EVALUATION OF RETROFITTING STRATEGIES FOR ENERGY SAVING IN BRAZILIAN HOTELS

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ABSTRACT. A strong increase of hospitality infrastructure is taking place in Brazil due to imminent international events. In order to understand energy saving potential of this sector, an existing business hotel in Goiânia, a mid-western Brazilian metropolis, was analyzed as case study taking into account Brazilian energy saving incentives. Ten different scenarios were tested, evaluating different strategies, building systems and materials, as well as renewable technologies. The effects on energy consumption were simulated and most efficient strategies were identified with 60.3% of energy saving.

Keywords: energy efficiency, hotels, simulation, Brazil.

1. INTRODUCTION

1.1. BRAZILIAN POLICIES FOR ENERGY EFFICIENCY

In the last decade, a number of public policies and guidelines was promulgated by the Brazilian government in order to foster rationality on energy consumption. This movement towards energy efficiency in buildings and cities has been mainly induced by a strong crisis in the national energy supply system in 2001 [1]. The Brazilian energy system is composed predominantly by hydroelectric power, representing 77.3% of the energy used in the country [2].

Despite initiatives to expand national energy supply, a relevant outspread the energy crises aimed at reducing energy demand in the Brazilian territory: the promulgation of a Law for the Energetic Efficiency, which defined guidelines for national policies of conservation and rational use of energy [3].

Through this law, the National Program for the Electricity Conservation (PROCEL) was created, and the labeling methodology to classify energy efficiency of electric devices and appliances was one of its reflects. All these facts have created increased the level of awareness about energy issue in many fields of the contemporary society, such as on the building sector (with consequences on the design process, execution and operation, as well as on building regulations).

Previous analysis on existent buildings shows that energy efficiency strategies' regarding artificial lighting, air conditioning and architectural interventions on buildings' envelope have a savings potential on energy consumption for operation of around 30%, and this potential is raised to 50% in new buildings [4]. According to Brazilian Energetic Review, buildings respond to around 44% of energy consumption in the country in 2008 [2], demonstrating the relevance of promoting energy efficiency in the national built environment.

1.2. BRAZILIAN BIOCLIMATIC ZONES

Brazil is a vast country covering 8.5 million square kilometers from latitude 5° N to 34° S, which results in a wide variety of climates. In order to allow an adequate relation between building energy regulations and these varied conditions, a bioclimatic zoning was defined to distinguish areas with different climate [5].

By dividing the Brazilian territory in several pieces and analyzing their climatic conditions, these units were grouped in eight different bioclimatic zones. For each one of them, the application of twelve different bioclimatic strategies was evaluated [5], resulting in guidelines for the design of dwellings in each zone.

In this work the proposed bioclimatic strategies (originally proposed for dwellings) are not directly applied due to the specificities of hotel's requirements, design and operation. However some of the guidelines were taken as reference, such as the use of and insulated light roofs and heavy external walls.

1.3. RELEVANCE OF HOTELS IN THE ENERGY ISSUE

Hotels are a complex building typology regarding energy uses, due to its intensive energy use (Table 1) and wide diversity of activities. Hosting purpose, as the main function, asks apartments with exceptional environmental conditions, which usually means high energy consumption rates (also consequence of administration, services, events and leisure) despite of passive efficient strategies.

Table 1

Proportion of energy consumption in the Brazilian commercial sector [6]

Sub-sectors	Proportion
Retails	22,5 %
Hotels and restaurants	**13,4 %**
Commercial buildings	12,4 %
Financial entities	12,2 %
Communications	5,6 %
Wholesale	4,0 %
Transports	3,6 %
Other (ports, hospitals, etc)	26,4 %

In the near future, hospitality demand in Brazil must pass through wide changes: in 2014 the FIFA World Cup will take place in twelve Brazilian capitals and in 2016 the Olympic Games will come about in Rio de Janeiro. In the coming years, the country must be focused on infrastructure expansion: tourist flows in those cities will reach unprecedented numbers and, to support such event, public and private sectors must receive investments to answer this demand. Following parallel aspirations, it is a challenging opportunity to foster environmental sustainability in this remarkable heritage that will remain after events.

Within the National Program for Electricity Conservation, the PROCEL Edifica subprogram was also created in 2003. Such public policy, oriented to the construction field, resulted in a decisive action to improve and regulate Brazilian buildings' energy performance: the Brazilian Energy Labeling Program for Buildings (acronym of "Programa Brasileiro de Etiquetagem" in one of its addresses). This program defines evaluation methodologies for commercial and residential buildings. Concerning hotels, targets are the building envelope quality, lighting system and air conditioning system efficiencies.

Analysis and classification of these three features must be developed on the project and the as-built phases [7]. Both steps are related to the evaluation of a building by the INMETRO (acronym for National Institute of Metrology, Quality and Technology) through its design definitions, physical and technical specifications. The second evaluation, performed when the building is already concluded, must confirm its previous project's indexes of energy performance, allowing the final overall label to be issued [8].

Concerning the recent implementation of the Brazilian Energy Labeling Program for Buildings and the peculiar moment for hospitality infrastructures in the country, the program ProCopa Turismo was created. The principal aim of this program is to offer financial support for hotels' construction, renovation and modernization in which rational use of energy resources is being played. Projects holding a level "A" energy consumption's overall label are eligible to the BNDES (acronym for Brazilian National Bank for the Development) funding, which means loans with subsidized interest rates to finance their construction or renovation [9].

2. BUILDING SIMULATION

2.1. BUILDING DESCRIPTION AND LOCATION

The studied building is a hotel placed downtown Goiânia (Fig.1), a mid-western Brazilian metropolis. Goiânia has been chosen as location because it is located in a bioclimatic zone with only a few documented studies dealing with buildings energy performance [10]. Its natural landscape is composed by cerrado, an extensive savanna formation, and its climate is characterized as tropical wet and dry. There is a wet season, from October to April, and a dry one, from May to September. Monthly average temperature varies between 13°C and 32°C with rather low humidity levels which fall to less than 10% in some days of the dry period. The city is placed on the latitude -16.68° (south), 749 meters above the see level [11].

Classified as a business economic hotel, its average physical structure, high guests' turnover and central localization are features which reproduce the most recurrent type of hotel in the country.

With 8041 m^2 divided in 16 above-ground floors, the building is composed by 196 rooms and hotels' regular facilities such as administrative areas, meeting and conference rooms, spaces for leisure, bar, restaurant and kitchen, laundry service and four lifts. All its internal spaces of long permanence are artificially conditioned, which means continued mechanical cooling. Main facades are north-south oriented and underground floors are used as garage (with no spaces of regular occupation or artificial cooling).

Building's components and systems are compatible with common practices in Brazilian constructions and all its internal spaces of extensive occupation are provided with single window air conditioners of individual control of operation and temperature.

Fig. 1. 3D realistic representation of the studied hotel (with no adjacent buildings).

2.2. BUILDING MODELING

Simulations regarding the case study were run on the Integrated Environmental Solution <Virtual Environment>. Software selection was made mainly because it allows dynamic simulations of buildings' energy behavior worldwide, in any kind of climate, and also considering its easy interface, suitable to architectural analysis.

For the quality assurance of such simulation tool, a consolidated procedure for software validation was previously performed: the Building Energy Simulation Test (BESTEST), complying with ASHRAE 140 [12,13].

Case study simulations run on IES were performed for a whole year (2011) and using time steps of 1 hour. Their expected outcomes must regard detailed data about building's heat balance, especially final cooling loads for the air conditioning system.

a. Thermal zones

Building's model has been simplified in only three thermal zones (Fig. 2) based on their functions, operation and profiles of usage. In this sense the building was divided in ground floor zone (mainly composed by collective and administrative spaces), room zone (containing all 196 suites within 14 floors) and the terrace zone (other collective areas).

In order to avoid mistakes during modeling and produce faster results, building's shape was simplified and only significant elements were reproduced in the model. Windows dimension and position, as well as relevant shading devices and adjacent constructions, were modeled in order to run simulations also considering solar direct incidence (through the SunCast tool within the IES <VE> software).

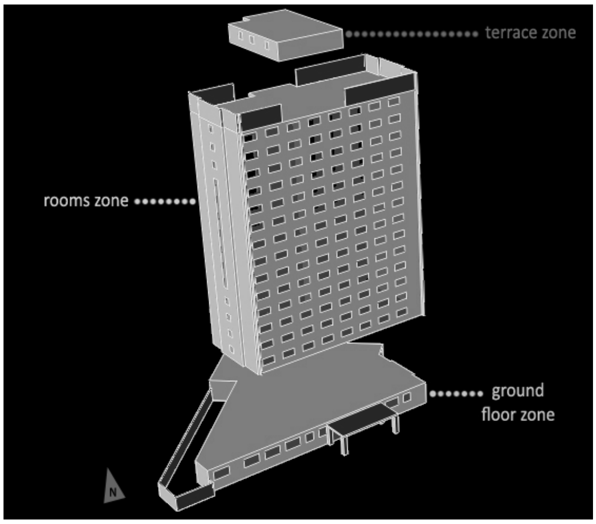

Fig. 2. 3D scheme of the thermal zones in model's simulation.

b. Solar radiation and weather data

Building's location was set on the software for solar radiation calculation regarding shading. There is no weather file available for Goiânia, therefore weather data for Brasília was employed [14]. The capital of Brazil is far 160 kilometers from building's real location, with very similar weather conditions and need of buildings retrofits.

c. Building constructions

As-built documentation and in-loco survey allowed identification of materials used in the building constructions. Mainly through the Brazilian regulation for thermal performance in buildings [15], material properties such as thermal conductivity, density and specific heat capacity, as well as surface thermal resistance of components, were referred in order to describe construction on simulations (Table 2).

Table 2

Thicknesses and thermal transmittance coefficients of opaque envelope's constructions.

Construction	Total thickness *m*	Total U-value *W/(m²K)*
External walls	0.15	2.32
Flat roofs	0.25	1.75
Internal floors	0.25	1.33
Ground floor	0.17	1.77
Single glass + Allum.frame	0.004 + 0.05	5.23

Building external walls are made of concrete blocks sided by cement plaster and regular painting, predominantly beige on the main facades and dark brown on gables. Internal walls were not taken into account within the simulation model.

Flat roofs are cast concrete slabs overlapped by a waterproofing layer and cement plaster. There is an air cavity before ceilings of gypsum plasterboard. Intermediary slabs of internal floors were built in the model only between the three thermal zones (slabs between most floors were not taken into account). Any kind of insulation neither in vertical nor horizontal envelope's surfaces is provided.

On building's current state the ground floor is composed of a cast concrete slab below cement plaster and timber flooring. Nevertheless, on simulations a thick layer of glass fiber was added as model soil, in order to thermally decouple the building from ground (due to underground floors which were not considered in the model).

Within hotel's physical structure any kind of insulation neither in vertical nor horizontal envelope surfaces is provided, highlighting that it is not current practice in Brazilian constructions to use thermal insulation.

Facades' external glazing is composed of simple float glasses of average reflectance and a solar factor equivalent to 0.86, assembled on aluminum frames which represent around 20% of windows area. Average thermal transmittance of such component is 5.23 W/(m2K). Window-to-wall ratio is around 14 %, most part of windows with vertical flaps for ventilation of low opening percentage (not taken into account on simulations and analysis).

Table 3

Solar absorptance coefficients of envelope surfaces [15].

Type of surface	Solar absorptance (α)
Light cement grout	0,48
Simple glazing	Transparent
White paintwork	0,20
Beige paintwork	0,25
Brown paintwork	0,90

External colors and materials of envelope's components influence solar absorptance coefficients (α) and emissivity (ε) coefficients of facades, so they have direct effects on building's solar gains. Values taken into account on simulations are listed on Table 3; the emissivity is considered constant and equal to 0.9.

2.3. USAGE PROFILES

The definition of usage profiles within buildings energy simulation has a major importance because various energy uses follow contrasting schedules and respect to different conditions. Identification of patterns regarding these uses is essential to understand building's energy performance, and the studied hotel was divided in three zones also considering these profiles.

a. Artificial cooling

Due to the use of stand-alone air conditioning systems for each room, there is no automatic set-point defined for artificial cooling in the whole building, so their operation is carried manually. In order to set correct usage profiles for simulations, input values concerning cooling set-points which correspond to current conditions were estimated. In this sense cooling set-point on simulations was defined as 24°C for all zones. Due to high temperature averages in Goiânia and in most parts of Brazil, usually Brazilian buildings have no heating system.

The ground floor and terrace zones are composed by common areas, several facilities and administration, generally operating for the whole day and night, which means that air conditioning is assumed as always on operation.

Differently, activities developed in the room zone and their schedule depends of each guest. Artificial cooling can be turned on only when guests are in rooms, which usually happens between 6 p.m. to 8 a.m., and it is assumed that active cooling is available during this period.

There is no ventilation system, and users can open windows when the feel fresh air is necessary. Windows have good airtightness to reduce air conditioning load and save energy. Air infiltration rate of 0.5 ACH is assumed for simulations in all zones. Windows assumed to be always, i.e. there is no ventilation.

b. Users presence and artificial lighting

The number of users in the *ground floor zone* was estimated in 100 people and in the *terrace zone* in 10 people, taking into account rooms' capacities and staff, present from 6 a.m. to midnight. Artificial lighting is assumed as turned on while there is users' occupation.

The hotel is classified as business economic, therefore presence of users in rooms zone can be predicted as opposed to working hours, so from 6 p.m. to 8 a.m. Therefore artificial lighting is assumed as on operation only when users are awake, so between 6 p.m. and midnight and between 6 a.m. and 8 a.m..

In order to calculate number of guests, it must be considered that the hotel is not constantly full. Moreover there was no as-built documentation regarding building's lighting project, so ASHRAE standards were used to define installed power for artificial illumination within the building. It defines a lighting power density (LPD) of 1 W/ft^2 for hotels [16], so this value has been assumed for all thermal zones.

2.4. SIMULATIONS ASSUMPTIONS AND SOURCES OF UNCERTAINTY

Model simplifications are a frequent practice to shorten calculations time and avoid mistakes on simulations. Often they are necessary due to missing accurate input data, requiring some assumptions which can be sources of uncertainty on simulation results.

Regarding building location, the weather file related to Brasilia was used on simulations of a building placed in Goiânia, as mentioned. Brasilia is located in an altitude of 1060 meters above the see level and its climate is characterized as *high altitude tropical*, with average temperatures up to 3° C lower than in Goiânia.

Model has not taken into account negligible differences on building's envelope. Also an average coefficient of performance (COP) of 3.0 was assumed for all individual air conditioners used in the hotel [17].

On cooling set-point's definition, the exaggerated culture of artificial cooling in Brazil was considered. A temperature of 24°C must seem quite comfortable to avoid cooling activation, but this is a reasonable value concerning a Brazilian hotel.

Concerning model thermal zones, internal building components were ignored, such as most part of internal slabs, all internal partitions and vertical shafts. Thus effects of the internal thermal mass on building its performance were ignored on simulation. Furthermore underground floors of garages were also ignored, because their spaces are neither artificially conditioned nor extensively occupied by users and their artificial lighting system is provided with users presence sensors.

In order to analyze building's overall energy performance, assumptions about percentages of energy final uses in the studied building were done. An energy analysis of a hotel in Florianopolis, a southern Brazilian city, was performed by Melo *et al* [18] and gives to us reasonable consumption proportions of energy end-uses in a hotel (Fig.3), even if it regards a Brazilian case study not placed in Goiânia. It's noticeable that energy consumed in the building is only electrical and natural gas is used only for cooking in the restaurant's kitchen.

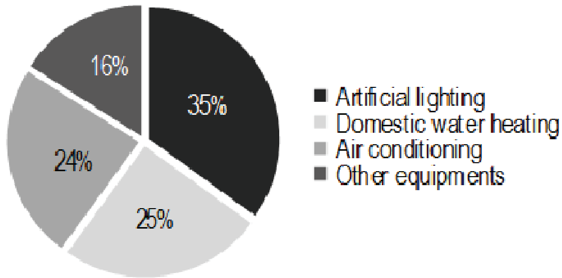

Fig. 3. Percentage of energy consumption by end-uses assumed for the case study [18].

2.5. BUILDING'S CURRENT STATE SIMULATION RESULTS AND DISCUSSION

Detailed output data supplied by IES <VE> simulations allow the comprehension of heat transfers through different components of building envelope. Such inquiry is essential to identify building critical points regarding its indoor cooling sensible loads, so its energy consumption for air conditioning.

High solar gains were expected due to the building physical characteristics such as the absence of shading devices on external glazing and high solar absorptance of opaque envelope and high solar factor of windows. In the other hand, substantial internal gains are related to building's function, with a high occupation rate and a considerable installed lighting power density (Fig. 4).

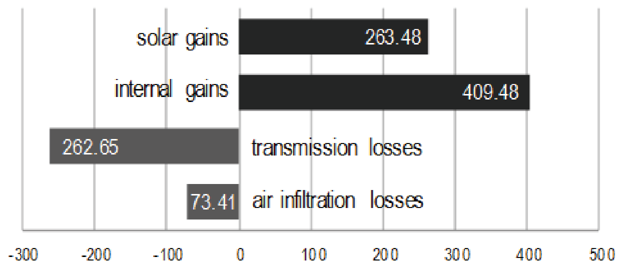

Fig. 4. Resumed variables involved on building's heat balance, which result in the building cooling load (MWh/year).

Moreover conduction through the envelope result in heat losses through external walls, glazing and ground-contact floor, because inside temperatures is generally higher than outside. Through roofs, instead, significant transmission gains highlight the need of insulation strategies on horizontal envelope surfaces, especially for locations with high temperatures and solar incidence.

Minor air infiltration losses are related to the low air changes rate within internal spaces. The comparison between external and internal gains shows that retrofitting actions must intervene not only on building envelope, but also on some internal issues, such as the artificial lighting system and the air conditioner equipment.

Thus the performed simulations show the annual sensible load for air conditioning in the whole building is 342.03MWh/year. Considering a coefficient of performance (COP) for the air conditioning system equivalent to 3.0 [17], electricity consumed for cooling is estimated in 114.01MWh/year.

Following the reference percentages for energy end uses within the building (Table 4), the above mentioned consumption is assumed as 24% of the total intake. In this sense it is possible to estimate all the other end uses consumptions within the analyzed hotel.

Table 4

Estimated end use energy consumption, in accordance with reference percentages [18] and simulated values for artificial cooling.

Energy End Uses	Percentage	Consumption (MWh/year)
Artificial lighting	35%	166.26
Water heating	25%	118.76
Artificial cooling	24%	114.01
Other uses	16%	76.01
Total annual consumption	**100%**	**475.04 MWh/year**

In one hand, electrical energy bills of the studied building show annual energy consumption in 2010 of around 536 MWh. In the other hand, through simulations and overall estimations, the annual total consumption is assumed as 475 MWh. It means a difference of around 11% between building current state and its simulations, value considered reasonable in this kind of analysis.

3. ENERGY LABELING FOR THE ENVELOPE

The *Energy Labeling Program for Buildings* defines three building aspects for evaluation: envelope, artificial lighting and air conditioning systems. In order to understand the impact of architectural decisions in the achieved label, calculations regarding the envelope of the analyzed hotel were performed.

The *Technical Quality Regulation for Commercial buildings* (RTQ-C) provides an equation to calculate the label of a building based on its location [5], as well as roofs area and shape factor of the studied building. Considering that Goiânia belongs to the Brazilian bioclimatic zone number 6, hotel's roof area is superior to 500 m^2 and its shape factor is below 0.48, the following equation was used to measure the envelope consumption indicator IC_{env} [8]:

$$IC_{env} = (-\,0 \cdot 4) + (77 \cdot F) + (-19.21 \cdot PAFT) - (2.95 \cdot FS) - (0.36 \cdot AVS) - (0.16 \cdot AHS) - (290.25 \cdot FF \cdot PAFT) - (0.01 \cdot PAFT \cdot AVS \cdot AHS) - 120.58 \quad (1)$$

FA = height factor = $A_{P\,cob} / A_{TOT}$ (-)
FF = shape factor = A_{ENV} / V_{TOT} (-)
PAF_T = window-to-wall ratio, i.e. WWR (-)
FS = external glazing solar factor (-)
AVS = vertical shading angle (°)
AHS = horizontal shading angle (°)
$A_{P\,cob}$ = total horizontal roofs projection (m^2)
A_{TOT} = built-up summed area of all floors (m^2)
A_{ENV} = total envelope area, including facades, roofs, openings (m^2)
V_{TOT} = total built-up building's volume (m^3)
IC_{env} = envelope consumption indicator (-).

Geometrical survey and the contents of the building as-built documentation have subsidized the definition of input values, as shown on Table 5, required by the equation above. Underground floors are not taken into account, as defined in the methodology.

Table 5

Calculated input values required for envelope labeling, according with the indicated equation.

Variables	Values
FA	0.12
FF	0.23
PAF_T	0.14
FS	0.84
AVS	0°
AHS	0°
$A_{P\,cob}$	975.4 m^2
A_{TOT}	8041.2 m^2
A_{ENV}	5662.8 m^2
V_{TOT}	24550.6 m^3
IC_{env}	**163.9**

There are no shading devices installed and building's self-shading is very punctual and results in small angles, therefore AVS and AHS were considered null. Solar factor of glazing is given by the manufacturer [19].

Using the previous equation and reference values prescribed by RTQ-C (Table 6), it is possible to calculate minimum and maximum values for the IC_{env} [8].

RTQ-C uses the minimum IC_{env} (resulted in 159.54) and maximum IC_{env} (resulted in 185.03) to calculate the limits for each label, which varies from *level A* to *E* (Table 7).

Table 6

Variables for minimum and maximum *ICenv* calculation.

Variables	Min. IC_{env}	Max. IC_{env}
PAF_T	0,05	0,60
FS	0,87	0,61
AVS	0°	0°
AHS	0°	0°

Table 7

Labels assigned for building's envelope by *ICenv* intervals.

Label	A	B	C	D	E
Min. Limit	159.54	165.92	172.29	178.67	185.04
Max. Limit	165.91	172.28	178.66	185.03	-

The actual IC_{env} for this building is 163.90, which is calculated using equation (1) and the properties in Table 5. The comparison of this value with the intervals in Table 7 shows that the preliminary label for building's envelope is level A. Nevertheless there are other pre-requisites regarding the building constructions which influence the label, such as thermal transmittance of external walls and roofs (U) and their solar absorptance (α). These pre-requisites are summarized in Table 8, for Brazilian bioclimatic zone number 6, while the properties of the building are listed in Table 9.

According with presented criteria, total thermal transmittance value of roofs is not in accordance with the requirements for label A nor label B. Therefore, the classification to be issued for hotel's envelope on its current state is label C.

Table 8

Variable limits for building's envelope labeling.

	Level A	Level B	Level C / D
U_{ROOF}	< 1,00 W/m²K for artificial conditioned rooms < 2,00 W/m²K for non-conditioned rooms	< 1,50 W/m²K for artificial conditioned rooms < 2,00 W/m²K for non-conditioned rooms	< 2,00 W/m²K
U_{WALL}	< 3,70 W/m²K	< 3,70 W/m²K	< 3,70 W/m²K
α	α < 0,50 for external walls and roofs	α < 0,50 for roofs	-

Table 9

Further variables of the analyzed building for its envelope labeling.

	Building properties
U_{ROOF}	1,76 W/m²K
U_{WALL}	2,32 W/m²K
α_{ROOF}	0,48
α_{WALL}	0,42 (average)

4. RETROFITTING STRATEGIES

Besides the punctual indication for improvement shown by the *Energy Labeling Program for Buildings,* several points on energy consumption were analyzed for this building. Having maximum energy savings as objective, some retrofitting strategies were proposed to improve its performance.

Seven independent scenarios were simulated aiming at reducing building's energy needs. Other two scenarios addressed the integration of systems for renewable energy generation within the hotel. These scenarios are discussed in the following sections.

4.1. SHADING DEVICES FOR EXTERNAL GLAZING

Solar gains through envelope have a relevant importance on cooling loads, and the absence of shading devices on external glazing strongly influences it. Through the solar diagram for the location's latitude, direct solar incidence on the four building's facades was analyzed and two types of shading devices were tested: shading overhangs and louvers.

Shading efforts must consider differences between facades in order to avoid internal overheating while preserving natural lighting inside the building [20]. However, shading devices were applied homogeneously on all facades as a model simplification.

The first scenario consists on a grid of 1-meter depth overhangs and vertical fins, applied both in south and north facades (Fig.5). Such strategy produced shading angles of 40° on vertical and 35° on horizontal over external glazing. Shading devices were explicitly modeled in the 3D interface of IES, and shading performance was calculated for different hours of the year.

In the second scenario, fixed louvers' frames with narrow blades were applied over all building's external glazing. These louvres were modeled by providing a numerical input: the shading interval of blades was defined as 15°. Fig. 6 shows the solar gains on the two scenarios and on the base case.

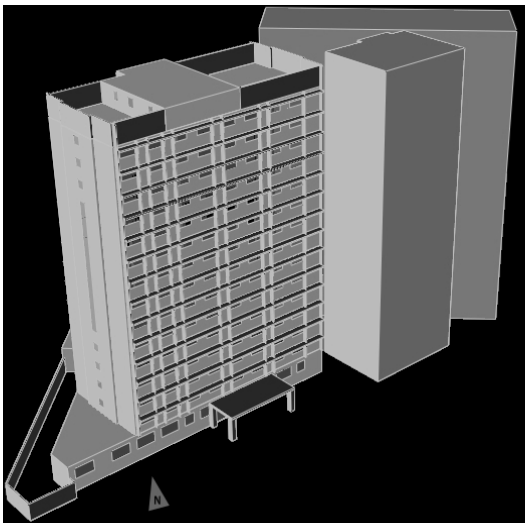

Fig. 5. Model's south facade with shading overhangs and fins, as well as adjacent buildings.

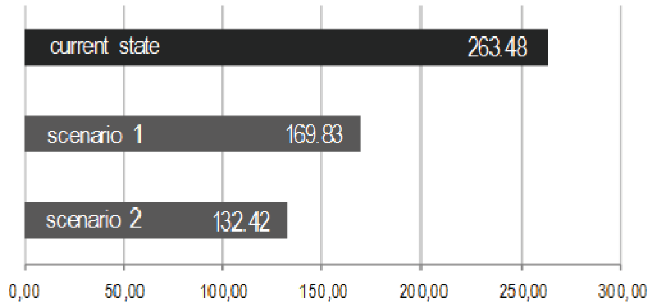

Fig. 6. Solar gains using different shading devices (MWh/year).

The reduction in solar gains results in different reductions on cooling loads (Fig.7). In the scenario 1, there is a reduction of 5.4%, while on scenario 2 the reduction is 33%, showing louvers are a more effective strategy.

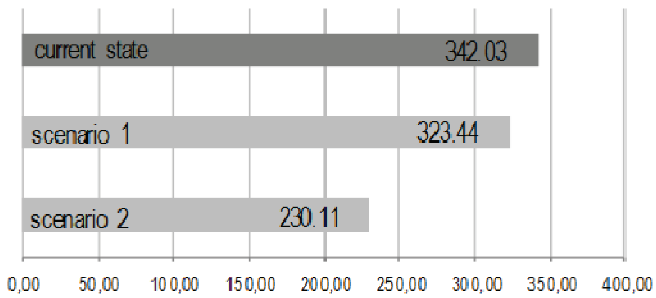

Fig. 7. Reductions of cooling loads through shading devices (MWh/year).

4.2. EFFICIENCY OF AIR CONDITIONING SYSTEMS

Currently artificial cooling in the analyzed building works under manual activation. In order to avoid its overwork, in the third scenario cooling set-points within the comfort zone [5] were defined for all hotel's thermal zones.

According to Givoni's chart adapted for Goiânia [5], indoor thermal comfort could be kept by the cooling set-point temperature of 26°C. Such definition will reduce effective cooling loads of air conditioners, resulting in energy savings.

However air changes rates within the building must be also object of intervention, considering its indoor healthy conditions. An infiltration change of 0.5 ACH was predicted for the building's current state analysis and, using the Italian regulation for indoor air changes rates in buildings (Table 10) it was possible to calculate adequate values to be proposed [21].

Table 10

Required air changes values for hotel spaces [21].

Zone	Functions	People	Air change
Ground floor	Collective spaces	100	$10 \cdot 10^{-3}$ m^3/s person
Rooms	Dormitories	406	$11 \cdot 10^{-3}$ m^3/s person
Terrace	Collective spaces	10	$11 \cdot 10^{-3}$ m^3/s person

Estimation of air renovation, as shown on Table 11, refers to activities performed within a hotel and the hourly changes rate can be calculated through thermal zones' volumes.

Table 11

Satisfactory building's indoor hourly air change values.

Zone	Required air changes (m^3/s)	Volume (m^3)	Required air change (ACH)
Ground floor	1	3706.5	0.97
Rooms	4.47	20315.5	0.79
Terrace	0.11	528.6	0.75

Due to the increase in the air change rate, simulation shows that heat losses by air infiltration rises around 52%. It indicates that outdoor air temperature is lower than indoors in many hours. The increase in the air changes rate helps on cooling down the building (particularly in during the night) decreasing the cooling loads (Fig. 8).

Assuming the above mentioned changes as ideal conditions for the air conditioning operation, scenario 4 keeps them and goes further, proposing an increment of system's coefficient of performance (COP).

Average COP for current individual air conditioners is estimated as 3.0, and energy consumption is presented in Fig. 9, for the current state and scenario 3 [17]. Energy savings to be achieved by the implementation of a centralized system must be relevant because such system could reach a COP of about 5.0 [17], as presented in Fig. 9, scenario 4.

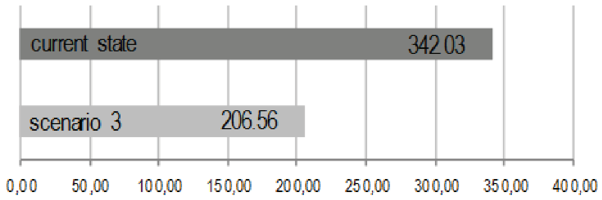

Fig. 8. Reductions of cooling loads through the definition of cooling set-points and adequate air changes rates (MWh/year).

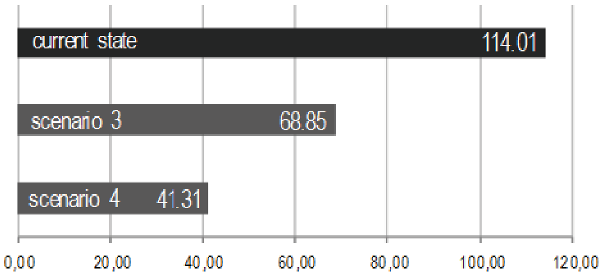

Fig. 9. Reductions on energy consumption for artificial cooling achieved on scenarios 3 and 4 (MWh/year).

Simulated energy savings for artificial cooling reach 39.6% on scenario 3 and 63.4% on scenario 4. It means global savings of 9.5% and 15.3%, respectively, in comparison with the simulated building's current consumption.

4.3. ARTIFICIAL LIGHTING EFFICIENCY

Due to the lack of as-built documentation regarding building's lighting project, it is not possible to analyze in depth the energy savings on artificial lighting as end-use, but it is possible to estimate its effect on artificial cooling. By reducing the indoor heat gains due to lighting, cooling loads for air conditioning are indirectly decreased.

Hotel's lighting systems in Brazil usually adopt incandescent and fluorescent lamps. These lamps have luminous efficacy around 13.8 Lm/W and 60.0 Lm/W, respectively [22]. Building's current state is assumed an average luminous efficacy of 41.5 Lm/W, considering 40 % of the installed power as incandescent and 60 % as compact fluorescent [23].

By employing control systems for their operation, such as presence and daylight sensors, and by upgrading luminous efficacy of light sources, it is possible to reduce their overall heat emission. A new average luminous efficacy can be estimated on scenario 5 as 82.9 Lm/W, correspondent to a white LED lamp efficacy, for instance [24]. It means a reduction of 50 % in the artificial lighting absorbed power with the same emitted luminous flux, as presented on Fig. 10.

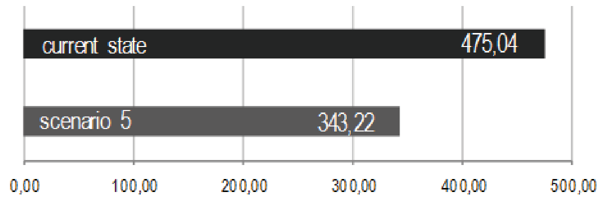

Fig. 10. Reductions on building's energy consumption achieved on scenarios 5, considering savings on its artificial lighting and cooling (MWh/year).

Such intervention means a proportional reduction of 50% on internal gains from artificial lighting, reflected then in lower cooling. Energy savings achieved on artificial cooling are around 28%; associating energy savings for artifial cooling to savings on lighting, reductions on building's overall energy consumption is almost 28%.

4.4. SOLAR ABSORPTANCE COEFFICIENT AND SOLAR FACTOR ON ENVELOPE COMPONENTS

Pointing to reductions on heat gains through the envelope, scenario 6 consists on decreasing solar absorptance coefficients on building's external walls and roofs, as well as the solar factor of external glazing.

The average solar absorptance coefficient for external walls is 0.42, considering different colors of facades, and for roofs it is estimated as 0.48 [15]. It remarkable that this coefficient can reach considerably lower values. Moreover, solar factor of envelope's glazing is informed by the producer as 0.86 [19] but this value can be far lower on new products.

In this sense the sixth scenario simulates an ideal condition in which all the opaque external surfaces of the hotel on its current state would receive a regular white paintwork of solar absorption coefficient estimated as 0.20 [15]. In addition all external glazing would be replaced by high performance glazing with 0.28 of solar factor [25].

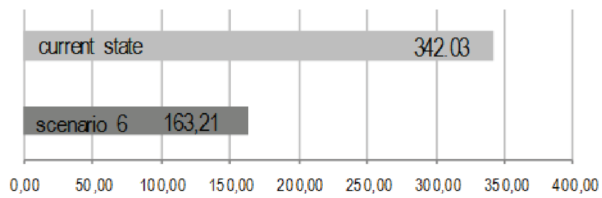

Fig. 11. Reductions of cooling loads through the new envelope's solar absorptance coefficient and solar factor (MWh/year).

By reducing external heat gains through the envelope, cooling loads within the building are reduced in 52% in simulations (Fig. 11). It means overall energy savings in the hotel of around 13%.

Although heat gains from outside are outstanding on building's overheating, heat flows through the envelope predominantly go towards outside due to building's interior temperature higher than exterior.

4.5. REQUIREMENTS FOR AN ENVELOPE LABEL A

Even if questionable, thermal transmittance is the single characteristic which does not allow the hotel to reach a *label A* concerning its envelope. Roof's insulation is even considered a guideline location's bioclimatic zone [5], but these components in the studied building have received no treatment to avoid solar overheating.

On scenario 7 a further layer is added in order to insulate roofs, increasing their thermal resistance. The chosen material is expanded clay and a layer with 0.06m of thickness is proposed covering external slabs. This is a low cost material with low density (27kg/m^2), so it does not mean a significant additional load on building structure.

By adding this insulating layer, roofs' total thermal transmittance value is decreased to 0.93 W/(m^{2}K) from previous value of 1.75 W/(m^2.K). However it is necessary to pay attention to its low solar absorptance. Through these actions building's envelope would be in accordance to *Label A* requirements.

Nevertheless the envelope labeling, running simulations of this scenario is important to understand how thermal insulation influences remarkable heat gains through roofs on building's current state.

Due to the decrease of heat gains through roofs, expanded clay's insulation layer resulted in a reduction of about 23 % on annual cooling loads (Fig.12), which means a global economy on annual energy consumption of about 5,5 %.

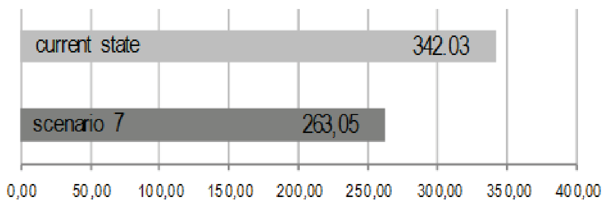

Fig. 12. Reductions of cooling loads due to roofs' insulation (MWh/year).

4.6. ON-SITE RENEWABLE ENERGY GENERATION

Instead of actions aiming at reducing building energy needs, the integration of systems to generate renewable energy on-site is another way to improve hotel's energy efficiency. Consumption of such clean energy in more specific end-uses, such as for water heating and users appliances, is a way to save energy from city's electricity system.

Scenario 8 proposes a solar thermal system for water heating. For demand calculation and systems sizing, the RETScreen software was used with input data reported on Table 12. The weather database available in the program allows prediction of system's performance in a Brazilian context, based on climate data of the location.

Table 12

Building's hot water demand (calculated by RETScreen)

Hotel data for solar thermal system sizing	
Building typology	Hotel
Number of rooms	196
Occupation rate	80%
Operation week days	7/7
Daily hot water demand	**11.885,0 Liters/Day**

Input water's average temperature ranges from 21.3°C to 24.5°C and system must provide output water with an average temperature of 45°C. RETScreen calculated energy demand is 106.2 MWh/year, value close to 25% of building's total consumption, as assumed [18].

Due to location's latitude, collectors must be oriented to the north with a tilt of around 30°. Thus, by the definition of collectors' quantity to be installed and their technical specification, system's energy generation can be calculated.

The designed system is composed by 65 panels [26] with solar azimuth of 297.6°, totalizing 102,74 kW and 156.72 m^2 to be installed above ground floor's roof. Main storage tanks were defined to be placed in the underground floor, from where hot water could be sent to small storage tanks in each floor. Furthermore an auxiliary electrical pump consuming about 1.3 MWh/year would be requested.

Thermal energy generated by the system for water heating is around 96.6 MWh/year, which means around 90% of the total amount necessary for this end use and a direct energy saving in the overall consumption.Aiming at producing electricity on-site, scenario 9 consists in the proposition of a photovoltaic system. Considering remaining roofs' surface, 40 photovoltaic panels [27] with solar azimuth of

342.6° and a tilt of 30° would be placed above last floor's slab. High efficiency polycrystalline cells, with a maximum power capacity of 135 W, were employed on system's design.

Through RETScreen software, the annual energy generation of the proposed system, with 40,2 m^2 of solar collectors, is estimated as 8.6 MWh. It means only 1.8% of the annual energy consumption of the building (Fig.13), considered a quite low contribution despite the high investment needed for its implementation.

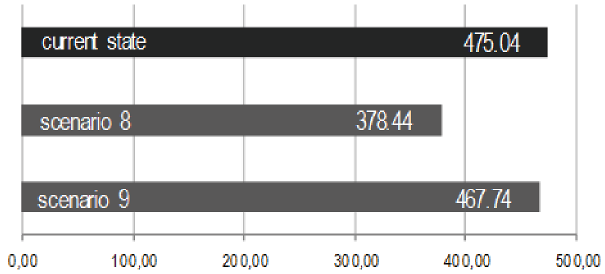

Fig. 13. Building's energy consumption, excluding renewable energy, on scenarios 8 and 9 (MWh/year).

4.7. ASSOCIATING THE BEST STRATEGIES

Interventions on building's systems and envelope as well as new renewable systems' were evaluated on previous scenarios. Nevertheless, each scenario provided results that were not cumulative and strategies, if applied together, might not result in a cumulative energy saving.

Not all tested strategies have shown outstanding results: shading overhangs on scenario 1 have performance inferior than louvers on scenario 2. Scenario 4 suggests a central and more efficient air conditioning system and results in better energy savings than scenario 3, which only touches the redefinition of cooling set-points and air changes rates in the existent equipment. Scenario 9, which concerns a new photovoltaic system for the hotel, is substantially expensive and supplies a small amount of energy to the building. Besides, this technology could be adopted with public incentives.

Considering that larger savings were reached through scenarios 2, 4, 5, 6, 7 and 8, a final scenario was proposed in order to verify their integrated performance of optimal strategies.

On the final scenario, shading devices and interventions on the building's envelope reduced solar gains in about 75 %; cooling loads were reduced in 72 % and, due to COP improvement, air conditioning energy consumption was finally reduced in about 83%. By decreasing therefore artificial lighting absorbed power in 50 %, overall energy savings were also affected. Moreover the proposed solar thermal system results in energy savings of 91 % for this end-use. By combining all strategies in the final scenario, building's global energy consumption decreased 60.3 % (Fig. 14).

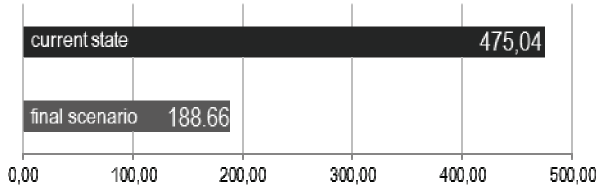

Fig. 14. Building's overall energy consumption in the final scenario (MWh/year).

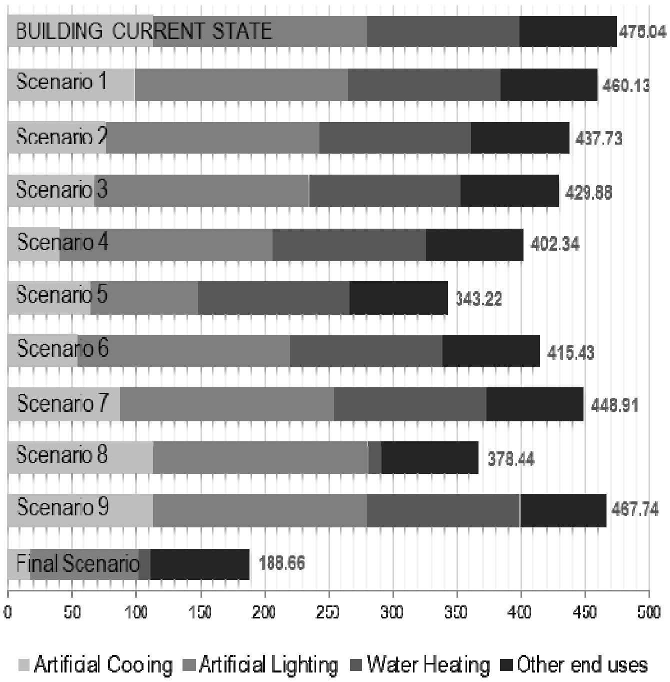

Fig. 15. Global energy consumption of all scenarios by end-uses, including the final scenario

4. CONCLUSIONS

Most of the proposed scenarios have addressed reduction of building cooling loads, variable more influenced by architectural choices, materials and constructions. That was the case of scenarios 1 and 2, concerning solar shading, which clarified the importance of effective shading devices on external glazing.

Scenario 6 can be considered one of the most unexpected results, because facades' colors and textures, as well as glazing's solar factor, have had an impressive influence on heat external gains, and so in cooling loads. Moreover scenario 7 has sensibly decreased building's overheating with a simple and cheap intervention to insulate roofs.

Nevertheless this work has also highlighted the major importance of systems' efficiency on energy consumption. The energy consumption for artificial cooling was highly influenced by just regulating operation of air conditioners in the scenario 3. The coefficient of performance of the cooling system is also very relevant, as shown on scenario 4, avoiding the consumption of a considerable amount of energy specifically on equipment operation.

The intervention on the artificial lighting system, addressed on scenario 5, has shown the highest energy savings of all single strategies. It happened because of the reduction both in lighting and on the resultant internal heat gains.

Scenario 8 revealed an interesting alternative for renewable energy integration in the building due to outstanding results on water heating. Similar results were not reached by the photovoltaic system of scenario 9, which seems to be a less effective alternative for this building typology.

A clear picture of interventions shows the most interesting case is the final scenario, in which relevant strategies are associated for a maximum reduction on energy consumption: resulting savings are more than 60% of base consumption, but involves large interventions and, probably, a substantial investment.

Economic feasibility of proposed strategies is not an objective of this work, which aimed at providing energy consumption values for simulated scenarios and a comparison of strategies' effectiveness (Fig.15).

However the economic results can be estimated by knowing energy price, which is defined as 0,124 €/kWh for 2012 in Goiânia. Through the reduction on energy consumption achieved in the final scenario, hotel's annual economic savings is estimated in more than €35000.

It must be also considered the eventual allowances of the Brazilian Bank for National Development (BNDES), if the studied hotel achieves an overall energy efficiency Label A (considering building's envelope, air conditioning and artificial lighting systems).

Still regarding the Brazilian Energy Labeling Program for Buildings, it is remarkable that requirements for an envelope level A are evidently understated. Beyond the required roofs' insulation, scenarios concerning other changes on the building's envelope have shown potential savings are much higher than the labeling method suggests. The so-called levelA is not close to the best energy performance achievable in this case study. Components' proprieties such as solar shading, glazing's solar factor and facades' solar absorptance must be weighted in fairer way in order to properly classify buildings.

The need of a quantitative approach on energy efficiency promotion in buildings is revealed as necessary to evaluate their energy performance. Public policies aim to be a start up action but, in order to finally obtain effective results on future buildings' retrofits to take place in Brazil, more must be done.

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