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Interventions for Ensuring Thermal Comfort Equality in Apartment Buildings

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Abstract
Energy reduction is one of the goals of sustainability. Thermal comfort and sustainability refers to smart dealing with natural resources to be acceptable for people. In order to provide thermal comfort to occupants, it is necessary to prevent excessive thermal transfers from the building's envelope. To this end thermal insulation is provided and windows with low U values are installed in buildings. However, the orientation of living spaces in a building determines the amount of solar gains from the facades, which in turn influences the thermal conditions within. Thus, spaces facing different directions need different amount of thermal control to achieve thermal equality. On the other hand, the standard practice for reducing the energy loads of a building is to select the same type of thermal insulation and windows for the entire façade, regardless of the direction of the external walls. This state of affairs gives rise to an inequality in the thermal comfort conditions of residential units facing different orientations. The aim of this study was to eliminate this inequality through certain local interventions on the part of the residents themselves; e.g. increasing insulation, reducing U values of the windows and providing solar shading. To this end an apartment building was modelled with the aid of an energy simulation software: DesignBuilder. The heating and cooling loads obtained from the residential units facing North, South, East and West directions were compared for various intervention scenarios, based on the application of various thicknesses of insulation inside the external walls, improved U values for windows and solar shading devices; as well as natural ventilation. The simulated energy loads demonstrate the effectiveness of case based refurbishment interventions for achieving thermal equality and energy expenditures in all units regardless of their orientations.

Keywords: Orientation, thermal insulation, U-value, heating load, cooling load

1. Introduction

Energy reduction is one of the goals of sustainability. Thermal comfort and sustainability refers to smart dealing with natural resources to be acceptable for people [1]. In order to provide thermal comfort to occupants, it is necessary to prevent excessive thermal transfers from the building's envelope. According to reference [2], heat transfer through a building's envelope depends on many factors such as the building's age and type, the construction techniques and material, its orientation, geographic location, and climate. Orientation is important in terms of passive solar design [3] because the amount of solar radiation falling on a building envelope and absorbed at its surface, depends on the orientation of the facade and solar absorption coefficient [4] of the facade material. The thermal performance of a building's envelope, which is made up of the external walls, floor, roof, windows and doors, is important in terms of energy

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required for heating and cooling [2]. In other words, heating and cooling loads of a building depend mostly on the thermal transfer occurring from the building's envelope [5]. The three factors determining the heat transfer at the building envelope are differences in internal and external temperatures, area of the building envelope and the thermal transmittance coefficient [6] of the envelope material (i.e. its U value).

Solar radiation falling on the building envelope directly affects the thermal conditions in the building [7]. Hence thermal performance of the external walls is an important factor in terms of increasing the thermal performance of a building and, consequently, reducing its energy loads. This in turn reduces the energy demand, leading to a decrease in greenhouse gas emissions also. One way to reduce thermal energy transfers from the envelope is to increase the thermal insulation on the walls; this results in decreasing their U value as well as the energy expenditures [8].

The walls and windows of a building facade facing different orientations behave differently. Yet, thermal insulation material with the same thicknesses and windows with the same U values are installed on all exterior walls of the building regardless of their orientation. This practice results in different thermal performances of spaces facing different orientations; and this is why the fuel expenses of families living in the same building may be different from each other, for the same internal temperatures.

The Thermal Insulation Requirements for Buildings Standard TS 825 is mandatory in Turkey. According to this standard, the country is divided into five degree-day regions [9] and each region has its own prescription based on the highest acceptable U values for walls, ceilings, floors and windows for a building in this region. These regulations do not take into consideration the orientation of the building envelope component.

The orientation of the housing unit can become an advantage for some families and disadvantageous for others, in terms of thermal comfort. It may not be possible to apply additional insulation material on the facade or change the windows of a whole building due to design considerations. It is also very difficult to persuade owners of all flats to undertake the considerable cost of thermal refurbishments, especially when their residential unit faces a favourable direction. This problem can be solved by the owners of flats that suffer from the negative effects of orientation through remedial interventions such as: additional insulation material inside the exterior walls, changing windows and installing solar shading devices. The aim of this study is to investigate the effects of such interventions on the energy loads of the units facing different orientations and to propose intervention scenarios for ensuring thermal comfort equality in apartment buildings.

2. Material and Method

A three storied hypothetical apartment building measuring 18m x 18m was modelled with DesignBuilder energy simulation software. For the sake of simulations, the ground and top floors of the building were defined as adiabatic and analyses were conducted for the middle floor only. In order to examine the thermal performance of spaces facing different orientations, this floor was divided into a 3x3 spatial grid, thus creating 9 thermal zones. The schematic floor plan of the simulation model and the selected zones are shown in Figure 1. These selected central zones faced the four cardinal directions only; thus making it possible to understand the impact of orientation on thermal performance.

The set points for indoor temperatures were kept constant to minimum 22°C and maximum 25°C for the building. The building was assumed to be cooled by natural ventilation when outdoor temperature was below 27°C and the difference between internal and external temperatures was at least 2°C; however, mechanical air conditioning was activated when the temperature rose above 27°C.

The location of this hypothetical apartment building was assumed to be Ankara, which is the capital city of Turkey. Ankara has a continental climate with cold winters and hot and arid summers. According to the Turkish Standards for Thermal Insulation Requirements in Buildings (TS 825), Ankara is located in the 3rd degree-day region. The highest U values for the components of a building envelope in this region as set by TS 825 are given in Table 1 below.

Table 1. The highest U values for the 3rd degree-day region (TSE, 2013)

Wall	Ceiling	Floor	Window
0.48 W/m^2K	0.28 W/m^2K	0.43 W/m^2K	1.8 W/m^2K

The research methodology adopted in this study consisted of 5 stages, which are given below:

1. First Stage: First of all the walls, floors, ceilings and windows of the hypothetical building model were assigned construction materials having U values prescribed by the Turkish thermal standards for buildings located in the 3rd degree day region., This model was simulated for its thermal performance and the heating and cooling loads of the 4 selected zones, facing different orientations, were obtained. This version of the building is called the "Base Case" for the study.
2. Second Stage: Thermal insulation material with increasing thicknesses, from 1 to 5 cm was applied to the interior surface of the exterior walls of the "base case" building, and heating and cooling loads for each 1 cm increase in the insulation material were calculated as a result of simulations.
3. Third Stage: U values of the windows of the "base case" were decreased from 1.8 to 1.3 and the cooling and heating loads were calculated through parametric simulations, for each 0.1 W/m^2K decrease in the 4 zones.
4. Fourth Stage: Blinds were installed on the windows for solar control and were assumed to be used only in the summer months. Horizontal blinds were used on the South facing windows, while vertical blinds were used for the East and West facades of the "base case" building; and then cooling loads were calculated as a result of the simulations.
5. Fifth Stage: Parametric simulations were carried out and alternatives were generated, and additional thermal insulation with different thicknesses, windows with different U values and blinds were proposed for the walls facing different orientations.

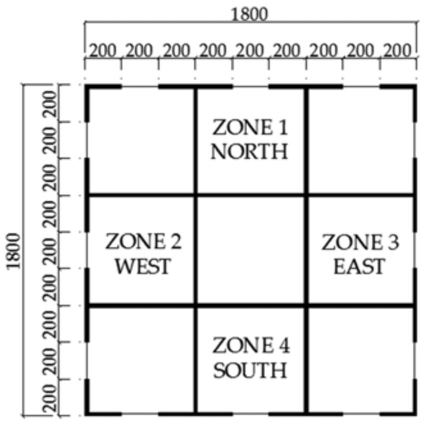

Figure 1. Dimensions and zones of the modelled building

3. Results and Discussion

The following sections will present the simulation results for the base case building, and the interventions for improving thermal comfort in the residential units, one by one. Results obtained by combining the interventions in various scenarios, are also presented here.

3.1 Base Case simulation results

At the 1st stage of the study, the U values of the walls, ceiling, floor and windows of the building were determined according to the Turkish Standards for Ankara; these are presented in Table 2 below. The recommended U value for the walls was achieved when the thickness of the thermal insulation material was taken as 5 cm. The base case model was simulated and the annual loads for cooling and heating were obtained for the units (zones) facing the four cardinal directions only; these are presented in Figure 2 below.

Table 2. U values of building envelope components at the 1st stage

Wall	Ceiling	Floor	Window
0.468 W/m^2K	0.28 W/m^2K	0.43 W/m^2K	1.8 W/m^2K

As can be expected heating loads are much higher than the cooling loads. The highest heating load was obtained in the North facing zone, followed by the loads for zones on the East and West facades, which were fairly close to each other. The lowest heating load was obtained in the South facing zone, due to the higher solar gains in this direction. The highest cooling load was determined to be in the West and the lowest cooling load was in the North. Cooling loads in the East facing zone were very close to the one in the West but higher than the cooling loads of the unit in the South.

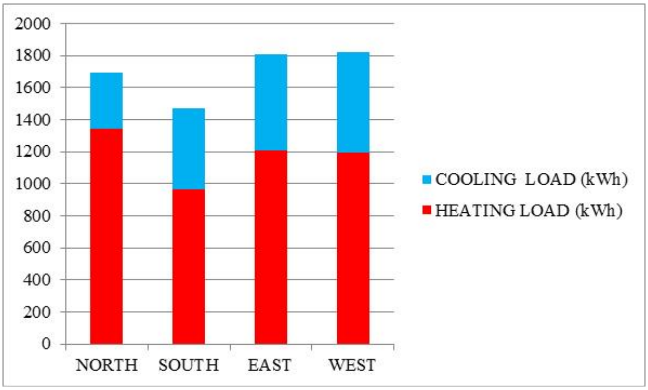

Figure 2. Annual heating and cooling loads obtained at the building

3.2 Influence of Additional Interior Thermal Insulation

Additional thermal insulation material with thicknesses of 1, 2, 3, 4 and 5 cm was applied to the interior walls of the "base case" one by one, and heating and cooling loads for each increment were simulated. The improved U values with added thermal insulation material for the walls are given in Table 3. It can be seen that applying thermal insulation on the inside surface of the exterior walls lead to a decrease in the heating loads. This decrease was 9.23% in the North, 8.86% in the West, 10% in the East and 10.09% in the South facing units (Figure 3).

Table 3. The U values of the walls according to insulation material thickness

Insulation Material Thickness (cm)	Wall U Value (W/m²K)
5 (Base Case)	0.468
5 (Ex.) + 1 (Int.)	0.419
5 (Ex.) + 2 (Int.)	0.379
5 (Ex.) + 3 (Int.)	0.328
5 (Ex.) + 4 (Int.)	0.319
5 (Ex.) + 5 (Int.)	0.295

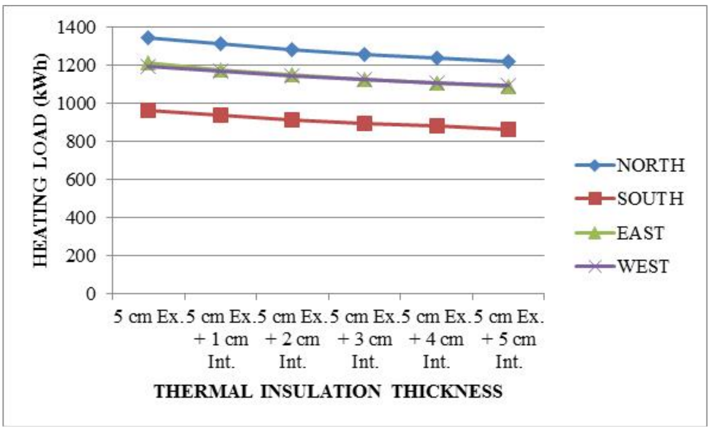

Figure 3. Effect of additional interior thermal insulation on the heating loads

On the other hand, this additional thermal insulation lead to a very slight increase in the cooling loads of the spaces. This increase was by 3.46% in the North, 0.48% in the West, 0.16% in the East and 1.37% in the South. However, for the sake of simulations the windows were considered to be shut and there was no natural ventilation at this point. Hence, it would be safe to assume that under ventilated conditions applying additional thermal insulation inside the exterior walls of the building would not have a significant effect on the cooling loads (Figure 4).

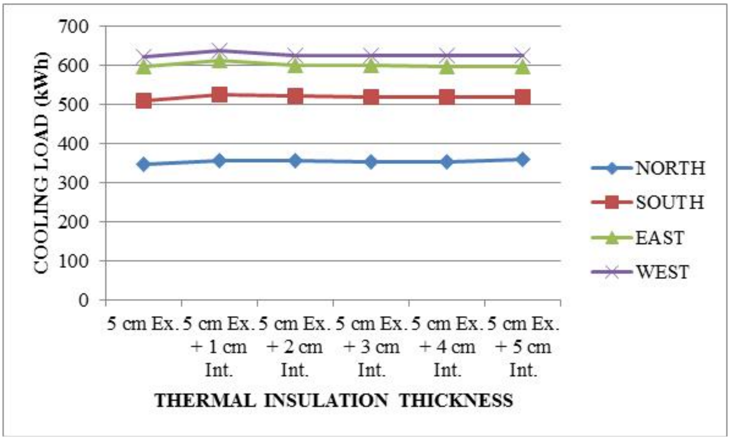

Figure 4. Cooling loads obtained in four zones of the building according to additional interior thermal insulation

3.3 Influence of Window U Value

In the 3rd stage of the study, U values of the windows in the "base case" building were decreased in steps of 0.1 W/m²K from 1.8 to 1.3 W/m²K and the cooling and heating loads obtained in the 4 zones were simulated for each step (Figure 5). The decrease of 0.5 W/m²K in the U value of the windows decreased the heating loads by 5.95% in the north, 6.27% in the west, 6.85% in the east and 8.22% in the south oriented unit.

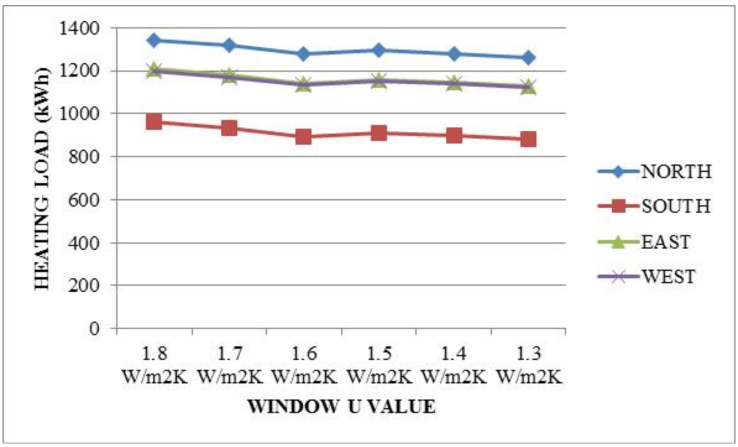

Figure 5. Heating loads obtained in four zones of the building according to window U value

The change in the U value of the windows, lead to an increase in the cooling loads (Figure 6). Cooling loads increased by 5.49% in the north, 3.69% in the west, 4.53% in the east and 4.5% in the south oriented units. However, this increase can be offset by incorporating natural ventilation in the cooling period.

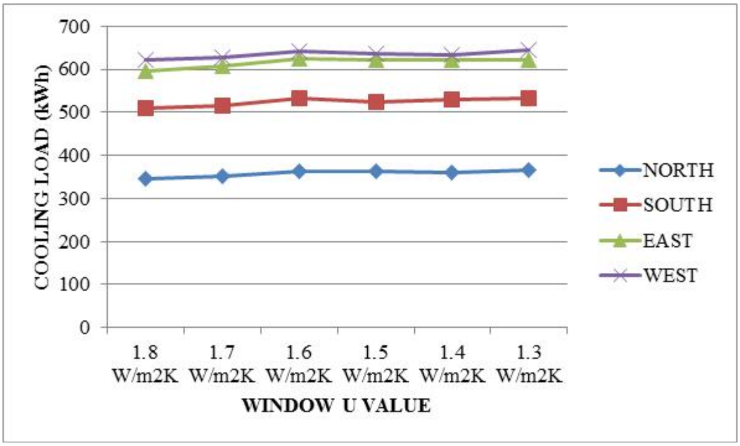

Figure 6. Cooling loads obtained in four zones of the building according to the U value of the windows

3.4 Influence of Solar Shading

Horizontal blinds were installed on the South, and vertical blinds on the East and West facades of the "base case" building, and cooling loads were simulated. Results were compared with the cooling loads obtained for the base case (Figure 7). It was observed that cooling loads were reduced by 12.94% in the South, 17.44% in the East and 21.54% in the West.

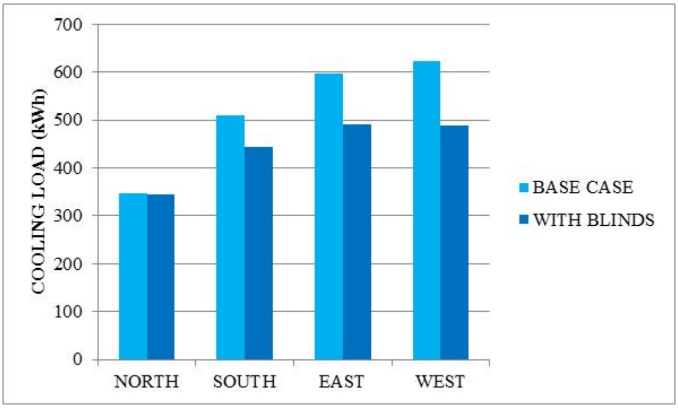

Figure 7. Cooling loads before and after installing solar shading devices

3.5 Proposed Intervention Scenarios for Thermal Comfort Equality

According to the results of the previous steps of the study, interventions such as applying interior thermal insulation, changing the windows or installing solar shading devices were separately able to equalize the energy loads of units facing different orientations. In order to understand the combined effect of the interventions, four different scenarios were simulated based on the results from the 1st 4 stages of the simulations.

According to the results of the previous steps, applying thermal insulation inside the exterior walls and installing new windows with lower U values reduced the heating loads considerably; while the cooling loads were reduced by installing blinds during the summer months.

Since the lowest heating loads were obtained in the unit facing South, increasing thermal insulation or changing windows was not considered for this facade in the simulation scenarios. On the other hand, since the highest heating loads were obtained in the North facing unit, additional 5 cm interior thermal insulation and new windows with lower U value (1.3 W/m²K) were proposed in all scenarios. However, interventions proposed for the East and West facades in terms of thermal insulation applications and window U values differed; the variations in the 4 alternatives are given in Table 4.

In the first simulation scenario, only additional interior thermal insulation of 2 cm was used for reducing heating loads in the western and eastern units. In the second simulation scenario, both interior thermal insulation (2cm) and new windows with a lower U value (1.3 W/m²K) were proposed for these two directions, in order to reduce the heating loads. The third simulation scenario uses both the insulation and new windows with a U value of 1.5 W/m²K for these units. Finally, in the fourth simulation scenario additional thermal insulation was not used, only new window with U value of 1.3 W/m²K were proposed for the east and west facing units.

Table 4. Proposed intervention scenarios for thermal comfort equality in the units facing different orientations

ORIENTATION	1			2			3			4		
	Added ins. mat. thick. (cm)	Window U value (W/m²K)	Blinds during summer	Added ins. mat. thick. (cm)	Window U value (W/m²K)	Blinds during summer	Added ins. mat. thick. (cm))	Window U value (W/m²K)	Blinds during summer	Added ins. mat. thick. (cm))	Window U value (W/m²K)	Blinds during summer
NORTH	5	1.3	-	5	1.3	-	5	1.3	-	5	1.3	-
WEST	2	1.8	✓	2	1.3	✓	2	1.5	✓	-	1.3	✓
EAST	2	1.8	✓	2	1.3	✓	2	1.5	✓	-	1.3	✓
SOUTH	-	1.8	✓	-	1.8	✓	-	1.8	✓	-	1.8	✓

Heating loads calculated for the base case and the proposed scenarios as a result of the building simulations are shown in Figure 8. It can be seen that heating loads are closer to each other for all units after applying the necessary changes to the facades. As can be expected, heating loads obtained in the units facing East and West are lower for the second and third scenarios because here both interior thermal insulation and window changes were applied.

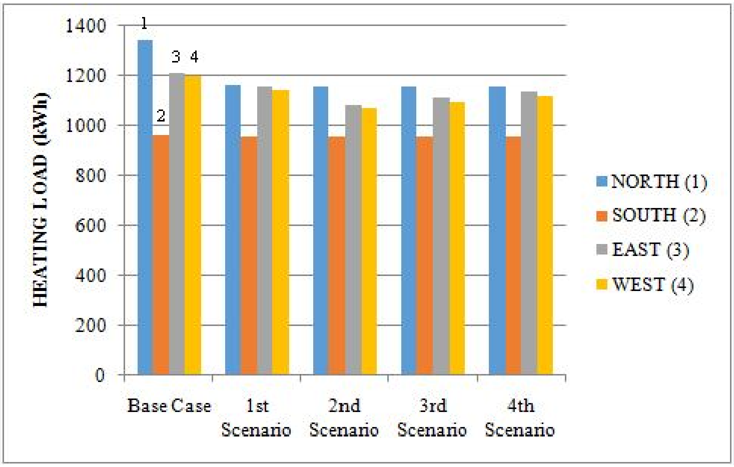

Figure 8. Comparison of heating loads obtained for the base case and the proposed interventions

Figure 9 shows the cooling loads calculated in the 4 units for the base case and the suggested scenarios. After adding the blinds for solar shading, the cooling loads for all four units became closer to each other.

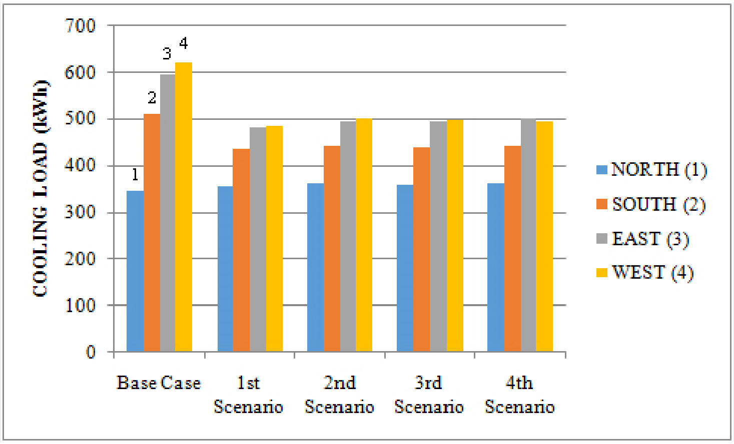

Figure 9. Comparison of cooling loads for the base case and the proposed interventions

The heating and cooling loads obtained for the four units oriented to the North, South, East and West for the base case and the four scenarios were added together to obtain their total energy loads, and the results were compared (Figure 10). The highest total energy loads were obtained for the base case in the study; while a reduction of 9% was achieved by applying the first and fourth scenarios, 10.6% by the second scenario and 9.9% by the third scenario. In other words, the proposed interventions not only brought down the heating and cooling loads of all units but also managed to bring their total energy loads closer together; thus achieving equality from the point of view of thermal comfort and energy expenditures in all units, regardless of their orientation

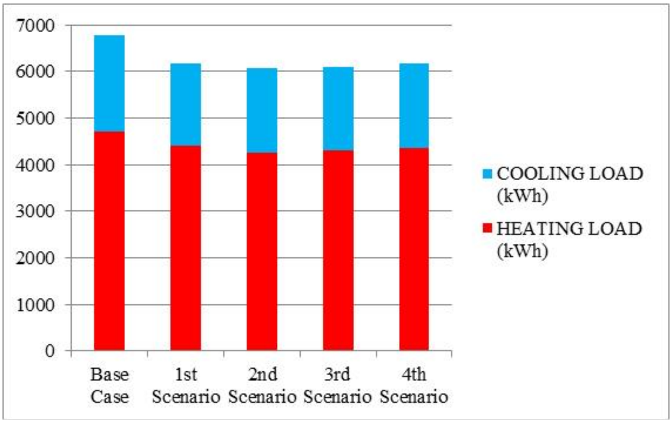

Figure 10. Comparison of total heating and cooling loads of the four units in the hypothetical building, for the base case and the proposed scenarios.

4. Conclusion

Apartment buildings have residential units that are symmetrically grouped around the central vertical transportation cores, i.e stairwells and lifts. Each unit is able to take in the sun, which is an important source for daylight and passive heating, from one or at the most two directions only. Such spatial configurations lead to different thermal conditions within the units, depending on the directions they face. In other words, residential units oriented towards the South get more sun than those in the North; on the other hand units facing West get the most solar gains while those facing East are comparable to the ones in the west. The amount of solar gain becomes important in colder regions because it is a source of passive solar heating, which lowers the need for active heating expenditures. In order to achieve the same level of thermal comfort occupants residing in units facing different directions get different energy bills; northern units having the highest and southern units the lowest amount of energy expenditure.

The owners of differently oriented residential units can, however, make some refurbishments to offset the impact of orientation on their energy bills. Such refurbishment measures can be adding thermal insulation to the inside surface of the external walls and replacing windows with ones having better thermal resistance to prevent heat transfer through the building façade; installing blinds that can be opened to prevent excessive solar gains in summer months; and use night purging to cool the spaces with natural ventilation. This simulation study has shown that by adopting such measures, occupants can create better thermal conditions and reduce their energy bills while achieving thermal comfort equality with their neighbours.

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