ENERGY EFFICIENCY FOR TYPICAL 2-FLOOR BUILDINGS IN PORTUGAL

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Summary

The purpose of this paper is to develop a relative evaluation, from the energetic point of view, of different building layouts. Buildings can be classified, according to their position within the lot, as perimeter yard buildings, rear yard buildings, and side yard buildings. This classification covers the layout solutions traditionally adopted by architects for 2-floor residential buildings.

The thermal performance of each building layout was evaluated through the quantification of its energetic consumption (per square meter of built area), for the heating and cooling seasons, and according to the geographic orientation. The simulation tool used in this evaluation is based on the Transfer Function Method.

The results obtained showed that the rear yard buildings have the better thermal performance, with an average energy consumption that is around 40% lower than in the other cases. In addition, for all building layouts studied, the North-South orientation requires the minimum energetic consumption to maintain comfortable indoor air temperature.

1 Introduction

The design of a particular layout solution for an urban area stands on a methodology that considers balance between demand and supply of land, on one hand, and location and space requirements, on the other hand [4]. In many situations where there are no significant constrains concerning slope, connection to utilities or others, alternative design options can be developed and considered. The variation of the available solar energy during the day and along the year is a potential factor that can differentiate spaces and that can be used as a decision criterion for layout and building design.

The purpose of this paper is to present and apply a methodology for evaluating the thermal performance of typical 2-floor buildings. Southern Europe buildings are different in form and type of construction from the ones in Northern Europe. In general, Portuguese and Mediterranean buildings have higher thermal inertia as they are more massive, less, insulated and therefore can account for more solar heat gains, both in winter and summer.

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2 Evaluating Building Thermal Performance: the Transfer Function Method

The Transfer Function Method is a numerical simulation tool that evaluates the building thermal (heating and cooling) loads, and predicts conditions in a space for different control systems, control strategies, and operating schedules [10]. Its major advantage consists on the accuracy of the dynamic calculation of the building mass effect, i.e., the way it takes into account the time that the building mass takes to absorb and to release the heat, as shown by Bragança [2].

The Transfer Function Method requires two steps to evaluate the heating or cooling load: the first step consists on the evaluation of the instantaneous heat flux through the envelope, and the second step consists on its conversion to heating or cooling load.

2.1 Heat Gains Calculation

The heat gain of a space depends on the nature of the phenomena (i.e., heat conduction through walls, direct and diffuse solar radiation, energy from lights, etc.) and on the mass and location of room objects that absorb the radiant heat. For example, the thermal load profile resulting from a unit pulse of solar radiation absorbed by window glass is quite different from the profile produced when the radiation is absorbed by a floor surface. Thus, the overall heat gain in a closed space is the sum of the heat gains through walls, roofs, interior partitions, and windows, on one hand, and the internal heat gains, such as the ones produced by artificial lights, occupants, and equipment, on the other hand.

The instantaneous internal heat gains, due to artificial lights, occupants, and equipment, can contribute significantly to the total thermal load, depending on the use of the building. However, as these heat gains are independent of the building envelope, they should not be included in the evaluation of the building thermal performance.

2.1.1 Heat Gains through Walls and Roofs

The heat gains through the opaque elements of the envelope are due to the temperature difference between the exterior and interior environments and to the solar radiation incident on the external surfaces. Different constructive elements lead to different heat gains, as the heat transferred by conduction to the interior surface, through the several layers of the element, depends on the mass and nature of the building materials.

In the first step of this method, the instantaneous heat fluxes through the opaque exterior envelope are determined using the Thermal Response Factors of the different elements according to the following equation:

$$\dot{q}(t) = \sum_{i=0}^{\infty} Y_i T_{as}(t - i\Delta) - \sum_{i=0}^{\infty} Z_i T_{\mathrm{int}}(t - i\Delta) \tag{2.1}$$

where T_{as} is the sol-air temperature, which account simultaneously for the effect of exterior temperature and solar radiation on the external surface; T_{int} is the inside air temperature; Y_i and Z_i are the Thermal Response Factors of each envelope element; and Δ is the time increment for the simulation (usually 1 hour).

The thermal response factors, Y_i and Z_i, used in this work were specifically calculated for typical envelope elements of Mediterranean buildings [3].

The heat gain through interior partitions, floors and ceilings can be calculated by using equation (2.1) whenever a conditioned space is adjacent to other spaces at different temperatures. When the temperature in the adjacent spaces is constant or when the variations of this temperature are small, the heat transfer through the partition can be calculated by the steady state expression:

$$\dot{q}(t) = K\left[T_{adj}(t) - T_{\text{int}}(t)\right] \tag{2.2}$$

where K is the overall heat transfer coefficient between the adjacent and conditioned spaces; T_{adj} is the air temperature of the adjacent space; and T_{int} is the interior air temperature of the conditioned space.

2.1.2 Heat Gains through the Windows

The heat gains through the windows are the result of the sum of two components: (i) heat conduction gains (or losses) through the windows, caused by temperature difference between the interior and exterior environments; and (ii) radiation heat gains, caused by the solar radiation transmitted through the glass.

The first component is always present, either with or without incident solar radiation, as it represents the conduction heat transfer through the windows. The second component only exists when there is incidence of solar radiation on glazed windows.

These two components are interdependent, as the solar energy absorbed by the glass and the temperature difference between glass and space combine to produce the convection and radiation heat gain (or loss). Nevertheless, they can be considered separately to calculate the correct value of the heat gains due to glazing [9]. Thus, these heat gains can be obtained summing the ones produced by the absorption of solar energy and the ones produced by conduction.

2.1.2.1 Conduction Heat Gains through the Windows

Independently of the existence of solar radiation, the difference between the outside temperature and the space temperature causes a conduction heat gain through the window. The heat gain that arrives to the interior surface of the window can be calculated by:

$$\dot{q}(t) = K\left[T_{ext}(t) - T_{\text{int}}(t)\right] \tag{2.3}$$

where K is the overall heat transfer coefficient between the window and the space; T_{ext} is the exterior design air temperature; and T_{int} is the inside air temperature.

Values of coefficient K can be found in Santos [8] and ASHRAE [1] for several types of windows and glasses. Values of T_{ext} for the different Portuguese climatic areas and for typical days can be found in Mendes [6].

2.1.2.2 Solar Radiation Heat Gains through Windows

The heat gains caused by the incidence of solar radiation on a glazed window depend on the amount of incident radiation and on the transmittance of the glass. The heat gain $\dot{q}(t)$, expressed in W/m^2, can be calculated by:

$$\dot{q}(t) = SC \times G_t(t) \tag{2.4}$$

Where SC is the glass shading coefficient and G_t is the global solar radiation incident on the external surface of the glass.

SC represents the ratio between the instantaneous solar heat gain and the incident solar radiation. It is a specific property of each glass type and it varies with the incidence angle of solar radiation.

Characteristic values of *SC* for a great number of glass types, with and without solar protections, can be found in the Portuguese Thermal Regulation [7]. In addition, a calculation methodology for *SC* values can be found in Mendes [6] and ASHRAE [1].

Typical values of G_t for the main geographical orientations can be found in [2], for an average cloudless summer day. For high altitudes or very clear atmospheres, the real values can be up to 15% higher than the tabulated values. For very polluted industrial atmospheres and for exceptionally humid places, values can be 20 to 30% less than the tabulated ones [1].

2.2 Thermal Load Calculation

As said before, the second step of the Transfer Function Method consists on the conversion of the instantaneous heat flux through the envelope into heating or cooling load, using the space Weighting Factors. The space load at a certain time depends not only on present heat gain values, $\dot{q}(t-i\Delta)$, but also on past values of the load, $\dot{Q}(t-i\Delta)$. This conversion is made using the following space transfer function:

$$\dot{Q}(t) = \sum_{i=0}^{\infty} \nu_i \; \dot{q}(t-i\Delta) - \sum_{i=1}^{\infty} \omega_i \; \dot{Q}(t-i\Delta) \tag{2.5}$$

Where ν_i and ω_i are the space Weighting Factors.

These factors depend on the space thermal inertia and on the type of heat gain (how much is in the form of radiation and where it is absorbed). Therefore, different space transfer functions are used to convert each heat gain component to cooling or heating load. Thus, each part of the room heat gain is a distinct part of the thermal load; the sum of all these parts at any time is the total thermal load at that time.

Appropriate values of the space Weighting Factors, for each heat gain component and for a wide range of construction materials, were specifically calculated in earlier studies [3].

While the basic form of equation (2.5) anticipates a series of ν_i and ω_i coefficients, the effect of past ν_i and ω_i is negligible and expression (2.6), which uses only 3 values of ν_i and 2 values of ω_i, can be used with confidence [1].

$$\dot{Q}(t) = \nu_0 \; \dot{q}(t) + \nu_1 \; \dot{q}(t-1) + \nu_2 \; \dot{q}(t-2) - \omega_1 \; \dot{Q}(t-1) - \omega_2 \; \dot{Q}(t-2) \tag{2.6}$$

2.3 Total Thermal Load

The building total thermal load must also include the heat gains associated to ventilation and infiltration. According to ASHRAE [1], the thermal load resulting from this heat gain contribution is given by:

$$\dot{Q}(t) = 1{,}23 \, \dot{\mathrm{V}} \left[T_{ext}(t) - T_{\mathrm{int}}(t) \right] \tag{2.7}$$

where T_{int} is the interior air temperature, T_{ext} is the exterior air temperature and *V* is the ventilation or infiltration air flow.

The total thermal load of a building is, in each instant, the sum of every load components described in the previous sections.

3 Case Study: Typical Portuguese 2-floor Buildings

3.1 Case Description

An application of the model presented in the previous section is now presented, consisting in a relative evaluation of the thermal performance of typical 2-floor buildings, according to the respective layout (position within the lot and relative to the neighbour buildings) and for different geographic orientations. It is not purpose of this case study to evaluate the importance of the energetic criteria in comparison with other relevant criteria for the design of buildings layout. The focus is on the analysis of the energy consumption of the building, considering the relevant parameters of its thermal behaviour.

For this study the buildings were classified according to their position within the lot, as perimeter yard buildings, rear yard buildings, and side yard buildings (Figures 1, 2 and 3, respectively).

The buildings under analysis are typical from the Portuguese residential areas and from many Mediterranean countries in their form and type of construction. These are 2-floor buildings, which exterior envelope is defined by double brick walls with light insulation between panes, a non-accessible insulated attic and single glazing windows. Table 1 lists the thermal properties and the geometrical characteristics of the buildings.

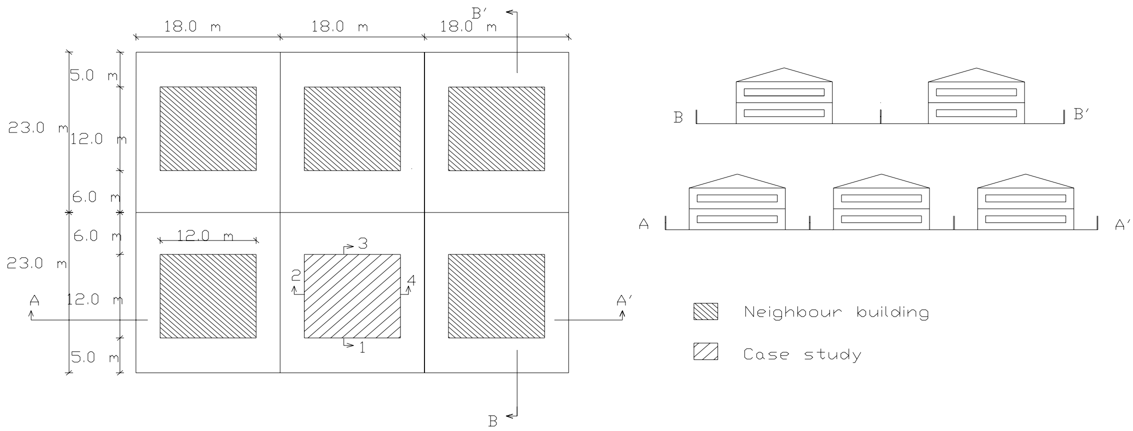

Fig. 1 Geometry of the perimeter yard buildings (Case 1)

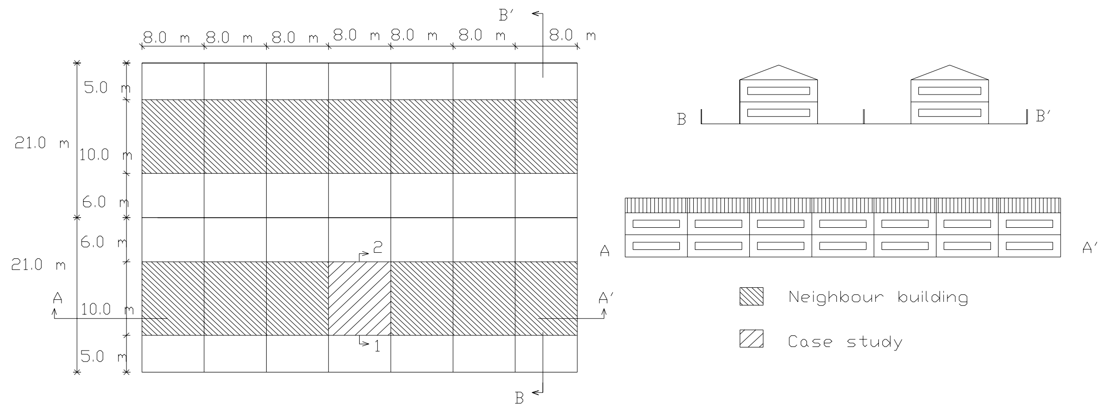

Fig. 2 Geometry of the rear yard buildings (Case 2)

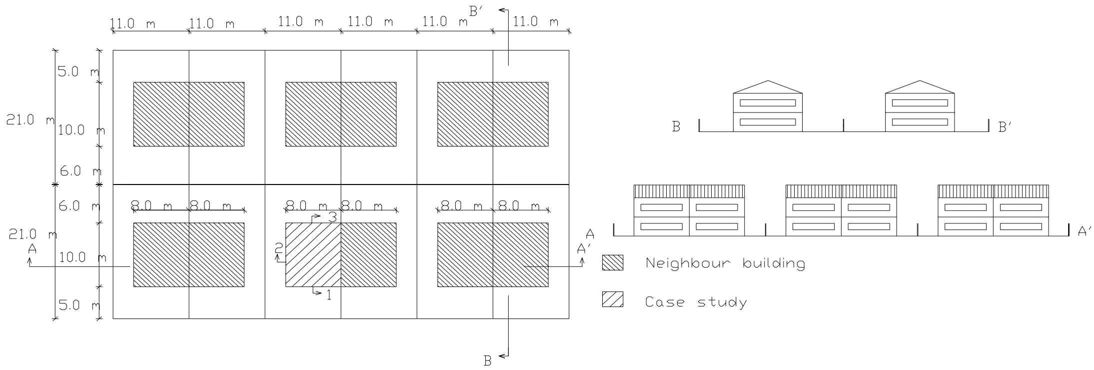

Fig. 3 Geometry of the side yard buildings (Case 3)

Table 1 Overall conductance and area of the exterior envelope

	K (W/m^2 ^{o}C)	**Area (m^2)**
Case 1 - Perimeter yard building (floor area)		288
Roof	0.85	144
Walls (facade 1, 2, 3 and 4)	1.20	4 x 52
Windows (facade 1, 2, 3 and 4)	5.80	4 x 20
Case 2 - Rear yard building (floor area)		160
Roof	0.85	80
Walls (facade 1 and 2)	1.20	2 x 36
Windows (facade 1 and 2)	5.80	2 x 12
Case 3 - Side yard building (floor area)		160
Roof	0.85	80
Walls (facade 1 and 3)	1.20	2 x 36
Windows (facade 1 and 3)	5.80	2 x 12
Walls (facade 2)	1.20	1 x 44
Windows (facade 2)	5.80	1 x 16

It should be stressed that the different layouts considered (perimeter yard, rear yard and side yard buildings) involve different surface-to-volume ratios, due to the fact that we wanted to keep the geometry and dimensions of actual typical buildings in Portugal.

The climatic data used for the heating season, was a sequence of typical winter days, corresponding to the climatic zone that includes most of the Portuguese territory (zone denoted by I2), according to the Portuguese Thermal Regulation [7]. For the cooling season the same methodology was followed, using in this case a sequence of typical summer days corresponding to the climatic zone that includes most of the Portuguese territory (zone denoted by V2).

Thermal comfort conditions usually accepted in Portugal where considered for the interior air temperature (20 degrees Celsius in winter and 25 degrees Celsius in summer).

The exposition of the different facades to solar radiation depends, both winter and summer, on their orientation and on the shading coming from the neighbour buildings. In order to get a more comprehensive analysis, the study was developed for the 8 main orientations (N, NE, E, SE, S, SW, W and NW), according to the scheme of Figure 4.

The evaluation of the energetic consumption was performed using the DOE-2 software as it is one of the most accurate and fast analysis tools available [5].

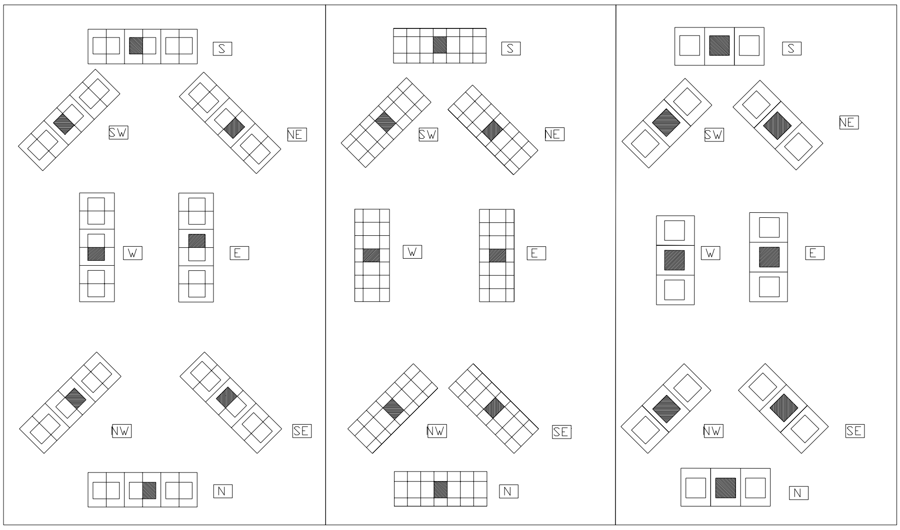

Fig. 4 Studied orientations of the buildings

3.1 Heating load (Winter)

For the studied building layouts, the thermal load highly depends on the shading produced by the neighbour buildings and lot separation walls. The results of the heating load calculations, for each case and for the winter season, are presented in Figure 5 and Table 2. Analysis of these results shows that perimeter and the side yard buildings require generally more 40% of energy than the rear yard buildings to maintain comfortable indoor air temperature, due to the special configuration of the later that allows minor losses through the envelope.

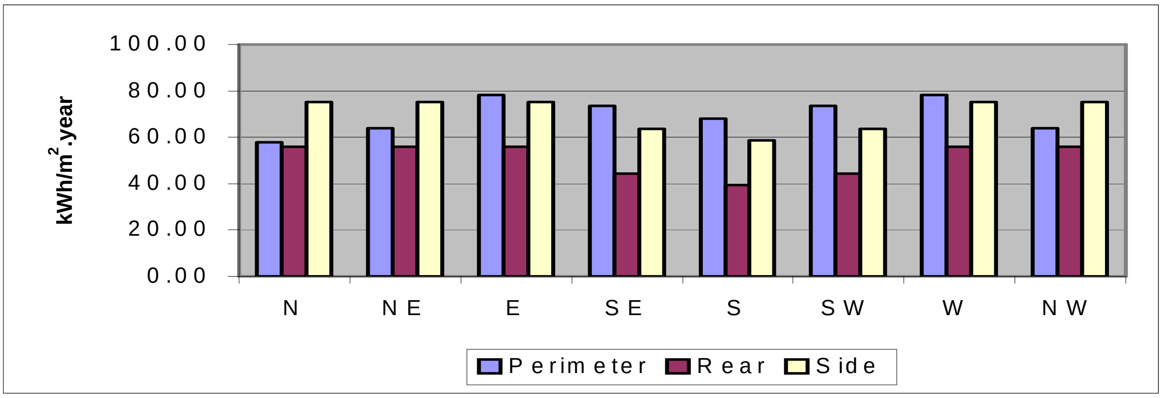

Fig. 5 Heating load for all cases

Table 2 Values of the heating load for all cases (kWh/m^2.year)

Orientation	N	NE	E	SE	S	SW	W	NW	Mean	Max.	Min.	Amp.
Perimeter	57.89	63.87	78.33	73.58	68.01	73.58	78.33	63.87	69.68	78.33	57.89	20.44
Rear	55.97	55.97	55.97	44.25	39.43	44.25	55.97	55.97	50.97	55.97	39.43	16.54
Side	75.34	75.34	75.34	63.62	58.63	63.62	75.34	75.34	70.32	75.34	58.63	16.71

The amplitude of the heating load (i.e. the difference between minimum and maximum values) expresses the variation of the energy consumption. Analysis of this parameter suggests that the perimeter yard building is the most sensible to orientation. This was quite expected since it has a bigger window area and windows in all the four facades, which means more sensibility to solar gains.

It must be emphasised that the maximum heating load of the rear yard building is slightly lower than the minimum heating load of both the perimeter and the side yard buildings. This means that, in winter, the rear yard building is the most economic solution from the energetic point of view, independently of the orientation adopted.

3.2 Cooling load (Summer)

As in winter, shading constrains the envelope area exposed to solar radiation in summer. The results for the cooling load are shown in Figure 6 and Table 3. As in winter, the perimeter and the side yard buildings require much more energy to maintain comfortable indoor conditions than the rear yard buildings. In this case the waste of energy can be up to 70%.

In summer season, the variation of energy consumption with orientation has no significance for the perimeter yard buildings because all their facades are always exposed to solar radiation. The side yard building is the most sensible to different orientations, as it can be very well oriented or not. For the same reason, the rear yard building has an intermediate sensibility to different orientations but, as it has only two facades exposed to solar radiation, the cooling load variation is lower than in the previous case.

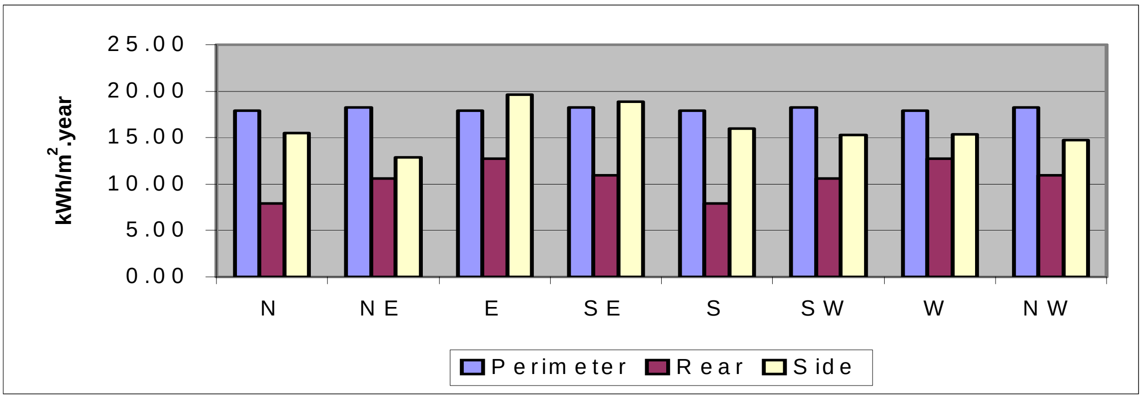

Fig. 6 Cooling load for all cases

Table 3 Values of the cooling load for all cases (kWh/m^2.year)

Orientation	N	NE	E	SE	S	SW	W	NW	Mean	Max.	Min.	Amp.
Perimeter	17.89	18.24	17.89	18.24	17.89	18.24	17.89	18.24	18.07	18.24	17.89	0.35
Rear	7.89	10.59	12.73	10.97	7.89	10.59	12.73	10.97	10.55	12.73	7.89	4.84
Side	15.52	12.88	19.61	18.89	16.00	15.29	15.37	14.71	16.03	19.61	12.88	6.73

For the rear yard buildings the maximum energy requirement is much lower than the minimum of the perimeter yard buildings (about 40%), and slightly lower than the minimum of the side yard buildings. This means that, also in summer, the rear yard buildings are the most economic solution from the energetic point of view.

3.3 Total load (Heating and Cooling)

The energetic consumption along a typical year can be approximately obtained summing the energetic consumption of both heating and cooling seasons. The results for the total load are shown in Figure 7 and Table 4. As expected, the rear yard buildings have the better thermal performance, while the other building layouts, perimeter and side yard, require higher total loads (around 40%). The sensibility to geographical orientations is similar in absolute value for the three cases, which means that percentually is more significant for the rear yard buildings.

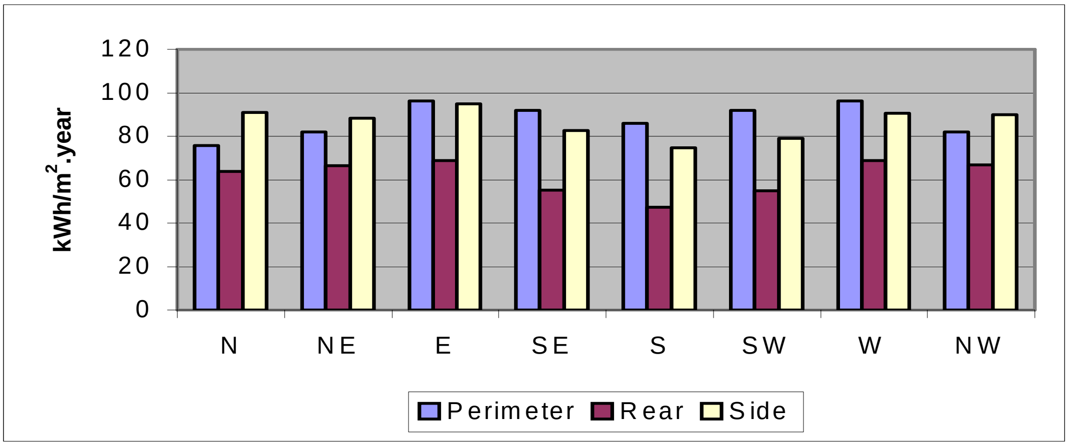

Fig. 7 Total load for all cases

Table 4 Values of the total load for all cases (kWh/m^2.year)

Orientation	N	NE	E	SE	S	SW	W	NW	Mean	Max.	Min.	Amp.
Perimeter	75.78	82.11	96.22	91.82	85.90	91.82	96.22	82.11	87.75	96.22	75.78	20.44
Rear	63.86	66.56	68.70	55.22	47.32	54.84	68.70	66.94	61.52	68.70	47.32	21.38
Side	90.86	88.22	94.95	82.51	74.63	78.91	90.71	90.05	86.36	94.95	74.63	20.32

4 Conclusion

The results obtained lead to the main conclusion that, from the energy conservation point of view, the layout and orientation of buildings are very important. When designing urban areas, the external shading caused by surrounding constructions cannot be neglected, because it has a high influence on the thermal load.

For all building layouts studied, the North-South orientation requires the minimum energetic consumption to maintain comfortable indoor air temperature. In this case, the energy savings oscillate between 25% and 45% of the maximum energy consumption. NE-SW or NW-SE orientations are also acceptable although with less savings (15% to 25%).

Among the studied cases, the rear yard buildings have the better thermal performance, with an average energy consumption that is around 40% lower than in the other cases.

Acknowledgement

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