ENGLISH VERSION

Procedimiento para análisis del desempeño termoenergético y económico de estrategias pasivas para la adaptación de un edificio en Brasil

Procedure for analysis of thermo-energetic and economic performance of passive strategies for retrofitting a building in Brazil

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Fecha de Recepción: 06/03/2018
Fecha de Aceptación: 11/05/2018
PAG 251-262

Abstract

The construction sector is responsible for high levels of energy consumption and for environmental impacts during the life cycle of a building all over the world. Therefore, sustainability has become an inherent topic in building design, in response to the stringency of natural resources and to performance. A way to design sustainable buildings is taking advantage of the available natural resources on site to reduce the needs for artificial conditioning. Requirements of performance have become more restrictive and existing buildings must conform to them. This is possible through a retrofit process which improves their performance to comply with actual requirements, besides improving the comfort of their occupants. Most of the developed procedures for retrofitting analysis take into account only energy consumption and emission of pollutants. The aim of this paper is to demonstrate a procedure to help designers and decision makers on choosing the best retrofit strategy considering energy consumption, thermal comfort and the cost-benefit of these strategies. A computational model of a building located at the State University of Campinas was developed to simulate different passive strategies and the results obtained are presented in an easy-to-use chart as part of the procedure.

Keywords: *Retrofit, passive strategies, computer simulation, energy efficiency, thermal comfort*

Resumen

El sector de la construcción es responsable de altos niveles de consumo energético y de impactos ambientales durante el ciclo de vida de un edificio. La construcción sustentable se ha convertido en un tema inherente, teniendo en cuenta la poca disponibilidad de recursos naturales y a las regulaciones de desempeño. Una forma de proyectar edificios sustentables es el uso adecuado de los recursos naturales disponibles. Los requisitos de desempeño son restrictivos y los edificios existentes deben ajustarse a ellos. Esto es posible a través de un proceso de adaptación que mejora su rendimiento para cumplir con los requisitos reales, además de mejorar la comodidad de sus ocupantes. La mayoría de los procedimientos desarrollados para el análisis de adaptación tienen en cuenta únicamente el consumo de energía y la emisión de contaminantes. El objetivo de este documento es demostrar un procedimiento para ayudar en la elección de la mejor estrategia de retrofit considerando consumo de energía, comodidad térmica y costo-beneficio. Fue desarrollado un modelo computacional de un edificio ubicado en la Universidad Estatal de Campinas para simular diferentes estrategias pasivas. Los resultados obtenidos son presentados gráficamente y utilizados en el procedimiento.

Palabras clave: Retrofit, estrategias pasivas, simulación por computador, eficiencia energética, confort térmico

1. Introduction

The high consumption of energy for building use is one of the greatest problems of the energy sector and has a significant environmental impact (Jiménez et al., 2011). Buildings are responsible for almost 50% of the energy demand in Brazil (Procel Info, 2006) and 40% in Europe (European Commission, 2010). Frequently the material used in the envelope, the poor ventilation or daylighting design makes it necessary the use of artificial systems even when conditions are not extreme. Since the global energy crisis in the 70's performance requirements for residential and office buildings have been implemented. In order to comply with those requirements, building materials and components have been developed as well as new tools to aid architects and engineers to design and predict the performance of buildings.

In order to meet current performance requirements, existing buildings may undergo a retrofit process. Within this scope one can see the resurgence of passive strategies to condition the buildings. Unfortunately, there is still a lack of knowledge about how to use them and unknown input data for computer simulation tools to evaluate their performance. Another important topic is which parameters of performance are evaluated. Most of the performance regulations focus on

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the energy consumption and air quality. Requirements of environmental comfort are not as specific or restrictive.

Besides performance criteria, the selection of an appropriate technology should consider other variables along the decision-making process and according to Asadi et al. (2014), the identification of retrofit actions represents technical and methodological challenges. As far as building performance is concerned, it is important not only to evaluate the initial costs of implementing the system, but also the cost of operation, as energy consumption and preventive maintenance.

The aim of this paper is to present a simplified procedure for the decision-making process for retrofitting buildings. The procedure takes into account three parameters: thermal comfort, energy consumption and costs. In order to exemplify its application, three passive strategies were studied by computer simulation: green roof, natural ventilation (daytime ventilation) and use of daylight.

2. Theoretical framework

2.1 The role of the green roofs in buildings

In climates of tropical countries, the need for heat mitigation is enormous, especially in the summer months, and in this part the vegetation does especially well. The green roofs provide protection from solar radiation, which is the main factor for passive cooling (Efthimiadou & Tzouvadakis, 2010).

The use of vegetation as a passive environmental conditioning technology has been gaining more prominence in the urban environment, given its multifaceted roles. Recent studies show the potential for significative reduction in energy needs for heating and cooling provided by green roofs (Cannata et al., 2018). Thus, it becomes possible to achieve various regulatory functions through a single technology, involving problems such as urban flooding, air quality, heat islands, and even high level of stress (Givoni, 1991; McPherson, et al., 1997; Nowak, 2006).

The impact of vegetated areas on the temperature of urban areas have been recently studied (Susca et al., 2011). Because of the benefits of greenery systems in urban scale, worldwide policies have been developed in order to encourage building owners installing green roofs. Examples of initiatives are found in: Germany, Canada, USA and Japan (Townshend & Duggie, 2007). Moreover, according to Wong et al. (2003), strategically placed vegetation on roofs and walls can be considered as a supplement of green surfaces in urban areas.

However, not always the insertion of vegetation in urban areas is a simple task, since the high demand for land use tends to relegate it to second. It is because of this limitation that currently there has been a lot of research looking for new ways to incorporate vegetation in cities, evaluating their efficiency (Perini & Magliocco, 2012).

2.2 Natural ventilation for thermal comfort and energy efficiency

Designing a building has the dual challenge of providing good performance of ventilation as well as energy conservation. One way to reduce energy consumption in buildings, without affecting the thermal comfort, can be achieved by designing a proper ventilation system (Chiesa et al., 2010). Thus, it can provide indoor air quality, thermal comfort and less energy demand for cooling.

Researchers worldwide have demonstrated that natural ventilation in buildings is an efficient passive strategy for thermal comfort and energy savings (Campaniço et al., 2014; Yu et al., 2015; Tong et al., 2016). According to the Brazilian bioclimatic zoning (ABNT, 2008), seven out of the eight zones are recommended to use natural ventilation for cooling. This standard is applicable to residential buildings, although studies demonstrated the potential of the strategy for cooling and reducing energy consumption in office buildings (Rupp & Ghisi, 2013).

Driving forces for the air to flow through façade openings are temperature difference between indoors and outdoors and wind pressure distributions on the façade due to local wind. Therefore, the success of this strategy also relies on building properties and location (obstructions from the surrounding buildings, geometry, permeability, size and location of the openings).

2.3 Daylighting with dimmers and automated blinds

Daylighting in buildings provides energy efficiency by reducing the demand for artificial lighting besides allowing visual comfort for their occupants (Alrubaih et al., 2013). It has positive impact on the health of the users and their productivity (Boyce et al., 2003). Hence it is recommended that building design allows a minimum number of hours of access to sunlight (Santamouris, 2001). On the other hand, this is a strategy that must be handled with caution mainly in tropical climates, since the solar gains may be excessive and need to be removed by artificial means (Carlo et al., 2004).

Automated controls for lighting and blinds have shown good results reducing energy consumption with lighting. However, the occupant behavior is determinant on the building performance (Sanati & Utzinger, 2013). Occupant behavior, daylight conditions throughout a year and its interaction with indoor surfaces are essential variables for daylight design and nowadays they can be estimated by means of computer simulation. An algorithm developed by Reinhart (2004) based on field surveys can predict occupant behavior in office buildings and their interaction with lighting and blind systems. The algorithm is incorporated to Daysim (Reinhart, 2017), a software that estimates the annual amount of available daylight for a given location which was used in this paper.

2.4 Technology selection process

In the decision-making process, which involves the selection or adoption of a technology, one of the main questions is how to choose the best alternative. In order to answer this question a multitude of methods has been developed in order to help decision makers during this process. Many different methods have been proposed over time. These methods are based on mathematical modeling with different levels of complexity varying according to the number of variables considered, mathematical methods employed and the number of actors involved in the decision-making process.

The idea in this research is to develop a simple procedure that could help designers in the analysis of alternatives for retrofitting buildings, which includes a limited but representative set of parameters: hours of discomfort, energy consumption and cost. Three different methods were analyzed in order to define the most suitable method to be *used: cost-benefit analysis; life-cycle costing analysis and multi-criteria decision analysis.*

Cost-benefit analysis, according to Adler & Posner (1999) is a technique that weighs and compares the costs and benefits of alternatives. It can range from an informal weighing of qualitatively described pros and cons to a highly sophisticated method that employs mathematics and is grounded in economic theory. It consists in determining the viability of a project by discounting future benefits and costs to present value, the main difficult being in the accurate estimate of costs and benefits and discount taxes.

Life-cycle costing analysis is a method that allows the evaluation of different alternatives considering all long-term costs involved in the life cycle of a project, that is: cost for acquisition, operation, maintenance and repair (Guinée et al., 2010).

Multi-criteria decision analysis is a method used to help decision among alternatives which involve a large number of complex, contradictory, technical and economical, quanti and qualitatitave parameters. Also, it is suitable when there is a large number of alternatives to be taken in to consideration during the decision-making process. There is a large number of multi-criteria decision analysis methods proposed in the literature, being AHP (Analytic Hierarchic Process) the most commonly used one in the construction industry according to Jato-Espino et al. (2014). These methods involve advanced mathematical procedures and require the help of specialist or of knowledge based systems for its application (Jato-Espino et al., 2014).

The cost-benefit analysis was chosen as the basis for the analysis presented in this research for its simplicity and considering that a small number of parameters and passive strategies have been analyzed for retrofitting the building. In the cost side of the equation it was considered the costs of implementation and maintenance and the benefit side was represented by the economy of energy and thermal comfort provided using computer simulation.

3. Research method

The purpose of this study is to present a new procedure to help decision makers on choosing the most suitable solution for retrofit. The parameters of choice are: thermal comfort (hours of discomfort during summer season), costs (implementation and maintenance of the technology) and total annual energy consumption. The solutions presented here are classified as passives strategies, namely: natural ventilation, daylighting and green roof. The authors highlight that the focus of the paper is not to demonstrate the effectiveness of the passive strategies, but the procedure itself for comparing their performance in a broader sense.

In order to ground this study, an existing building was investigated: the building of the Institute of Philosophy and Humanities (IFCH) at the campus of the University of Campinas (Figure 1). It is a three-story building featuring mainly academic and administrative purposes. It is surrounded by trees on the Southwest and Northeast facades. Its facade presents interleaved vertical stripes of blind walls and windows with external shading elements.


(a) (b)

Figure 1. *Entrance of the building (Southwest) (a) and detail of the facade(b)*

The city of Campinas is located in the Southeast of Brazil with summer average temperatures exceeding 30°C and high relative humidity levels throughout the year (Figure 2). Design strategies for this location include: natural ventilation during summer, solar radiation during winter and U-value for the roof less or equal 2 W/m².K.

For the simulations, the strategies were applied in six representative rooms. They are distributed as follows: two at each floor and preferably oriented in opposite directions (Northeast and Southwest). Figure 3 illustrates the location of the rooms on the third floor: 23A and 21B (researchers' rooms). In the first floor were chosen: the secretary where administrative activities are developed and the printing room, a very specific one, with equipment for printing. In the second floor, rooms 11A and 14B are classrooms and in the third floor: rooms 23A and 21B are used by research groups.

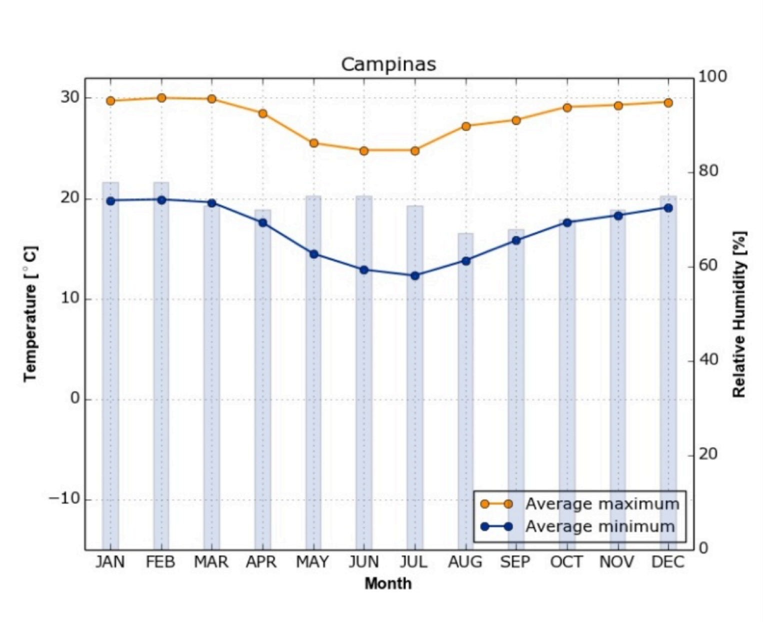

***Figure 2.** Weather profile of Campinas. Source: CEPAGRI (2017)*

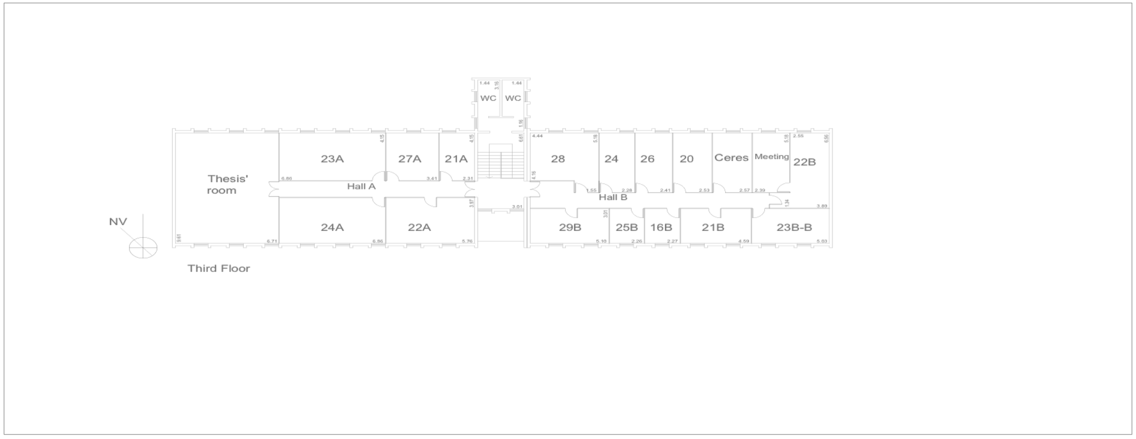

***Figure 3.** Plan of the third floor*

3.1 Modelling the base case

The building was modeled using the softwares EnergyPlus (DOE, 2017) and its plug-in for SketchUp (Sketchup, 2017): "Legacy OpenStudio" (GitHub, 2017). It will be referred as base case or reference model (Figure 4). The thermal properties of the building and main input data are described in Table 1. A hypothetical air conditioning system was modeled for all zones to simplify the simulation. The Ideal Loads Air System was modeled for supplying cooling to the zones to meet their loads consuming no *energy. The energy consumption was then calculated based on the district cooling and a coefficient of performance of 3 W/W. The internal loads modeled for the representative rooms are describe in Table 2. The choice of people activity level according to ASHRAE (2009) was based on the actual activities developed in the rooms. The loads from equipment and lighting was collected on site.*

From this reference model, further models were developed and simulated with the passive strategies. Those strategies were chosen based on the recommended design strategies for the location and on the potential savings of energy the building presented, as presented in the first section of the results. Detailed information on the strategies are described in the following sections. Each model was simulated for a period of one year with the weather file for the city of Campinas (Roriz, 2017) from the year of 2002.

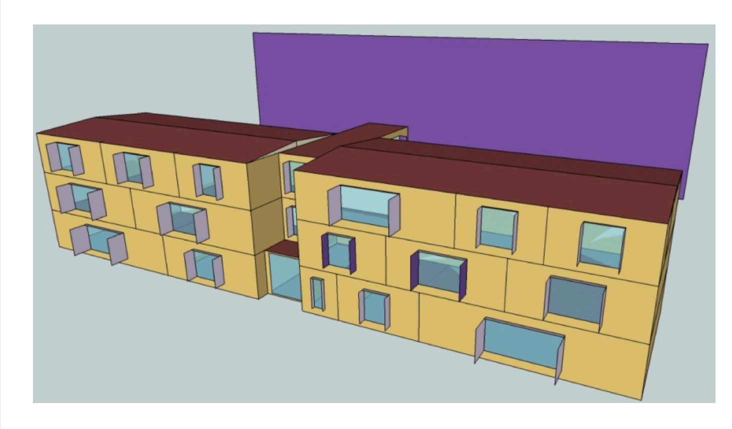

Figure 4. *Perspective of the building model on SketchUp*

Table 1. *Properties of the reference model*

Thermal properties		
	Description	***U-value (W/m².K)***
Roof	*Concrete slab, air layer and Fiber Cement Corrugated Roof Tile*	*1,15*
Internal walls	*Plywood.*	*1,69*
Floor	*Concrete slab, plaster and ceramic tiles.*	*2,12*
External walls	*Ceramic blocks*	*2,45*
Trees	*Shading elements surrounding the building with 20% transmittance.*	
Window	*Simple glazing 4 mm*	*SHGC*=0,825*
	Window-to-wall ratio: 17.73%	
Cooling system		
Type	*Ideal Loads*	
Setpoint temperature	*25°C*	
Relative humidity control	*50%*	
COP	*3 W/W*	
Conditioned building area	*35%*	

Table 2. *Internal loads of the six representative rooms*

Floor	Room	Internal loads		
		People	**Equipment**	**Lights**
1st	Secretary	08 (130W/person)	855W	768W
	Printing	02 (235W/person)	1610W	1488W
2nd	11A	22 (95W/person)	-	256W
	14B	29 (95W/person)	-	320W
3rd	23A	01 (130W/person)	165W	384W
	21B	02 (130W/person)	36W	128W

3.2 Modelling the green roof

The roof of the real building is made of a concrete slab, an air layer and Fiber Cement Corrugated Roof Tile. The green roof was modeled directly on the concrete slab. Its layers and properties are described in Table 3. The object "Material:RoofVegetation" in EnergyPlus was used for representing the vegetation and soil layer.

Table 3. *Description of the layers of the green roof (from outer layer to inner layer)*

Layers	Thickness (m)	Thermal conductivity (W/m.K)	Density (kg/m³)	Specific heat (J/kg.K)
Outer layer				
Vegetation layer	Height = 1.0 m	-	-	-
Soil	0.08 m	-	-	-
Drainage	0.06 m	0.08	800	920
Waterproof	0.007 m	0.17	1200	920
Concrete slab	0.20 m	1.75	2500	1000
Inner layer				

3.3 Modelling the natural ventilation

The natural ventilation was simulated using the module AirflowNetwork of EnergyPlus. This module does not run natural ventilation simultaneously with the Ideal Loads Air System calculations (what was observed to happen in the real building). Therefore, the natural ventilation was first simulated during occupancy with the AirflowNetwork module, resulting in an hourly infiltration rate schedule. In a second step this infiltration schedule was used as input for the object "ZoneInfiltration:DesignFlowRate" and the simulation was run again to calculate the cooling loads of the rooms.

The only intervention to be made in the real building, in this case, would be to open the existing windows during the day, while the air system is turned off. The windows are 1.8m² with fixed glasses and horizontally pivoted panes. The opening factor for natural ventilation is 12% and it was assumed a coefficient of discharge 0,61.

3.4 Modelling the daylight

The daylight strategy was simulated with the software Daysim. From input data as: geometry, material properties of surfaces, system requirements, occupancy profile and location (weather file), the program estimates the amount of daylight available over a year in a room. The output of this simulation is used as input in EnergyPlus to simulate the energy consumption with lighting and internal loads. The input data for the daylight simulation is presented in Table 4. For the daylight retrofit it would be needed to change the existing blinds for automated ones, to install dimmers in the existing luminaries and sensors of presence.

The daylighting and the natural ventilation strategies were applied to the six representative rooms. Together they represent 16% of the total area of the building. The analysis of thermal comfort for each strategy accounts for those rooms in the summer period (from January to March). Costs and energy consumption analysis refers to the whole facility (Table 5).

Table 4. *Input data for daylight simulation*

System settings	
Lighting	*Required illuminance on workplane: 500 lux*
Blinds	*Down when direct sunlight on workplane is higher than 50W/m² to avoid glare allowing 25% of diffuse lighting*
Occupancy profile	
Users operate electric lighting system and blinds to avoid direct sunlight on the work plane	

Table 5. *Application of strategies and evaluation of results*

Model	***Application of the strategy***	***Evaluation of***		
		Energy consumption	***Thermal comfort***	***Costs***
Green roof	*Roof*	*Whole building*	*Six rooms*	*Whole building*
Daylighting	*Six rooms*			
Natural ventilation	*Six rooms*			

4. Results and discussion

The hereby proposed procedure takes into account summer discomfort hours, costs (implementation and maintenance of the strategies) and energy consumption. Thus, the thermal comfort and energy consumption results obtained from the simulation of the models will be presented, followed by a table of costs for implementation and maintenance and an overview of the procedure. Noting that the aim of this paper is not to analyze the performance of the strategies in detail but to compare them to each other.

A previous analysis of the end use of the reference case shows that the building has a potential to reduce energy consumption with cooling (35% of the building area is conditioned) and lighting loads what corresponds to 53% and 25%, respectively, of the total energy consumption (Figure 5). The chosen interventions are related to these categories, therefore have a potential to reduce the energy consumption of the building. The summary of the resulting total annual energy consumption of the models is presented in Figure 6.

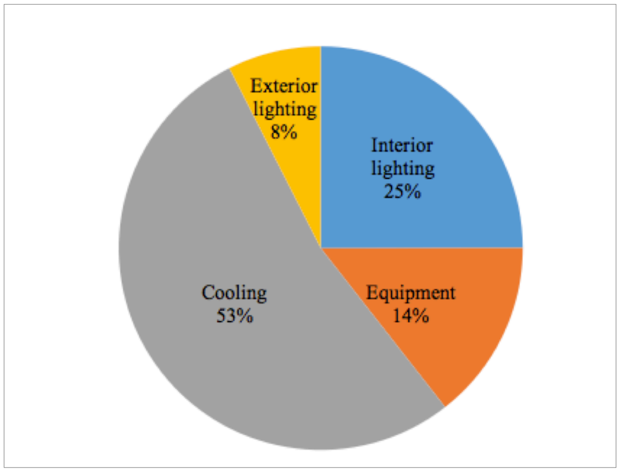

Figure 5. *End use of energy of the base case*

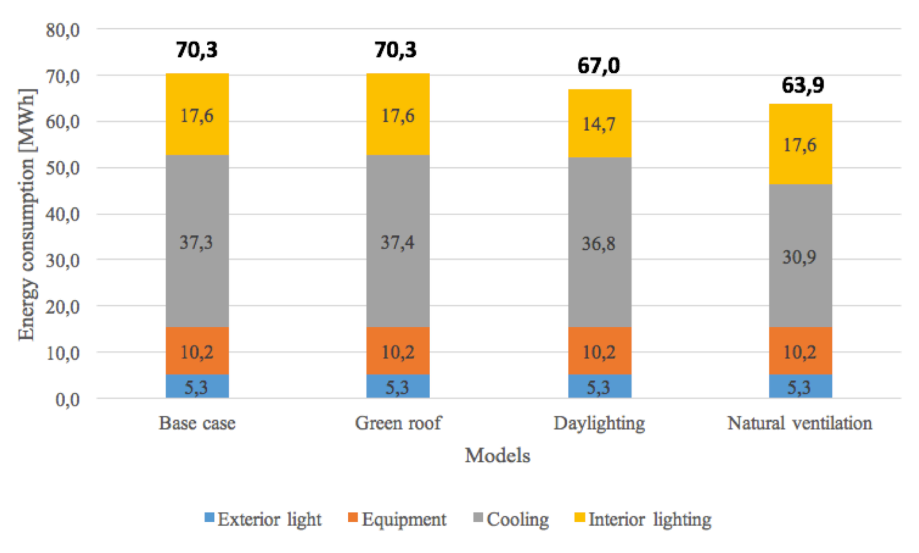

Figure 6. *Total annual energy consumption of the models*

Daylighting and natural ventilation were more beneficial from the point of view of energy consumption: reduction of 5% and 9% on the annual consumption, respectively. The decrease on the cooling loads with natural ventilation (17%) shows that this strategy was the most beneficial providing the lowest energy consumption among the cases. The impact of the green roof was not significant on the total energy consumption. Only the third floor (that responds to only 14% of the annual sensible cooling load of the building) takes the most benefit of it (reduction of 15% on its cooling loads) as shows Figure 7.

The thermal discomfort is analyzed for the months of summer: January, February and March, for the days when the selected rooms were occupied. An overview of the thermal performance of the strategies is presented in Figure 8.

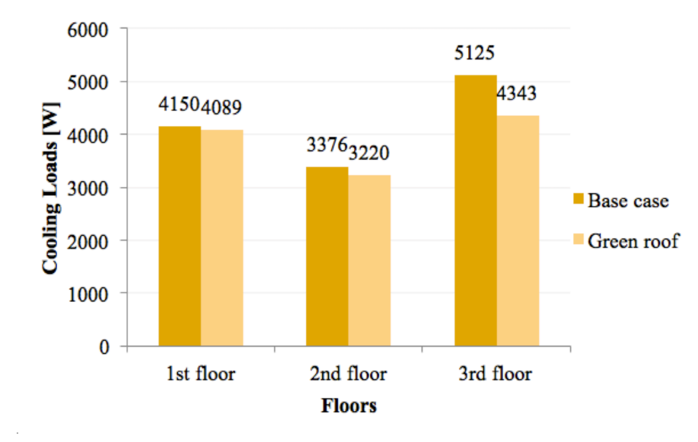

Figure 7. *Estimated annual cooling loads for each floor of the base case and the green roof model*

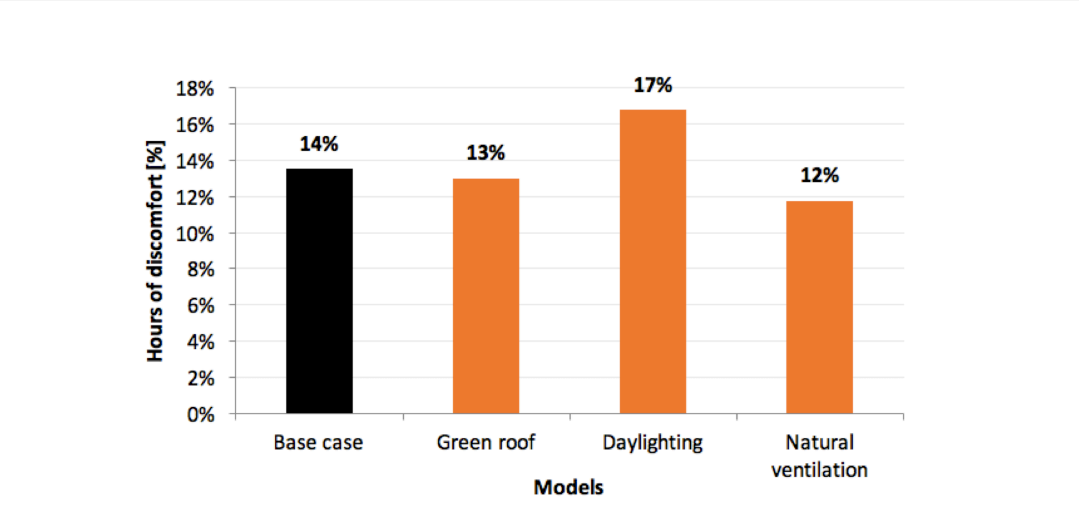

Figure 8. *Percentage of hours of discomfort in summer for the simulated models*

For the estimation of costs of the strategies, the installation and maintenance (for a period of 50 years) were considered. They were based in real values obtained from manufacturers. Detailed information about the estimated values is presented in Table 6.

The overall results (energy, thermal and costs performance) are presented in Table 7 and in an easy-to-use chart (Figure 9). It is intended that even those unfamiliar with advanced techniques of data analysis are capable of reading the results. This "radar" graph allows more variables to be added. Figure 10 is an overview of the proposed procedure.

Table 6. *Estimation of costs*

	Description	***Cost (US$)***
	Green roof	
	Installation: 367 m² of green roof (entire roof). Includes waterproofing layer, draining layer, substrate and grass.	*9,000*
	Maintenance: pulling the weed out every 3 months and organically fertilizing the grass every 6 months.	*30,000*
	Total	***39,000***
	Daylighting	
	Installation: dimmers, sensors and automation system for the blinds of the six selected rooms	*5,000*
	Maintenance: 1 visit per year	*11,000*
	Total	***16,000***
	Natural ventilation	
	No need for interventions	*0,000*
	Total	***0,000***

Table 7. *Overview of the results*

Model	***Energy consumption [GWh] in 50 years***	***Discomfort hours in summer [%]***	***Cost of implementation and maintenance [$] in 50 years***
Base case	*3,5*	*14*	*0,000*
Green roof	*3,5*	*13*	*39,000*
Daylighting	*3,4*	*17*	*16,000*
Natural ventilation	*3,2*	*12*	*0,000*

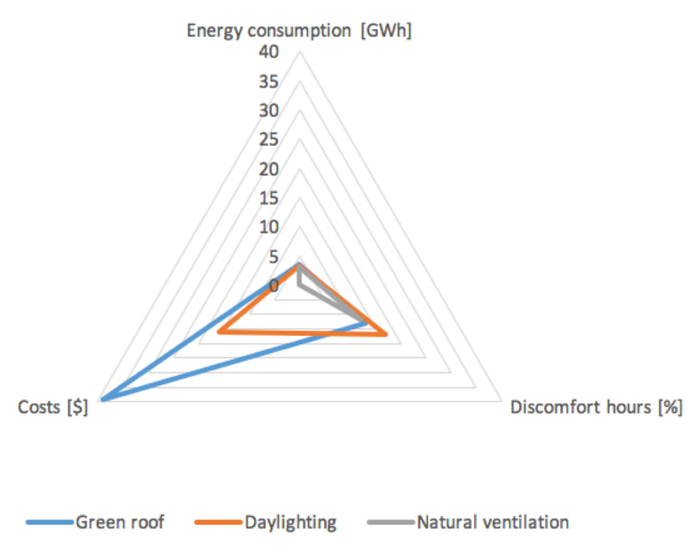

Figure 9. *Graph summarizing the performance analysis of the studied strategies*

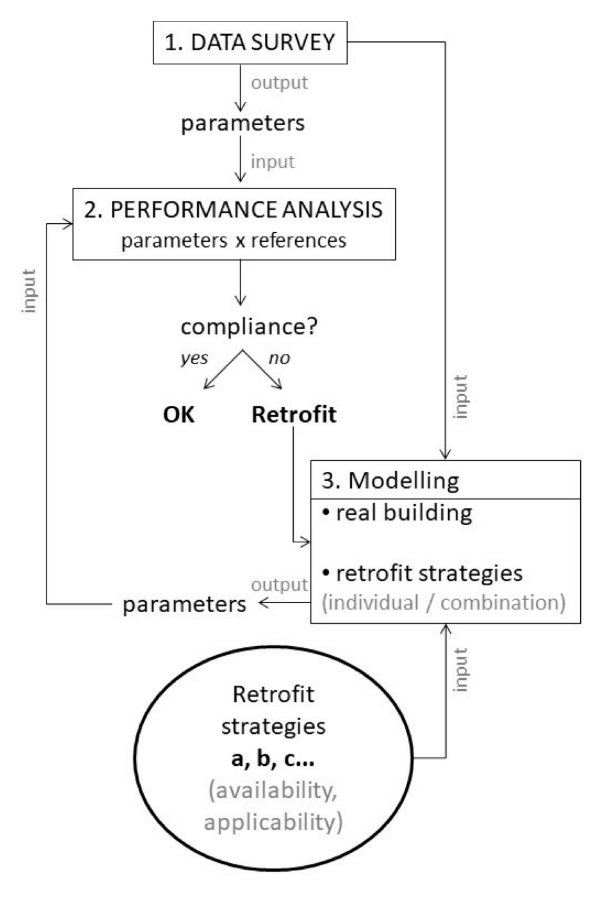

Figure 10. *Diagram of the procedure to evaluate retrofit strategies*

The developed procedure starts with a data survey for collecting parameters for comparison with requirements as well as identifying potential energy savings in the building. Examples of parameters are: dry bulb temperature, humidity ratio, energy demand or consumption, etc. If the data collected does not comply with the requirements (e.g.: discomfort hours, contracted energy demand, thermal performance regulations), the retrofit planning phase starts.

This procedure is based on modelling the real building as a reference case on which the options of retrofit strategies can be applied. These retrofit strategies can be chosen based on availability, applicability or other criteria. The output from the simulation of the strategies must contain the same parameters collected during the data survey for comparison purposes. Considering the parameters have the same weight of importance in the decision process, they are then compared with the requirements of interest using the radar chart. The smaller is the area, the better is the solution.

The aim of this procedure is to help decision-makers optimize the performance of a building by minimizing objective functions that in this case were: energy consumption, summer discomfort and cost, giving them the same importance. For this particular case, the natural ventilation was the best solution. Despite the summer discomfort is a little higher than the green roof, the solution would be much cheaper.

5. Conclusions

Performance regulations demand different intervention strategies when retrofitting buildings. A simplified procedure is needed to help designers and decision-makers for choosing retrofit actions. This paper proposed a procedure where energy consumption, thermal comfort, and costs of implementation and maintenance have the same importance and were analyzed altogether. The study was based on an existing building from which a computer model was developed as a base case for further investigation of passive strategies for conditioning.

It is emphasized here that the purpose of the paper was not to demonstrate the effectiveness of the strategies, but the methodology of analysis highlighting the importance of the parameters. The output of the simulation (energy consumption and discomfort hours) together with the estimated costs of installation and maintenance were demonstrated in a radar chart. This option of chart was chosen for it gives a more intuitive overview of the results and the possibility to add more data. It is intended that this procedure encourage designers making a deeper approach on performance analysis of buildings.

6. Acknowledgements

The authors would like to acknowledge CNPq, FAPESP, CAPES and Fundação Meridional for funding this research.

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