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Abstract	The thermal characteristics of a social interest archetype in Uruguay were analyzed in order to determine possible improvements. EnergyPlus was used to simulate the household during a typical year, estimating cooling and heating requirements for thermal comfort in several configurations. The accuracy of the model was verified by simulating a real case where the temperature of a particular household was monitored during a period of 2 weeks; good agreement was found between numerical and experimental results. The obtained results show that the energy requirements to achieve thermal comfort in this particular archetype can be reduced with small design variations and specially implementing training workshops for the owner of the houses.	
Keywords (separated by '-')	Thermal Comfort - Social Interest Household - EnergyPlus Simulations	

Chapter 92
Thermal Analysis of a Social Interest Household in Uruguay

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Nomenclature

HVAC	Heat Ventilation Air Conditioning
MEVIR	Movement for the Eradication of Unhealthy Rural Housing
COP	Coefficient of Performance
NPV	Net Present Value

92.1 Introduction

In recent years, social inclusion policies have been paying more attention to the energetic demand for low-income socio-economic sectors in Uruguay. The energy required for thermal comfort usually cannot be affordable for families in this context. In the present work, the thermal behavior of a household of a social-interest typology is studied in order to analyze possible improvements for its design. The house is the archetype designed by the "Movement for the Eradication of Unhealthy Rural Housing" (MEVIR).

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M. Z. Sogut et al. (eds.), *Proceedings of the 2022 International Symposium on Energy Management and Sustainability*, Springer Proceedings in Energy,
https://doi.org/10.1007/978-3-031-30171-1_92

92.2 Methodology

The study was carried out by means of numerical simulations using EnergyPlus software developed by Dury et al. (2000); a sketch of the geometry is presented in Fig. 92.1.

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EnergyPlus default models were used for the surface heat balances and convection coefficients calculations. For solving the conduction heat fluxes at walls and roofs, the *ConductionTransferFunction* was used. To determine conduction through the ground, the model selected was *GroundDomain:Slab*. For windows heat transfer, the layer-by-layer approach was followed, whereas infiltration and ventilation loads were solved by means of the *AirflowNetwork* model. Finally, energy requirements were calculated using an ideal HVAC system.

The internal and external temperature of one particular household was monitored during a period of 2 weeks. The obtained measures were compared with a simulation for that particular period in order to verify the accuracy of the model, obtaining a very good agreement between numerical and experimental data, according to the ASHRAE Guideline 14.

Using the verified model, a base case is simulated for an entire year to analyze the thermal behavior of the house. To do that, the Typical Meteorological Year of Montevideo from Alonso-Suarez et al. (2016) was used. The Uruguayan climate is mild and wet according to the Köppen classification. It must be noted that Uruguay is located in the south hemisphere, and because of that, winter is from June to August and the sun path is through the north. The energy required to achieve the adaptive thermal comfort ASHRAE-55 was determined by varying the orientation with a step of 30°. Cooling and heating requirements were differentiated. Then, variations of the base case were simulated, such as (i) reduction of the roof thermal transmittance, (ii) inclusion of solar protection in every window, and (iii) a more efficient user regarding the solar protections and natural ventilation operation. These variations

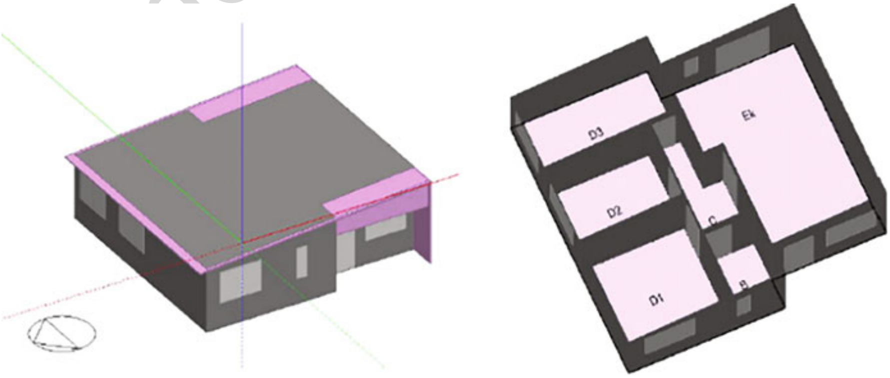

Fig. 92.1 Model of the household

represent 48 simulations. Therefore, in order to automate the simulation process, a python script based on Eppy libraries was implemented.

For each energy efficiency measure, an economic analysis was performed in order to determine which are the more attractive measures. The cost for implementing each measure is calculated considering additional materials and labor costs. The economic benefits due to energy saving were estimated considering that the thermal requirements are covered with electric systems with a COP of 2. Finally, the repayment time (as the time to achieve positive NPV) is calculated according to these estimations for each measure.

92.3 Results and Discussion

92.3.1 Base Case

First, a standard case, named Base Case, was simulated in order to characterize the household thermal behavior for the original design. The geometry is presented in Fig. 92.1. The envelope materials are summarized in Table 92.1 and correspond to the one reported by MEVIR.

To determine the air tightness, a blower door test was carried out in a particular MEVIR household. A value of $n_{50} = 7.77ACH$ was measured. With this value, local tightness was estimated according to the windows' and doors' locations in order to define the AirflowNetwork parameters.

The occupants' schedules and behaviors (regarding ventilation and solar protections) were defined, trying to represent as accurately as possible the real occupants. To do so, several interviews were carried on with families living in MEVIR houses. A family with two adults and two minors was defined as standard. The schedule and user behavior according to solar protection and ventilation are summarized in Table 92.2.

Impact of Orientation

The base case was simulated for different orientations. The 0° orientation corresponds to the front facade oriented to the north, as shown in Fig. 92.2, which in the south hemisphere is the one facing the sun. The cooling and heating requirements obtained are presented in Fig. 92.3. As can be observed, this house performs better in

Table 92.1 Typology specifications

Item	Composition (cm)	Thickness	U (W/m2K)
External wall	Brick (12) + Basecoat (1) + Air cam (2) + EPS (3) + Brick (12)	30	0.67
Roof	Sheet steel (0.05) + glass wool (5 cm) + OSB wood (1.5)	6.55	0.7
Floor	Ceramic (1.5) + Mortero (2) + concrete (12)	15.5	–
Windows	Simple glass and aluminum frame	0.4	5.8

Table 92.2 Users' schedule main point

Item	From 16/03 up to 15/11	From 16/11 up to 15/03
Bedroom occupation	22–07 (all); 17–20 (D2 & D3)	
Living room and kitchen occupation	07–09 (3p); 09–18 (1p); 18–20 (2p); 20–22 (4p). Weekends: 09–18 (3p).	
Ventilation (open windows)	12–13	08–13 and 18–24
Solar protection (open)	08–18	08–14 and 18–22

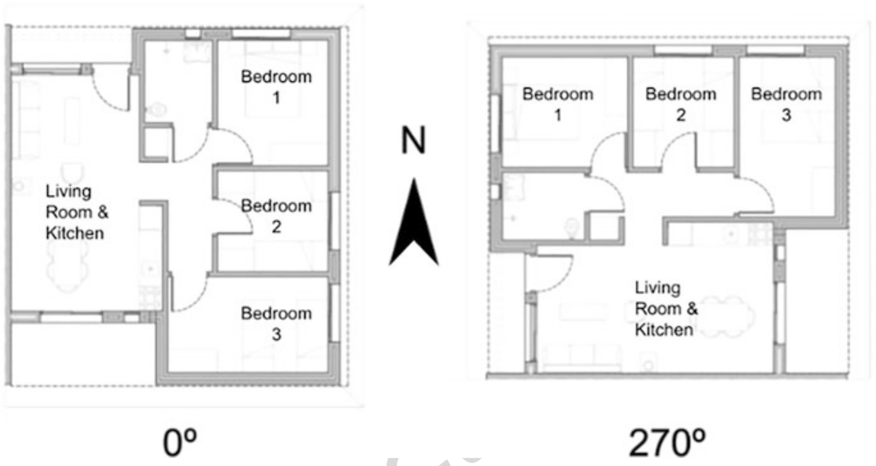

Fig. 92.2 Model of the household

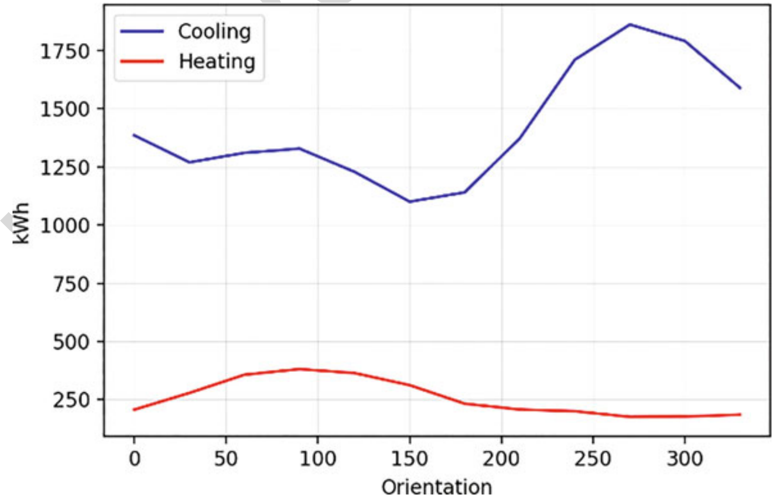

Fig. 92.3 Base case HVAC requirements

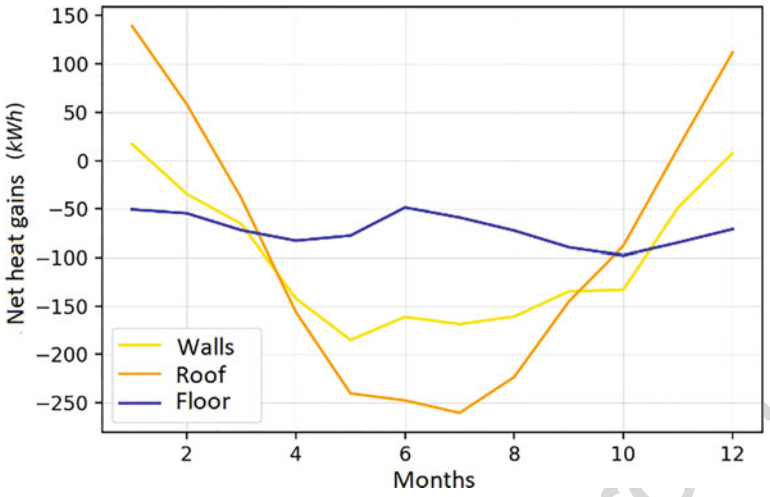

Fig. 92.4 Envelope net heat gains; house orientation 0°

winter than in summer for all orientations, being cooling demand much higher than heating demand. This is due to the low transmittance of the envelope. Because of that, in winter with the internal gains (people and equipment), the solar gains, and a small energy demand, the comfort temperature can be achieved. However, in summer, this internal and solar gains, and also the gains through the envelope and air infiltrations, must be compensated by de HVAC systems, generating an important cooling demand.

As was expected, an important dependency between the energy requirement and the house orientation was observed. Cooling requirements are maximized for the 270° orientation, for which the bedroom windows (which include sun protection) face north, while the kitchen and living room windows (both without sun protection) face east and west, respectively. On the other hand, the most critical orientation for heating is 90°, for which no opening faces north.

Envelope Net Heat Gains

The difference between gains and losses for the roof, exterior walls, and floor are presented in Fig. 92.4. First, the floor heat flow is outgoing during all-year round. This is because the underground temperature is always lower than the inside temperature. These heat losses range from 50 up to 100 kWh per month, being significant (and negative) during the cold period. Second, the net balance for the exterior walls only generates heat gains in the summer months, although they are very low. Heat losses are maximized between April and August, overtaking 150 kWh per month. Lastly, according to the results of the simulations, roof is the opaque envelope surface that causes greater heat gains in summer and greater heat losses in winter for this typology. This is the usual behavior of houses exposed to Uruguayan climate, with similar walls and roof thermal transmittances. A reduction of the roof transmittance could reduce energy demand.

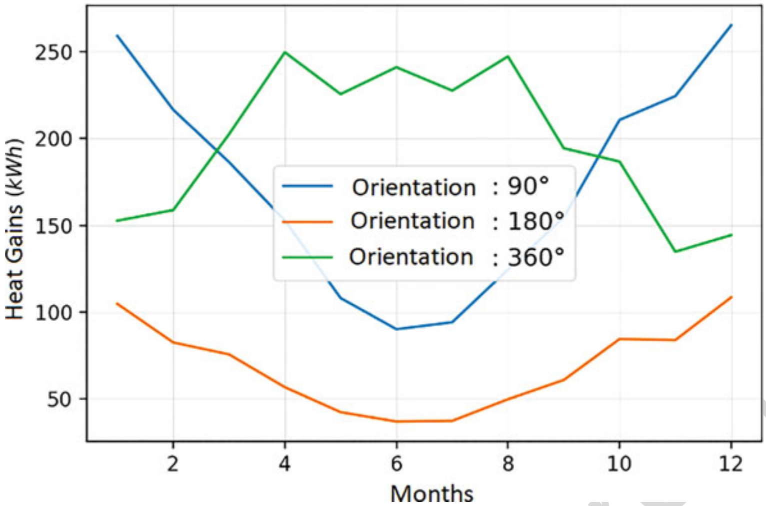

Fig. 92.5 Windows' solar gains; house orientation 0°

Windows' Solar Gains

Glazed surfaces are the ones that generate the greatest net heat gains, so their orientation is central to the house thermal behavior. The net heat gains for each facade for the house at orientation 0° are presented in Fig. 92.5. As was expected, north facade windows (green curve) present a positive oscillation according to energy requirements. This means higher gains in winter (around 240 kWh/month) than in summer (150 kWh/month).

On the other hand, windows oriented to the east (blue curve in Fig. 92.5), as well as west oriented, present high net gains in summer, with values over 250 kWh/month in December and January. This is due to the high direct solar radiation during the morning. Therefore, including solar protections with an adequate operation could reduce cooling energy demand.

Air Infiltration and Natural Ventilation

The annual evolution of infiltrations and ventilation heat losses are presented together in Fig. 92.6 since the EnergyPlus version used in this study does not allow discriminating it. Important heat losses are observed in summer, over 400 kWh/month, mainly due to ventilation. These heat losses are good since they reduce cooling demand. Then, an adequate operation of the windows can be very beneficial in the final energy requirements.

In winter months, the occupants maintain the windows closed for more time. Because of that, low heat losses are obtained in that period (less than 100 kWh/month).

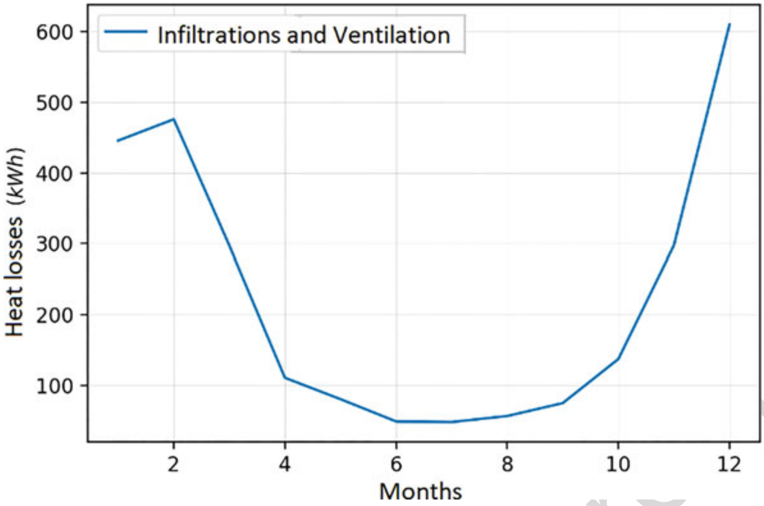

Fig. 92.6 Infiltration and natural ventilation losses. Base case, orientation 0°

92.3.2 Energy Efficiency Measures

Following, three energy efficiency measures are studied in order to improve even more the thermal behavior of the house. As was noted before, solar protection is expected to reduce cooling demand. Also, a more efficient operation of solar protections and openings can save energy demand. Moreover, a reduction of the roof transmittance can reduce both cooling and heating requirements.

Impact of the User

In order to estimate the occupants' behavior influence on the energy demand, an "efficient user" was defined. It consists of the same occupancy schedule but varies the way it operates the solar protections and the openings.

The annual evolution of cooling and heating demand for the efficient user are presented in Fig. 92.7. An important cooling demand reduction is obtained for all orientations. For orientations between 270° and 30°, the cooling demand is less than half for the efficient user; in particular, at 330° the cooling demand is less than a third of the original user one. This important reduction is due to efficient use of solar protections, which highly reduces the net heat gain through glazed areas. Moreover, the efficient user takes more advantage of natural ventilation, which also contributes to the cooling demand reduction.

The heating demand is less affected since for winter the original user also takes advantage of windows gains and does not ventilate much.

According to local energy costs, the savings for the efficient user are equivalent to 94.3 US$ per year. Considering a training program for the occupants of the houses with a cost of 240 US$, the repayment period is less than 3 years.

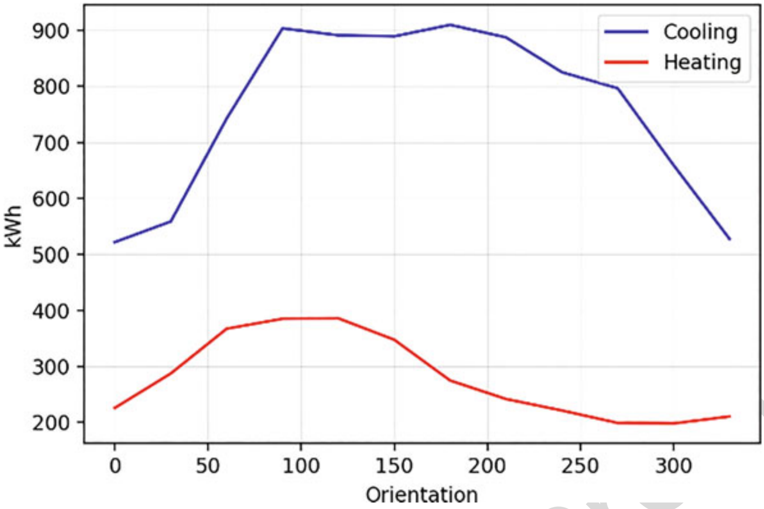

Fig. 92.7 Efficient user HVAC requirements

Solar Protections

When using blinds instead of curtains as solar protections for the kitchen and the living room, an important reduction of energy demand was estimated. For cooling demand, the reduction is thanks to the lower heat gains through the windows. Then, the most notorious reduction is for the orientation 90°, for which the front facade is oriented to the east. For the heating demand, the reduction is due to the lower transmittance of the windows when the blinds are down.

With this reduction in the energy demand, again considering the local costs of electricity, the inclusion of blinds can produce savings of 18.5 US$ per year. The cost of including this in the house design is estimated at 300 US$, meaning a repayment period of more than 20 years.

Roof with Less Transmittance

Considering a roof with less transmittance than the original (0.33 W/m^{2}K against 0.70 W/m^{2}K), a saving of around 60% is obtained for heating demand for an entire year for all orientations and savings of 30% for cooling demand. That means a saving of 25.8 US$ per year.

The proposed roof has a lower cost than the original. Therefore, the inversion for this measure is considered negative, estimated at −90US$.

92.4 Conclusion

The thermal behavior of a social interest household in Uruguay (MEVIR) was studied by means of numerical simulations using EnergyPlus. To define and calibrate the model, experimental measures were used. Moreover, interviews with families living in this type of house were performed to determine the schedules and behavior of the occupants in order to define this in the model. The results of the simulations for the base case show that the MEVIR archetype has a good thermal design because of the low thermal transmittance of its opaque envelope. Principally for winter, a low heating demand is estimated.

Thereafter, three energy efficiency measures were analyzed. All of them show a clear reduction in energy demand. The reduction of the roof transmittance is the most attractive because it has no cost and reduces energy demand. Actually, the proposed roof is cheaper than the original. Moreover, a training program for occupants to take advantage of solar protections and natural ventilation could have an important effect on reducing energy demand with a moderate cost. Finally, including blinds in the living room and kitchen windows also reduces energy requirements but with a high repayment period.

Acknowledgments This research was supported by “Administración Nacional de Usinas y Transmisiones (UTE)—Uruguay.” The authors also thank the “Dirección Nacional de Energía (DNE)” for assistance with the Blower door measurements and MEVIR for facilitating information regarding the house archetype.

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