EVALUATION OF THERMAL COMFORT CONDITIONS IN COMMUNITY CENTER IN PELOTAS, RS: SIMULATION OF CHANGES IN WINDOWS CHARACTERISTICS

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ABSTRACT

This paper evaluates the influence of windows in thermal energy performance of a social interest bulding in Dunas District - Pelotas/RS, analizing the performance for heating and cooling over the year.

The original design was modeled and analized through the energy efficiency software "Design Builder" (v:2.3.5.036), considering different sizes of window openings - 12.5%, 20% and 45% of the floor area - and three types of sun protection - blinds, shutters and brises-soleil.

The changes made in the sizes of the windows and in the type of sunscreens didn't affect significantly the thermal-energy performance of the building. The results indicate that, in this case study, variations of other features of the building could possibly bring better results.

INTRODUCTION

Energy saving has become focus of brazilian government action since the energy crisis of 2001, popularly known as "blackout", generating the need for rationing and causing, among other problems, reduced economic growth, loss of revenue taxes, increased unemployment and increased trade deficit. After this problem the government has directed several actions to battle the wastage and to promote awareness within the general public~~,~~ as well as to make energy consumption more efficient. PBE - Brazilian Labeling Program - was responsible at first for the labeling of home appliances and, afterwards, considering that buildings consume almost half of the energy produced in the country, the first regulations and codes were published: RTQ-C (2009) and RTQ-R (2010). The brazilian walk to increasing building thermal performance began its basis with the publication of the National Codes NBR 15220 (2005) and NBR 15575 (2008). The RTQ-C regulation for commercial, public and service buildings has the purpose of scoring the energy efficiency of the buildings through labeling . This code subdivides and score independently or together, the building envelope, lighting and air-conditioning system, considering two methods: a) the prescriptive - calculated through a preset equation b) computer simulation, performed with specific software.

The computational simulation tools for energy efficiency have proved to be excellent and reliable mechanisms in the process of evaluation and project, allowing the analysis of these results to guide the choice of constructive characteristics such as architectural typologies, materials, window frames and others. The application of standards can only be achieved by using simulation softwares to define consumption indicators and to analyze projects submitted to the evaluation criteria (Mendes et al. 2005).
The use of simulation tools such as Design Builder software allows endorsing project decisions through thermal energy performance of the buildings. This allows the verification of the obtained conditions according to their choices, including both solar orientation and building types , materials, colors, window frames and natural ventilation strategies (Oliveira et al. 2011).

The dimensions of the window openings and their solar protection are determinant in the thermal performance of the building. The heat gain through these items can be eight times the gain of the walls, so the frames are the main elements of gains or losses in buildings (Lamberts et al. 2004).

Objective

The objective of this work is to evaluate the influence of windows on thermal comfort of a community center already designed by the "model office"[1] of the Catholic University of Pelotas and will be built in Dunas District in the city of Pelotas – Brazil.

Methodology

The studies were based on the performance of computer simulation utilizing the software Design Builder version 2.3.5.036. The simulation was developed in seven stages:

1. climatic characteristics of the city;
2. characterization and building modeling;
3. model configuration;
4. base case simulation;
5. changes in windows openings and solar protection system and simulation cases;
6. analysis of thermal comfort of the interior space;

[1] The model office is an architecture office that meets the needs of underserved communities in the region of the city.

7. analysis of energy efficiency (degree-hour).

The case of study is the design of a community center building to be located in the Dunas District in the city Pelotas / RS (South Brazil). The building will be house of activities of the Womans Association and includes a library, activities room, toilet, kitchen and deposit (fig.1).

Climatic characteristics of the city

Pelotas is located in a humid subtropical climate (temperate), with latitude 31°46'19"S and longitude 52°20'34"W. The summers have regular rainfall with maximum absolute year temperature at between 34°C and 36°C. Winters are relatively cold with frequent frosts (having an average of 20 per year) and fog, with absolute minimum year temperatures between -2°C and 0°C.

The city has an average annual temperature of 17.5°C in the urban area. January is the hottest month with an average temperature of 23°C, and July is the coldest month, with an average of 12°C. The daily temperature range, which is the difference between the minimum and maximum temperatures of a day, is usually moderate, between 8 and 9 degrees, and there are days where the temperature ranges can reach up to 20 degrees, especially in the fall.

The city's average annual rainfall is 1,379 mm, with rainfall evenly distributed throughout the year. February, with 145 mm of precipitation, is the wettest month. The relative humidity is very high, with an annual average around 80% (table 1).

Characterization and modeling of the building

The object of study is a single storey building, with16 cm thick concrete block walls plastered on both sides, except the toilet walls, that are covered with ceramic tiles.

The roof cover consists of 6 mm thick fibrocement roof tiles , with 1cm PVC ceiling liner and a layer of air between the tiles and the liner. The aluminum window frames have two sliding panels with 3 mm conventional glass .The entire building has 1 cm thick ceramic tiles to floor, set with 2.5 cm mortar above with 7 cm lightweight concrete slab.

The project is illustrated below in figures 1 and 2.

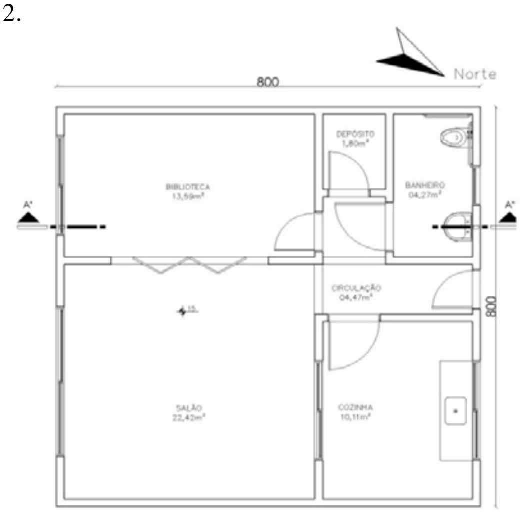


Figure 1 - Floor plan of the Community Center building.
Source: Catholic University of Pelotas

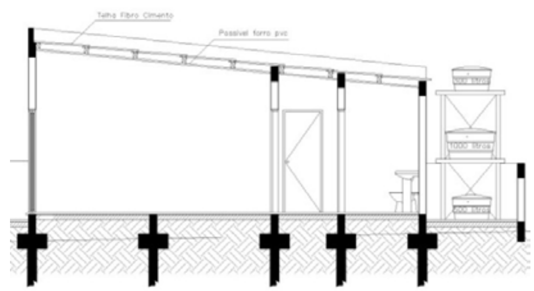
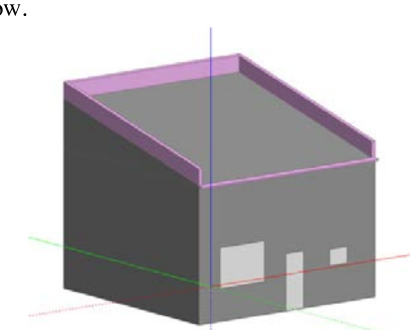


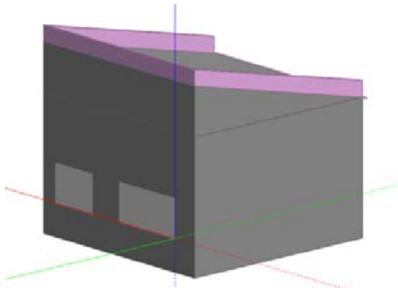
Figure 2 - AA' section of the Community Center building.
Source: Catholic University of Pelotas

The computational model was created on software Design Builder version 2.3.5.036. from the design specifications and materials listed above.

The results can be seen in figure 3 and table 2 bellow.



(a)



(b)

Figure 3(a,b) - Model created in Design Builder software

Model setting

The final step before simulation was to define the settings related to internal gains due to the use of the building.

For general lighting, suspended pendents were considered, achieving 12W/m² each. In the library and lounge areas, 4 W / m² were added due to the greater demand for lighting resulting from activities in these spaces.

Regarding occupation, 0.25 people/m² were considered during working hours from 9h to 17h on Monday to Friday. It was planned the occupancy of 100% throughout the day, with the exception of the interval from 12h to 14h. On Saturdays and Sundays, the operation hours were planned from 10h to 14h, with 100% occupancy too. In addition, nine holidays per year were considered.

As in ISO7730 (2005), in relation to metabolism, the activity considered was seated reading, with metabolic rate of 70 W/person. For clothing was considered a 1.0 clo in winter and 0.5 clo in the summer. Finally, the cooling setpoint was set to 25°C, according to Martins et al. (2009). If the outdoor temperature is below the internal and less than 25°C the windows are open. In such cases, we had simulated the opening of the window panels to allow natural ventilation.

Base case simulation

The first step for setting the base case was the choice of using TRY climate file for simulation. Santa Maria's city climate file was the most suitable for use in this work, considering that it is part of the same bioclimatic zone of Pelotas (ZBB2) as NBR 15220-3. (Oliveira et al. 2011).

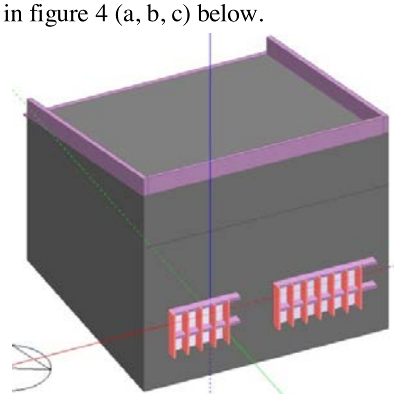
For the simulation, the ASHRAE 55 (2004) regulation was used as parameter of thermal comfort, stablishing the acceptable operating temperature for naturally conditioned ambient, considering that the space will be equipped with operable windows that open to the outside, adjustable by occupants, and physical activity is next to sedentary between 1.0 and 1.3 met, the occupants can adapt their clothing to thermal conditions internal and external, being not necessary parameters limits for humidity and airspeed.

Changes in windows and sun protection system

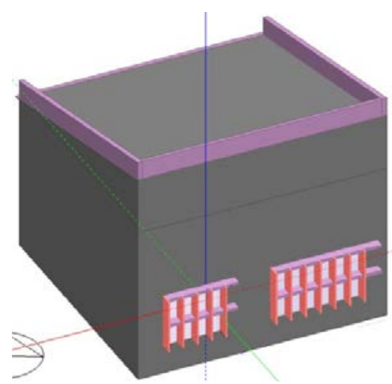
The variations in size of the windows were made based on NBR 15.220 (2005). This standard classifies the size of window openings for social interest housing - part 3 - Bioclimatic Zoning - in: a) small, with an area of 10% to 15% of the floor area, b) average, with an area of 15% to 25% of the floor area and c) large areas, greater than 40% of the floor area. For this work simulations, we considered the sizes of 12.5% of the floor area for small window openings, 20% of the floor area for the average window openings and 45% of the floor area for large window openings.

Besides the size of the window openings, different types of sun protection, either internal and external, four cases were tested for each opening size: a) absence of protection, b) internal curtains, c) external shutters d) external shading devices both vertical and horizontal awanings. The total of 13 configurations were tested, the base case plus the 12 alternative configurations.

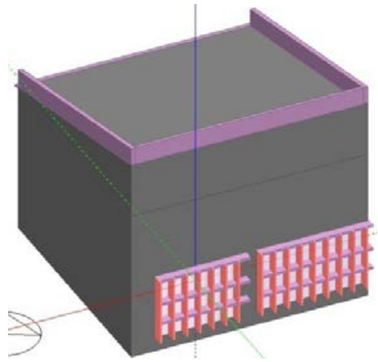
Changes in the window openings and brises soleil were also modeled in Design Builder, and can be seen in figure 4 (a, b, c) below.



(a)



(b)



(c)

Figure 4(a,b,c) – Model with brises-soleil, created in Design Builder software. Southeast facade

The brises-soleil, were designed to be made in concrete and fixed to the building, with the purpose of completely block the direct sunlight from 9am to the sunset on the summer solstice, to reduce heat gains of the building in the hottest period of the year.

The solar chart used as a reference was obtained using the Analysis SOL-AR 6.2 software (LABEEE), using the latitude as input (in the case of Pelotas / RS, -33 degrees). As a result, the software calculated the necessary angles for the design of the external awanings in the northwest facade, where the kitchen window is located, and southeast facade, where the windows of the library and lounge are located. The results are shown in figure 5 and table 3 below:

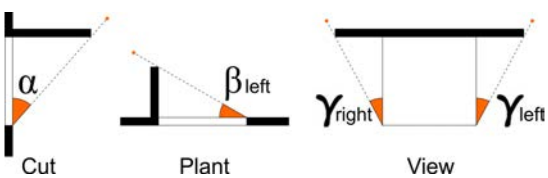


Figure 5 – Definition of the angles of sun protection

Ângulo	Facade	
	Northwest	Southeast
α	50º	70º
β left	50º	45º
γ right	75º	88º
γ left	50º	60º

Table 3 – calculated angles for the design of the external shading devices

Analysis of the interior space thermal comfort

With the models ready and configured, we performed a set of simulations for a year of reference, measuring the thermal comfort conditions from 8am to 22pm, totaling 5110 hours in a year. The nighttime period, from 22h at 8am the next day, was disregarded considering the institutional use of the building, not intended for residence.

Analysis of energy efficiency

The operative temperature is the uniform temperature of a radiant totally dark ambient, where an occupant would Exchange the same amount of heat by radiation and convection than in the real ambient. To determine the operative temperature, we used the following equation:

$$To= A.Ta + (1 - A) . Tr \qquad (1)$$

To: operating temperature hourly (°C);

Ta: air temperature in the ambient (°C);

Tr: medium radiant temperature (°C);

A: constant that varies with the airspeed in the ambient (in case of absence of airspeed data should be considered the coefficient in equation of 0.5)

Source: ASHRAE 55, 2010

To determine the comfort range the following equation: was used:

$$toc = 18{,}9 + 0{,}255\ text \qquad (2)$$

toc = operating comfort temperature

text = external temperature (to reach 90% acceptabilit, in other words, toc +2,5 or toc -2,2)

Source: ASHRAE 55, 2010

These parameters generated daily variations of thermal comfort, which were compiled into worksheets resulting in the percentage of heat, cold and comfort.

Degree-hours for heating is a climatic parameter which can be defined as the sum of temperature differences when they are below a base temperature (Tb). Meaning that when the hourly average temperature is less than Tb, we calculate the difference (Tmed. - Tb), accumulating these differences, every hour, for the whole year. Degree-hours of cooling uses the same calculation, but for temperatures above the average temperature (ASHRAE, 1993 apud Goulart et al. 1997).

ANALYSIS OF RESULTS

The analysis of output data generated by Design Buider software demonstrates, for the base case (Chart 1), that there is a predominance of discomfort in the building. The building has a higher discomfort by heat (35.5%) than by cold (27.6%) during the year, totaling more than 60% of time of discomfort. Analyzing the seasons separately, we have over 75% of heat discomfort during the summer and more than 55% of discomfort for cold during the winter. These results indicate the need of improvement in the design, considering that the building should be installed in a poor region of town, reducing spending on energy consumption for air conditioning and directing resources for actions of social relevance for society.

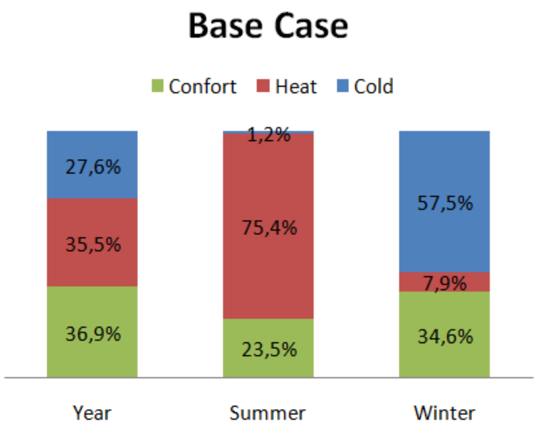


Chart 1 – Thermal comfort for the base case along the year, in summer and winter time.

The first tests were made changing the size of window openings, without sun protection. In this case it is possible to notice that the percentage of comfort remain relatively stable compared to the original configuration. The major difference, of only 0.4 percentage points, was achieved with the use of large windows (Graph 2). Is also noticeable that discomfort for heat increases with the increase in the area of window openings. At the same time, discomfort from cold is reduced, however the variation in the percentage is small. This change is related to greater solar radiation entering the building, caused by larger windows.

Curtains were the first type of sun protection tested. In this case, we observed a slight increase in comfort zone for all three cases, along with the decrease in heat discomfort zone (Figure 2). The discomfort zone by cold stays almost unchanged. The effectiveness of the curtains in the model increases with larger window openings, due to the greater area of exposure and hence greater protection area by curtains. Although the results show improvement in comfort compared to unprotected windows, these are very close to the values found for the base case.

With the replacement of curtains by shutters, we observed a lower percentage of comfort, with results nearly identical to those found in unprotected windows (Graph 2). We note that, in the studied case, shutter presents an almost null benefit to thermal comfort, not justifying the application of this type of element in the building. That happens because bigger windows, south oriented, receive lower amounts of sun radiation, not heating the ambient in winter and increasing the discomfort by cold.

The last case studied was the installation of brise-soleil in all windows. In this situation, the percentage of heat discomfort decreased, but the levels of discomfort from cold have increased (Chart 2). This result is due to partial shading caused by brises-soleil during other periods of the year but summer. Despite the increase in discomfort for cold, this proved to be the best alternative between the simulated cases to improve the percentage of comfort in the building. Still, the improvement is not significant enough to justify the investment.

In the case of medium-sized windows (20% of the floor area) the comfort period corresponds to 37.5% of total time, while the comfort obtained by curtains corresponds to 37.6% of total time. These were the maximum amounts of comfort obtained from simulation of the thirteen configurations tested. The lower percentage of comfort found in this study was obtained in the case of larger-size windows (45% of the floor area) without sun protection

Degree-hours of heating and cooling

When comparing the 13 cases studied by the method of Degree-hours, we can notice that for larger window sizes, it is greater the need for cooling the bulding, with little influence of the type of sun protection used (Chart 3).

We emphasize that the use of blinds and brises-soleil were the strategies that best protected the windows in summer, causing a lower demand for cooling. The shutters behaved very similar to unprotected windows, keeping the environment very hot in the summer, as causing a lower demand for heating in winter.

FINAL CONSIDERATIONS

We can conclude that, among the tested cases, the best types of sun protection are brises-soleil and curtains, due to decreasing the percentage of discomfort by heat and maintaining stable the levels of discomfort from cold.

However, the small difference in the percentage of comfort, for both cold and heat indicates that the high level of discomfort was due to other elements of the building, not just the variations of the window openings. Furthermore, additional studies are recommended regarding other elements of the building to identify critical areas that should receive greater investment in order to increase the quality of the Community Center building.

REFERENCES

ABNT - Associação Brasileira de Normas Técnicas. NBR 15220: Desempenho Térmico das Edificações. Rio de Janeiro, 2005.

ABNT - Associação Brasileira de Normas Técnicas. NBR 15575: Edificações Habitacionais-Desempenho. Rio de Janeiro, 2008.

ASHRAE Standard 55. Thermal Environmental Conditions for Human Occupancy. Atlanta, 2004.

Goulart, Solange V. G; Lamberts, Roberto; Firmino, Samanta; Dados Climáticos para Projeto e Avaliação Energética de Edificações para 14 Cidades Brasileiras. Florianópolis: Núcleo de Pesquisa em Construção/UFSC, 1997.

Lamberts, R.; Dutra, L.; Pereira, F. O. R. Eficiência Energética na Arquitetura. 2a Edição. São Paulo: Prolivros, 2004.

LABEEE – Laboratory for Building Energy Efficiency, Federal University of Santa Catarina. Computational software Analysys SOL-AR. Available: <http://www.labeee.ufsc.br/software/analysis BIO.html>. Acess in May. 2012.

Martins, David José; Rau, Sabrina Leal; Reckziegel, Simone; Ferrugem, Anderson Priebe; Silva, Antonio César Silveira Baptista da. Ensaio Sobre a Utilização da Automação de Esquadrias na Simulação do Desempenho Térmico de Edificações. ENCAC, 2009.

Mendes, N.; Westphal, F. S.; Lamberts, R.; Cunha Neto, J. A. B. Uso de Instrumentos Computacionais para Análise do Desempenho Térmico e Energético de Edificações no Brasil. ANTAC, 2005.

Oliveira, Liader S.; Silva, Antônio César S. B. da; Cunha, Eduardo Grala da. Análise das Condições de Conforto Térmico em Habitações de Interesse Social em Pelotas/Rs. ENCAC, 2011.

Climatological data for Pelotas - Brazil													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average maximum temperature (°C)	27	26	26	22	19	17	16	18	19	21	24	26	21
Average minimum temperature (°C)	19	18	17	14	10	9	8	9	10	13	15	17	13
precipitation (mm)	118	145	120	100	95	118	132	123	135	112	86	95	1379

Table 1 –Climatological data for Pelotas - Brazil

ROOF <u>3 layers</u> Transmittance: 2,361 W/m² K	1 – Fibrocement e = 6mm		Conductivity: 0,95 W/m K Solar Absorptance: 0,700 Emissivity: 0,900 Dark Gray Texture
	2 - High emissivity air chamber > 5cm e = 16cm		Emissivity: 0,900 Thermal Resistance: 0,21m² K/W
	3 – PVC (insulating materials) e = 1cm		Conductivity: 0,160W/m K Emissivity: 0,900
FLOOR <u>3 layers</u> Transmittance: 3,535 W/m² K	1 – Ceramic Floor e = 1cm		Conductivity: 0,90 W/m K
	2 – Plaster mortar e = 2,5cm		Conductivity: 1,15 W/m K
	3 – *concrete radier* e = 7cm		Conductivity: 1,75 W/m K
EXT. AND INT. WALLS <u>5 layers</u> Transmittance: 2,831 W/m² K	Plaster mortar e= 1,5cm		Conductivity: 1,15 W/m K
	Concrete block e=13cm c/ air chamber e= 8 cm	Concrete	Conductivity: 1,75 W/m K
		Air chamber	Thermal Resistance:0,14m² K/W
		Concrete	Conductivity: 1,75 W/m K
	Plaster mortar e= 1,5cm		Conductivity: 1,15 W/m K
WINDOW FRAMES	<u>External Windows:</u> Aluminum sliding Glass type: 3mm Solar factor: 0,87		Transmittance: 2,831W/m² K Conductivity: 0,90 W/m K
	<u>Internal Doors:</u> Open100% of the time <u>External Doors:</u> Open 5% of the time		

Table 2 –Building configurations of Base Case – Building Envelope

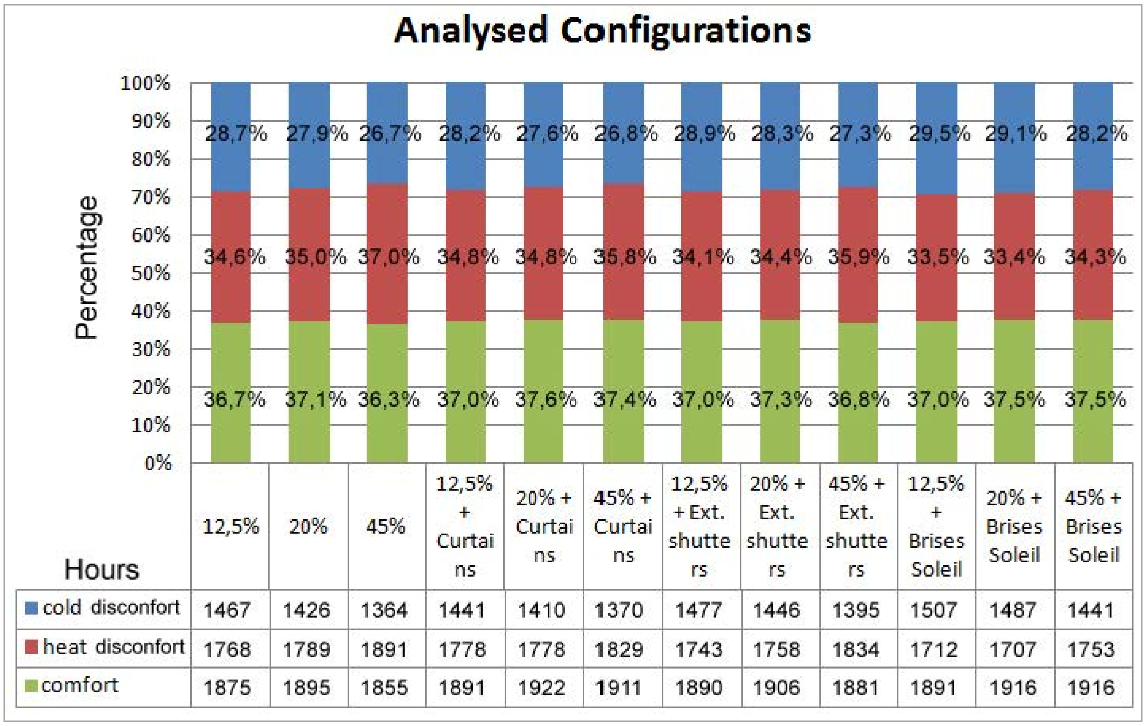


Chart 2 – Thermal comfort considering different sizes of window frames and sun protections.

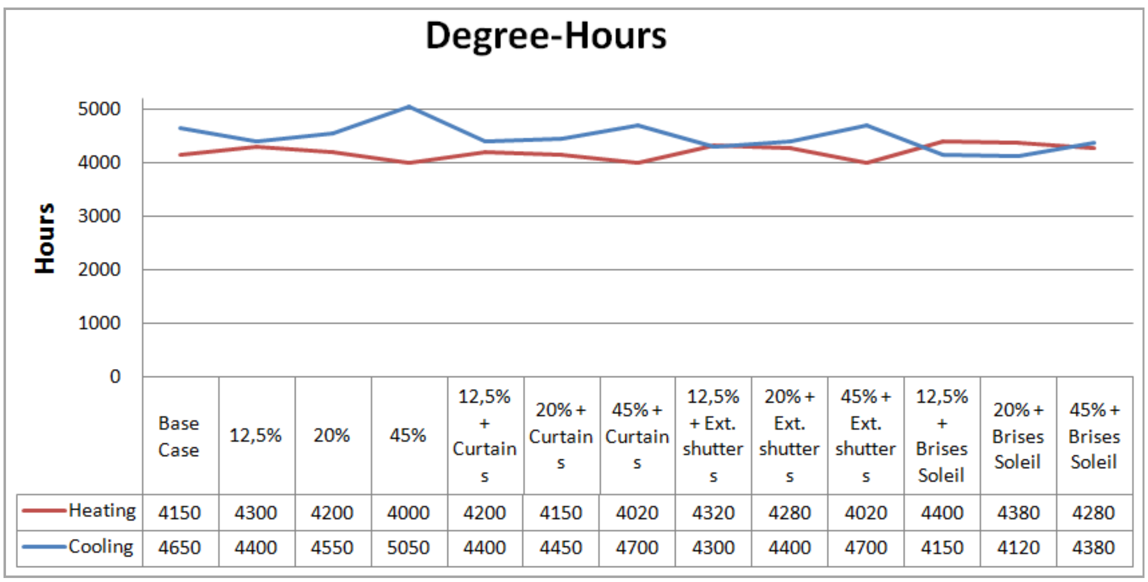


Chart 3 - Degree-hours of heating and cooling