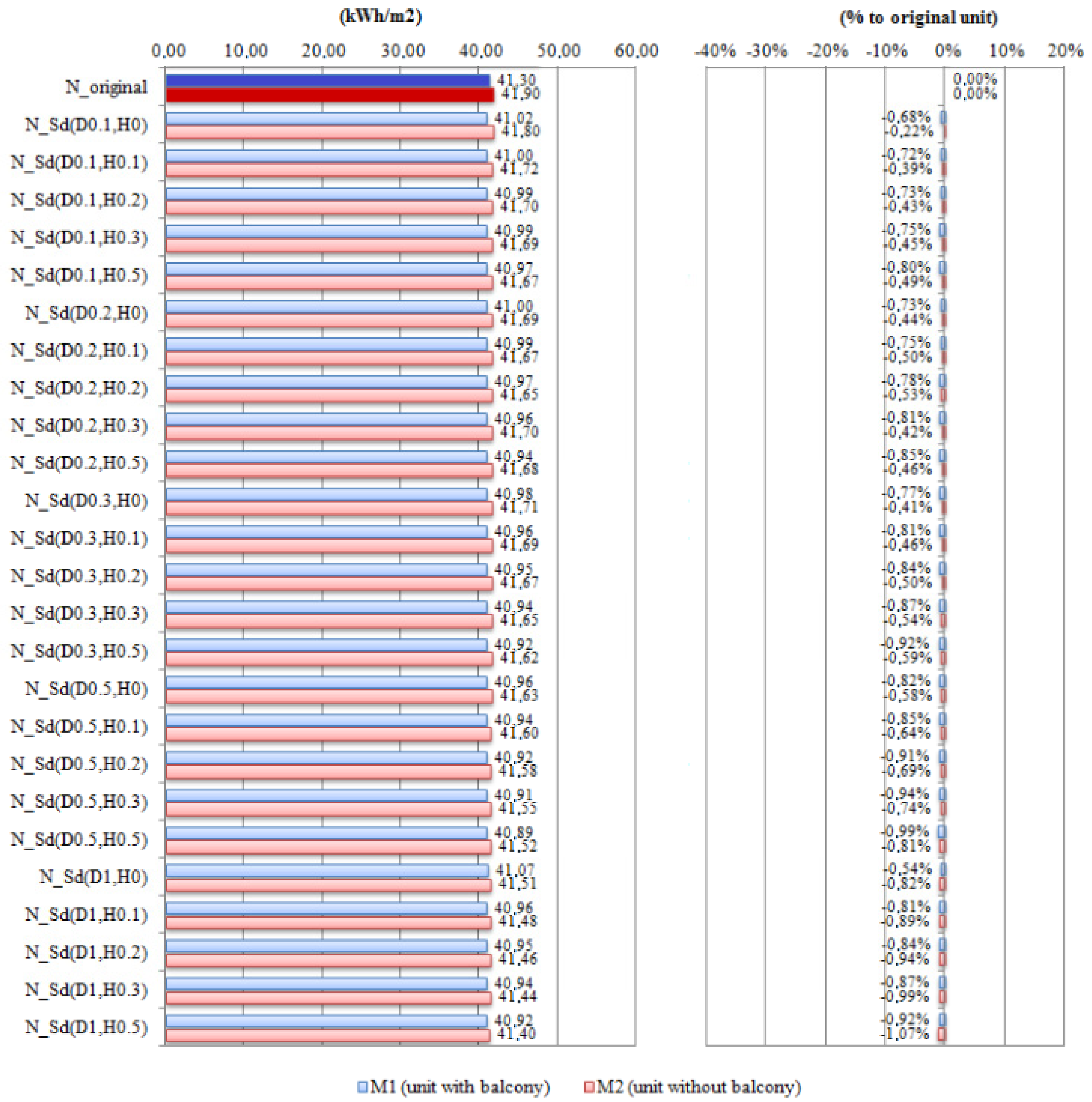

Figure A4. Ss Series: Annual thermal demand.

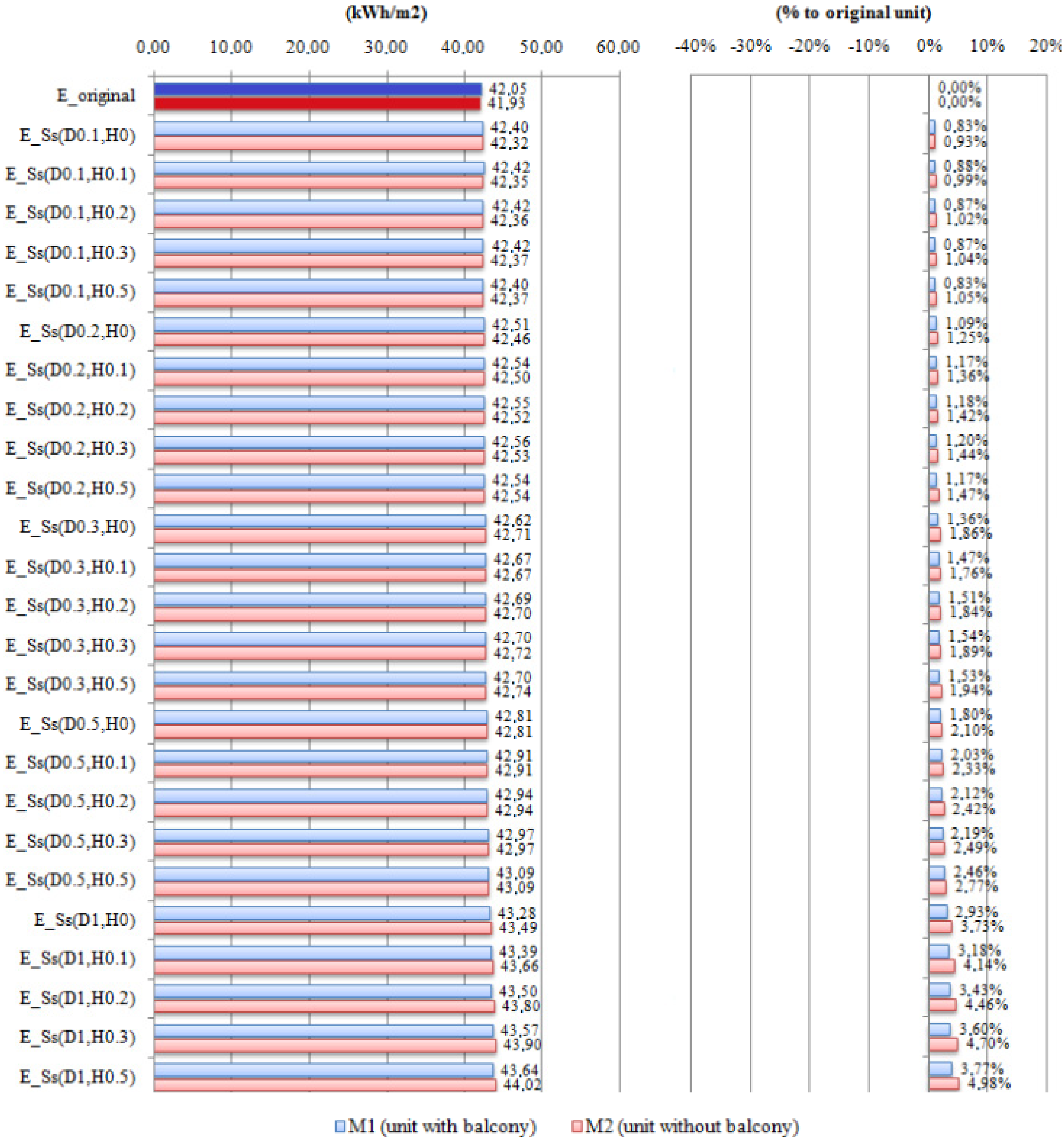

Figure A4. *Cont.*

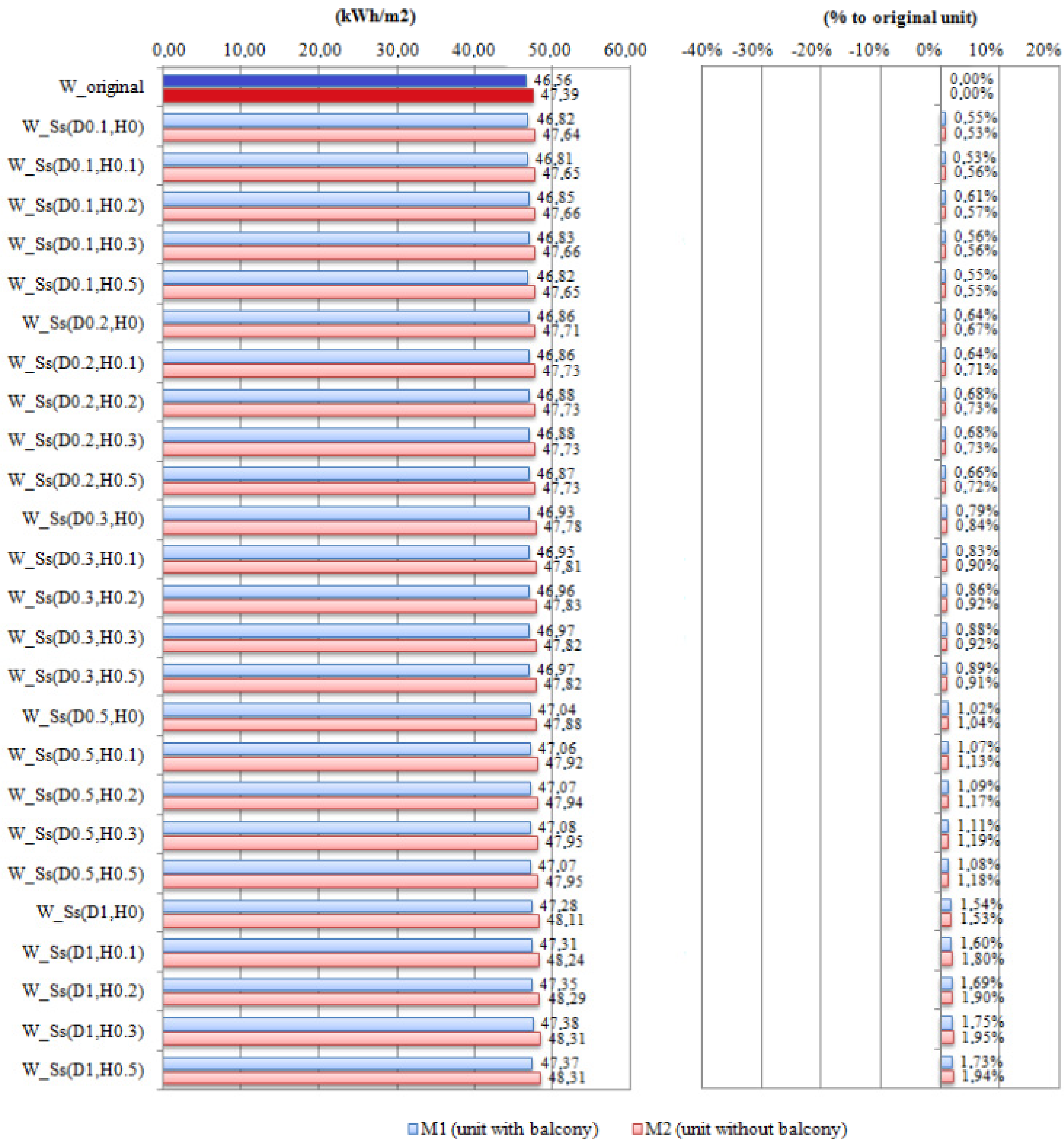

Figure A5. L Series: Annual thermal demand.

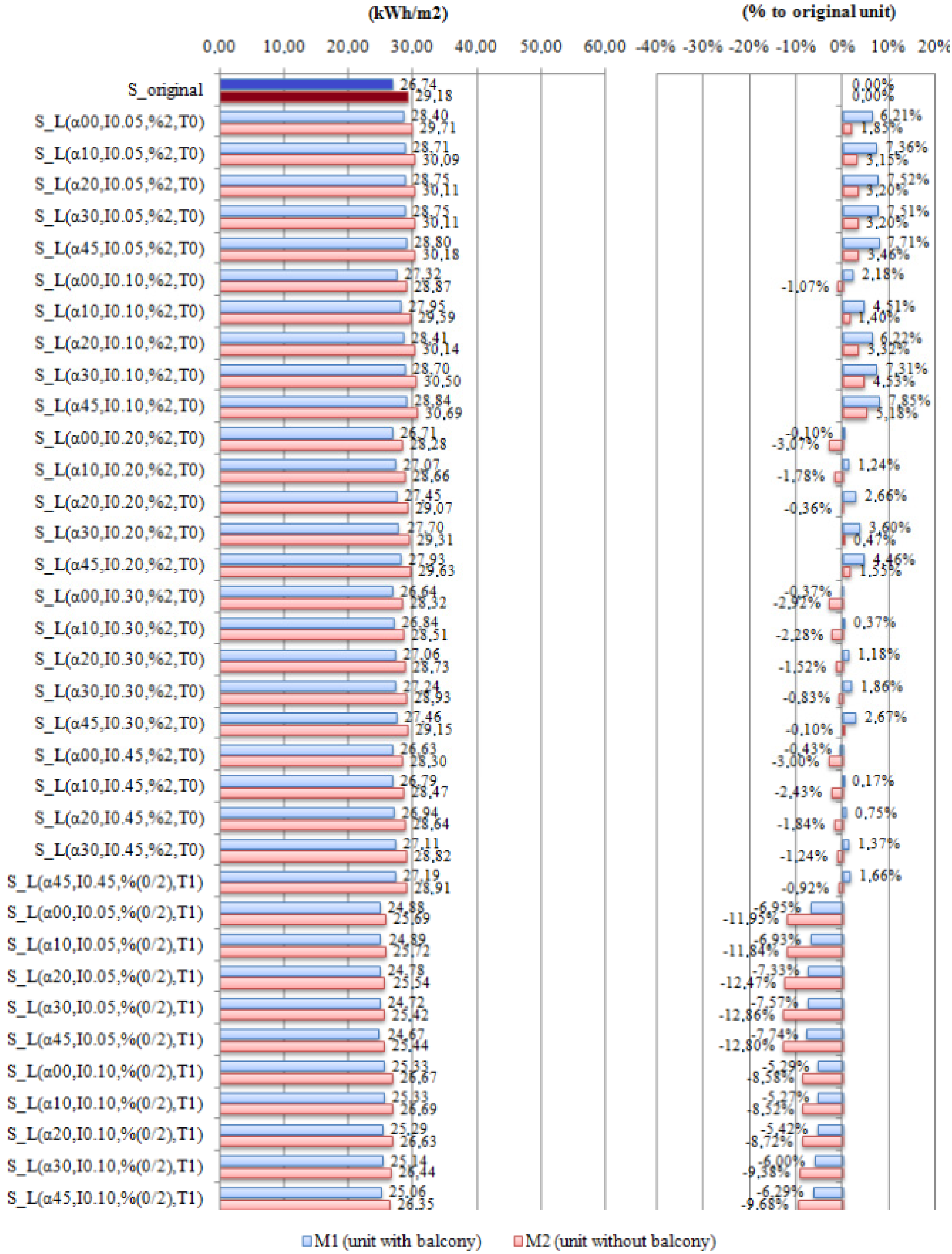

Figure A5. *Cont.*

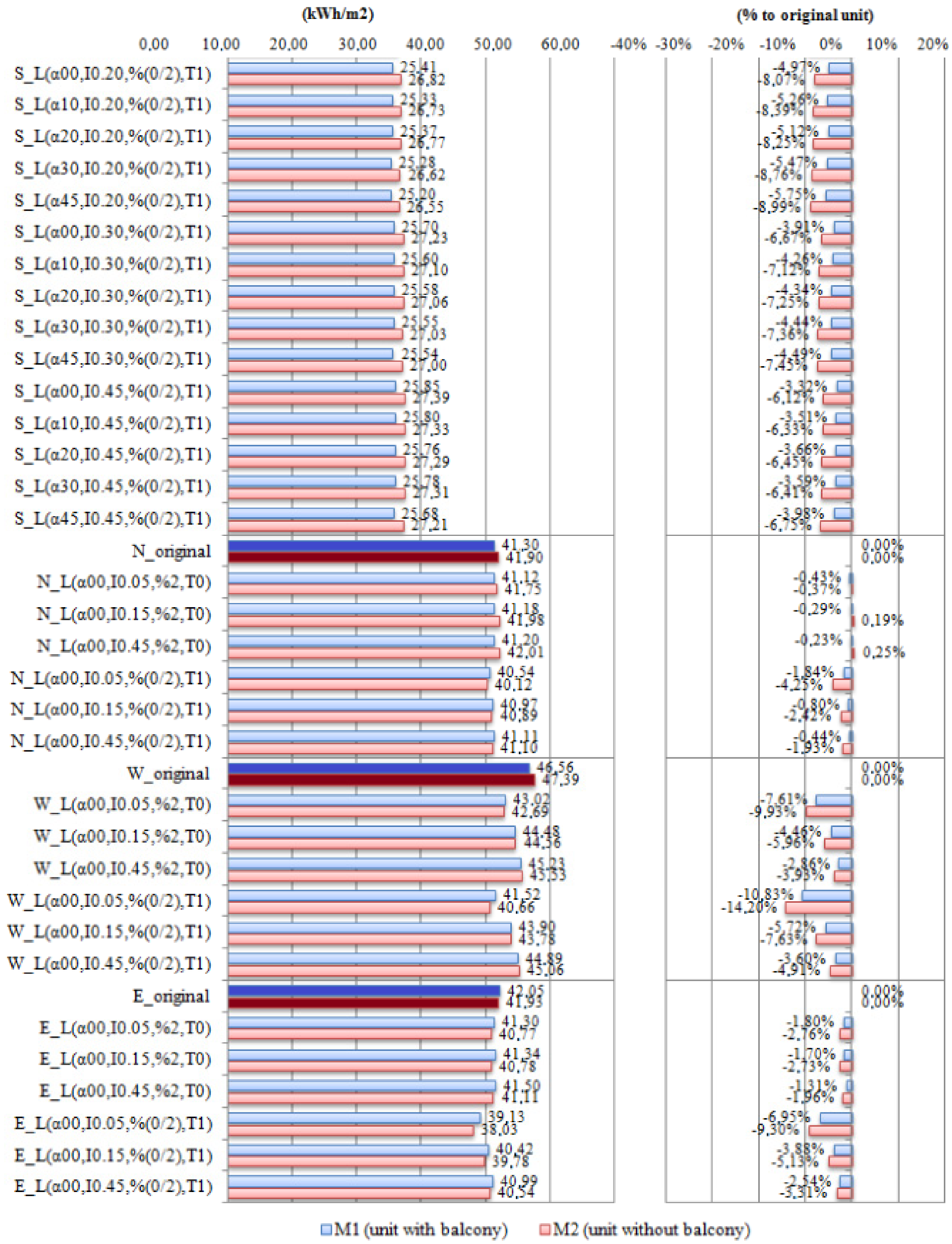

Figure A6. B Series: Annual thermal demand.