700: Energy Demand Reduction Applying Different Window Areas and Performance Glasses in Brazil

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Abstract

The heat gains and daylight transmitted through the windows influence directly the building energy demand. High performance glasses when correctly specified produce a great potential of energy savings, using daylight efficiently and controlling heat gains or losses. In Brazil, the no application of high performance glasses associated with large glazing areas has been showing as unsatisfactory results concerning energy efficiency. This article assesses the energy savings potential that can be achieved by using correctly the glasses on buildings facades. Applying the Light Design and Ideal Window Area methodologies, window areas as a function of different types of high performance glasses are simulated in TRNSYS program. The simulations are run for twelve cities in Brazil, in one of those cities, Cuiabá (-15° 35' 46''), the energy demand as a function of floor ratios and space dimensions is assessed. An approach into the DIN1946-2 is demonstrated, this norm allows increasing internal temperature limits, when the outside temperature exceed the 26°C. The results show a reduction on energy cooling demand keeping the PMV and PPD under certain acceptable limits. The annual results of hourly simulations display the building energy demand as a function of window area, glass type, window wall ratio, room ratio and size. The results evaluated under the energy efficiency perspective only are confronted with the problems and requirements of holistic literature.

Keywords: simulation; cooling demand; Brazil; WWR%

1. Introduction

In architecture the windows that have the important task of providing outside view, ventilation and daylight, are also responsible for the most part of the heat gains/losses in the buildings. When shade, orientation, size and glasses are not correctly specified, the windows can contribute significantly to increase the buildings energy consumption.

In Brazil, the influence of the window area in the energy consumption of 30 office buildings in the city of Salvador was evaluated [1]. The results indicated a correlation between the glass area and energy consumption. The buildings with window area lower than 20% of the facade area presented an average energy consumption of 96 kWh/m²·a, the buildings with window area higher than 40% had an energy consumption increased to 51%.

The buildings in Brazil are responsible for 42% of the energy consumption; 23% in the residential sector, 11% for office buildings and 8% in public buildings [2]. According to several authors (Table 1), the air-conditioning and lighting account the most part of the buildings energy consumption.

Table 1: End-use energy.

Source	City	A/C [%]	Light [%]
Lomardo [3]	R	37,4	37,1
Rodas [4]	F	39,0	30,0
Westphal [5]	F	41,0	50,0
Ghisi [6]	F	16,0	63,0
Toledo [7]	F	39,4	42,2
Roméro [8]	SP	42,4	14,4
Geller [9]	SP	20,0	44,0
Mascarenhas [10]	SA	70,0	15,0

Legend: R: Rio de Janeiro, F: Florianópolis
SP: São Paulo, SA-Salvador.

In England, according to [11] an energy-efficient building consumes 50% less energy than an existing building. It indicates that window areas should be limited and suggests glazing areas around 30% of the facade to limit the energy consumption.

In Brazil, the use of large windows areas can provide good daylight provision and a good view, but may also increase the energy consumption for buildings with air-conditioning [12]. The authors also revealed that narrow rooms may not have the lowest energy consumption, and concluded that windows areas recommended in

the current literature to ensure outside view are in the most part larger than the Ideal Window areas (IWA) to ensure energy efficiency.
Other authors [13] investigated the integration of daylight with artificial lighting using the daylight simulation software ADELINE and the thermo-dynamic simulation software TRNSYS. The authors report that larger the room width, lower the artificial lighting consumption by the area, reaching lighting savings from 50 to 80%.
In Germany [14] considering the thermal comfort, the integration of artificial lighting with daylight and the energy efficiency, defined an IWA between 50 and 70%. In winter, an increase of this window area can raise the heating energy demand. In summer, with window area up to 60% and low cooling demand, the over-heating hours are under 10%.
The researches above show that air-conditioning, lighting and heating consume the most part of the building's energy. The windows are responsible for major heat gains and losses, indicating that in Brazil the correct use of window areas, glasses and shadow devices, represent a large energy savings potential for cooling system.

2. Objectives

This article assesses the annual energy demand as a function of window areas with different types of glasses for mechanical conditioned office buildings in Brazil.

3. Methodology

When the artificial lighting system is integrated with the daylight that enters through the windows, energy savings are generated. An IWA may vary according to the classification of the building between naturally ventilated and mechanical conditioned.
In the first case, the window area depends solely on energy savings achieved by consumption reduction in the lighting system. In the second case, depends on the energy balance between the daylight's supply and solar heat load, aiming to reduce energy consumption in the lighting system and reducing the heat loads generated by it to the air-conditioning [12].

3.1 Current Methodology

Using the program BSim, [14] studied the energy consumption of one room model only. However, the authors simulated the model with three window areas, three types of high performance glasses, four shadow factors, four orientations, in one German city, indoor ventilation with/without night ventilation and air-conditioning. The result presented the over-heating hours, energy demand for lighting, heating and air-conditioning.
In [15], it has been studied the energy consumption variation as a function of window area applying the software VisualDOE. The author defined as IWA in which the energy consumption of the room is the lowest. In this study the researcher simulated rooms with five ratios, ten different sizes, eleven window areas, four orientations, single clear glass, no shadow devices, seven cities in Brazil and one in England.
The results showed the IWA in percentage and the increase of energy demand when the IWA is not applied. In this methodology, the IWA have wide variations when assessed with different ratios and rooms sizes. From the size perspective, larger rooms demand less energy than smaller rooms, independent of ratio. Regarding the ratio, deeper rooms (1:2) demand less energy than larger rooms (2:1), independent of size.

3.2 Applied Methodology

Using some parts of the methodologies adopted by the above mentioned authors; this article evaluates the energy efficiency of windows in office buildings for twelve Brazilian capitals of different latitudes (Table 2).
A more detailed study demonstrates the energy demand as a function of different sizes and rooms ratios for one Brazilian city of rigorous climate. This city is Cuiabá, one of the hottest capitals in the country, the city is located in semi-humid tropical climate and has high daylight availability and high demands on air-conditioning [16].
For these assessments, simulations are carried out by TRNSYS [17], the models were simulated over a whole year under TMY2 weather data files. This program was chosen for the simulations by completing all quality requirements [18].

Table 2: Geographical coordinates of the cities.

City	Latitude	Longitude	Altitude
Belém	-01° 27' 21''	48° 30' 16''	10m
Manaus	-03° 06' 07''	60° 01' 30''	92m
Fortaleza	-03° 43' 02''	38° 32' 35''	21m
Recife	-08° 03' 14''	34° 52' 52''	4m
Salvador	-12° 58' 16''	38° 30' 39''	8m
Cuiabá	-15° 35' 46''	56° 05' 48''	176m
Brasília	-15° 46' 47''	47° 55' 47''	1171m
Belo Horizonte	-19° 55' 15''	43° 56' 16''	858m
Rio de Janeiro	-22° 54' 10''	43° 12' 27''	2m
São Paulo	-23° 32' 51''	46° 38' 10''	760m
Florianópolis	-27° 35' 48''	48° 32' 57''	3m
Porto Alegre	-30° 01' 59''	51° 13' 48''	3m

3.3 The Rooms

The simulated room offices have three ratios (Figure 1) and eighteen sizes (Table 3) and have been simulated in function of a room index (K), well known in light design projects (Equation 1). This methodology adopted in [15] has been used in the simulations of Cuiabá to assess the energy demand as a function of ratio, size, orientation and glass type. The rooms are located in an intermediate floor of the building with all internal walls in adiabatic conditions. The external facade consists of light wall (Table 6) and glass (Table 4), thus, the percentage of the specified window area is effectively the glazed area.

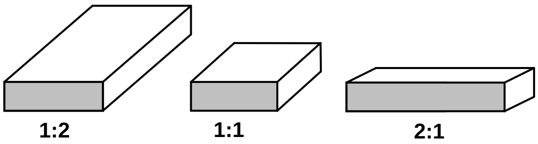

Fig 1. Room ratio. The first number (1: x) represents the external facade, the second number (y: 2) the wall depth.

Table 3: Room index and dimensions.

K	1:2		1:1		2:1	
	W [m]	D [m]	W [m]	D [m]	W [m]	D [m]
0,60	1,85	3,69	2,46	2,46	3,69	1,85
0,80	2,46	4,92	3,28	3,28	4,92	2,46
1,00	3,08	6,15	4,10	4,10	6,15	3,08
1,50	4,61	9,23	6,15	6,15	9,23	4,61
3,00	9,23	18,45	12,30	12,30	18,45	9,23
5,00	15,38	30,75	20,50	20,50	30,75	15,38

$$K = WD/(W+D)h \qquad \text{(Equation 1)}$$

Where:
K : room index (non-dimensional);
W: the overall width of the room [m];
D: the overall depth of the room [m];
h: mounting height between the working surface and the ceiling [m].

3.4 The Glazings

Representing a typical situation in office buildings with glass curtain walls in Brazil, the rooms have been simulated for the orientations north, south, east and west with three different glasses, no shadow devices and glazed area ranging from 0 to 100% at increments of 25% (Figure 2).
The windows have three types of glasses; (1) simple clear glazing, (2) normal double glazing and (3) double glazing SPG - solar protection glazing (Table 4).

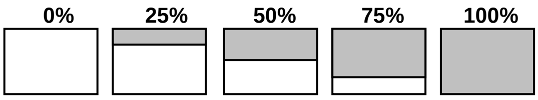

Fig 2. Window wall ration [%].

Table 4: Glazing properties.

	U [W/m²K]	t-value	g-value
1.Single glazing	5,8	0,901	0,855
2.Double glazing	2,8	0,817	0,755
3.Double glazing	1,3	0,659	0,330

3.5 Simulation Parameters

The artificial lighting works integrated with daylight, the light is turned on/off according to the external illuminance levels and keeping on the work surface an average illuminance of 500 Lux [19]. The light control depending on radiation, the light is switch off at 200W/m² global radiation on horizontal and is turned on again at 120W/m². In accordance with [20] the smaller the room, the higher the light power density (LPD) necessary to provide the same illuminance level as in larger rooms (Table 5).

Table 5: Room LPD for 500Lux.

K	LPD [W/m²]	K	LPD [W/m²]
0,60	22,0	**1,50**	14,5
0,80	18,9	**3,00**	11,5
1,00	17,1	**5,00**	10,0

In summer the HVAC cooling system, has temperature setpoint of 24°C (t_a), no night ventilation, no recover system and no heating system. The workdays occur from Monday to Friday between 08:00-18:00. Other input parameters and heat gains in accordance with [21] can be seen in table 6.

Table 6: Heat gains and thermal properties.

	M²	Total
Persons	6,25W	75W
Equipments	19,17W	230W
Air change rate [1/h]	1,5	-
Infiltration	0,3	-
Light walls	2,00 W/m²K	-

3.6 An Approach into DIN 1946-2

Studies of thermal comfort and adaptation in office buildings conducted in Pakistan and recently in Germany showed that constant temperature setpoints may despise the people's adaptability potential and increasing energy demand.
In hot climates as Pakistan, some researches showed that by constant temperature setpoint, office workers felt colder when ambient temperatures were higher and warmer when outside temperatures were lower, indicating an adaptation to outdoor climate [22].
In Germany, the investigations indicate that neutral temperature tends to coincide with operative temperatures, experiencing an adaptation to indoor climate. Probably this happens due to the high level of user's influence on the thermal conditions of the work places [23].
For these reasons, an approach into the German norm DIN 1946-2 [24] is present to Brazil. This norm allows the increase of internal temperature limits when the ambient temperatures exceeding 26°C and accepts a limit of 10% in the over-heating hours (Figure 3).

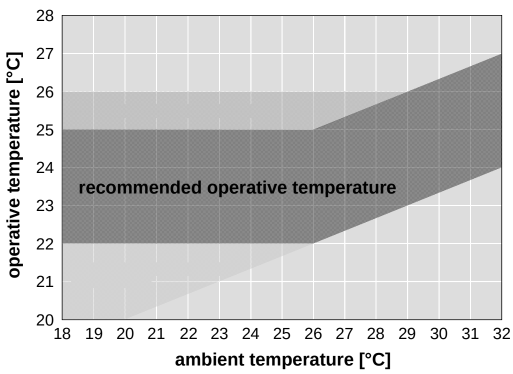

Fig 3. Figure from DIN 1946-2 [24].

As representative indices of the thermal conditions in indoor spaces [25], it is applied the PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) obtained by thermal simulation. These values may predict a supposed thermal sensation that people would have, and an estimated percentage of dissatisfied in respect to the thermal environment. The use of these indices allows assessing the influence of the thermal variation on the user's comfort.

4. Results

4.1 Results for 12 Cities

In this research project twelve Brazilian cities have been assessed. Due to restricted space in this article, some results into details are showed just for Cuiabá city. The results are presented in cooling energy demand by kWh/m²·a. Brazil has a vast territorial extension and as result is sighted in the major Brazilian capitals large difference on energy demand as a function of latitude. Figure 4 shows the simulation results for north orientation, using double glazing SPG (3). As can be seen from the graph, the capitals of southern regions need almost half energy than the capitals in northern regions. Even the cities from cooler climate regions, such as Porto Alegre, display almost linear increase on energy demand, which is directly related to the increase of the window area.

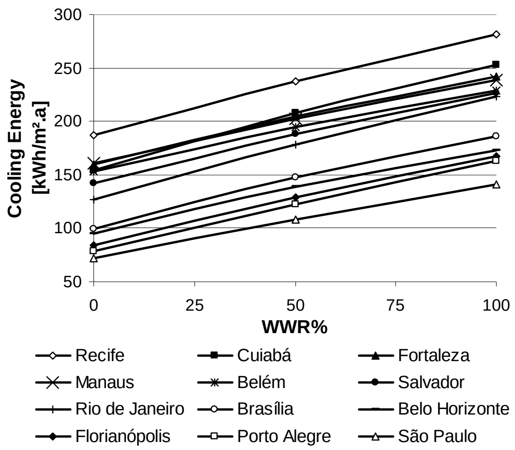

Fig 4. North, Ratio 1:2, K:0,60, Glass: U:1,30 SPG.

In extreme latitudes, there is a great difference in energy demand, for example the cities of São Paulo and Recife, however cities on the same latitude as Cuiabá and Brasília also have significant differences (Table 7), in these cases, due to the higher altitude of the Brazilian capital.

Table 7: Extreme values.

	Cooling Energy [kWh/m²·a]	Difference [kWh/m²·a]
Extreme Latitudes		
São Paulo (-23°32'51")	106,88	**128,37**
Recife (-08°03'14")	235,25	
Equal Latitudes		
Brasília (-15°46'47")	144,00	**61,32**
Cuiabá (-15°35'46")	205,32	

4.2 Results for Cuiabá City

The city of Cuiabá presents simulations results for the four main orientations, glass types, percentage of window wall ratios (WWR%), and room sizes. Brazil is located in the southern hemisphere, hence presents naturally lower energy demand for this orientation.

The glass 3 in relation to the glasses 1 and 2, as expected, is the most efficient for all orientations reaching an average energy savings of 47 kWh/m²·a in south orientation and 75 kWh/m²·a for the other orientations (Figure 5).

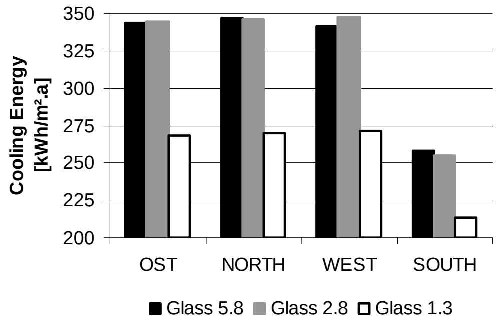

Fig 5. Cuiabá-BR, Room Ratio 2:1, K:0,6, WWR Average from 0, 25, 50, 75, 100%.

The glass 2 presents higher thermo-physicals parameters above the glass 1; however it presents no significant results, and simulating even a small reversal after the 65% of WWR (Figure 6).

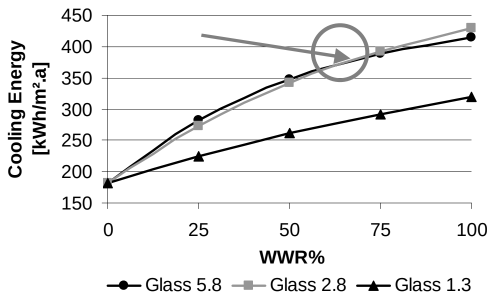

Fig 6. Cuiabá-BR, Room Ratio 2:1, K:0,6, WWR% Average 4 Orientations.

The normal double glazing (2) presents g-value and t-value close to the single clear glass (Table 4), this means that the solar gains into the room are almost equal in both situations. Thus during the day, the high thermal loads received through the windows are stored in the "indoor" fabrics. When the air-conditioning is switched off at 18:00 the t_{op} increases rapidly by convective process. The glass 2 (U: 2.8 W/m²K) has lower transmission factor than glass 1 (U: 5.8 W/m²K), it diminishes the heat dissipation capacity of glass 2 during the night. The night heat dissipation decreases the T_{op}, reducing the pre-cooling loads in the morning (Figure 7).

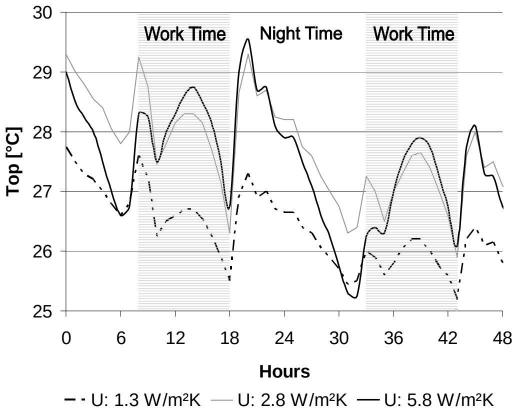

Fig 7. T_{op}, Cuiabá-BR, WWR 50%, North, Room Ratio 1:2, K:0,6.

The two following pictures show the energy demand as a function of different ratios (see figure 1) and room sizes (see Table 3). As can be seen in the figures 8 and 9, same size rooms with smaller facades (1:2) have lower cooling energy demand.

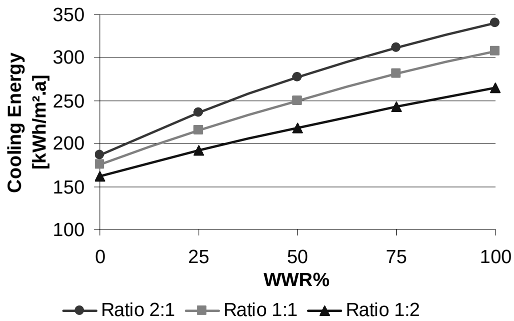

Fig 8. Cuiabá-BR, North, Room Index K:0,6, Glass: 1,30 W/m²K (SPG).

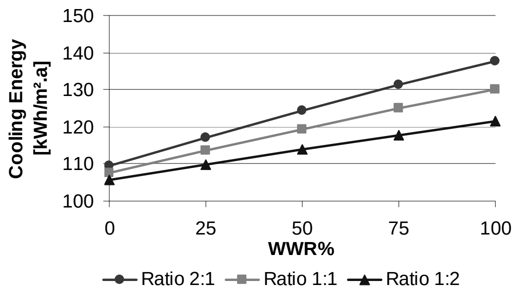

Fig 9. Cuiabá-BR, North, Room Index K:5,0, Glass: 1,30 W/m²K (SPG).

Figure 10 shows the correlation between energy demand and A/V index (facade area/volume). As described in [26], the index A/V is applied in Germany since the old ordinance [27] and in the current ordinance [28]. This index shows that index (K) when used with constant variable height (h), there is a correlation between the energy demand for air-conditioning, (A/V) room and (K) room.

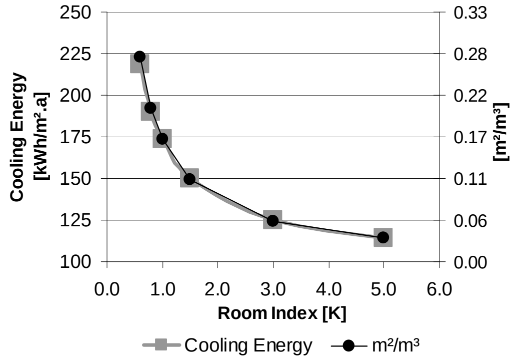

Fig 10. Cuiabá-BR, WWR 50%, North, Room Ratio 1:2, Glass: 1,30 W/m²K (SPG).

Figure 11 shows, the larger the room, the lower the cooling energy demand per floor area, this fact was also observed for other ratios and cities.
When the WWR% increases, smaller rooms have higher increasing rates on energy demand than larger rooms.
This happens because the solar gains through the glass in relation to volume, are higher (index A/V, figure 10) and the LPD in smaller rooms are higher to keep an illuminance of 500 Lux on the working surface [20].

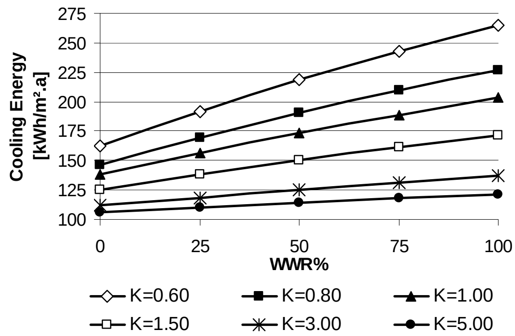

Fig 11. Cuiabá-BR, North, Room Ratio 1:2, Glass: 1,30 W/m²K (SPG).

Figure 12 displays an approach into the German norm DIN 1946-2 [24] for Brazilian climates. There are present two simulation scenarios for two Brazilian cities with high cooling energy demand (see figure 4). The first scenario occurs with constant cooling temperature setpoint about 24°C (t_a), no power limit used. The second correlates the indoor temperature setpoint to the ambient temperatures applying the German norm calculation method. The simulations occur to São Paulo and Recife, from September 10th to September 14th (Monday to Friday), north orientation, WWR 50%, Ratio 1:2, K:0.60 e Glass 1,3 W/m²K. In the city of Recife, when applied the norm [24], the t_{op} increases from 25,4±0,6°C to 27,2±0,5°C and the cooling energy demand decreases 17,2%. In São Paulo, the t_{op} increases from 23,4±1,2°C to 24,2±1,7°C only, the cooling energy demand decreases 29,9%. The t_{op} of the last example reflected directly on the calculated index PMV and PPD [25]. The increase of the index PMV in positive direction indicates an increase on the warm sensation and with an increase on the percentage of dissatisfied. In Recife, the norm [24], changed the PMV index from +0,99±0,15 to +1,47±0,11 and the PPD index from 24,3±1,3% to 48,5±3,4%. In the city of São Paulo the PMV and PPD respectively changed from +0,37±0,13 to +0,54±0,17 and 8±1,4% to 11,3±3,3%. The figure 12 shows the results over a whole year.

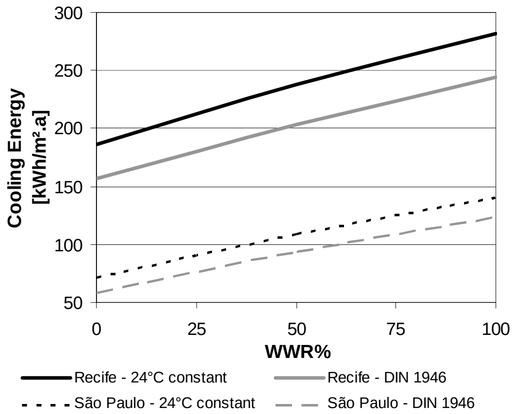

Fig 12. Recife-BR, São Paulo-BR, North, Room Ratio 1:2, K:0,60, Glass: 1,30 W/m²K (SPG).

5. Conclusion

This article has presented by simulating the different energy needs for the major Brazilian capitals and the ratio and size's influence on the cooling energy demand. Specifically to the energy field can be confirmed that:

1. There is a direct relation between the index window area/floor area and the energy demand;
2. Independent of ratio, the smaller the room area, the higher the cooling energy demand;
3. Independent of room size, the larger the facade, the higher de cooling energy demand;
4. Normal double glazing, when applied without shadow devices and night ventilation, shows results almost equivalent to the single clear glasses;
5. In hot climate cities such as Cuiabá, the use of double glazing SPG may reduce the cooling energy demand by an average of 21%;
6. The t_{op} definition as a function of ambient temperature, specifically when this one exceeds 27°C, produces interesting energy savings and at the same time reduces the undesired impact that high temperature differences can cause on the users' comfort.

The above findings show the results limited to the energy field, indicating that large rooms may be used as guidelines to energy savings. In this case, for example, the ratio 1:2 and index K:5,00 (15,38m x 30,75m= 473m²), disregarding the variation of the third variable height (h), leads to important results of energy efficiency. However, disregards the holistic perspective, in which one must not address the energy optimization only, but also the visual comfort, thermal comfort, acoustic comfort and air quality as well. The constant maintenance of variable height (h) leads to high values in the depth variable (D). As result, the user located in the central sector and the building quality may be affected in different ways:

1. By limited personal control on the windows and sun protection systems, preventing the setting of any discomfort sensation on thermal, lighting and air quality aspects [23];
2. An investigation into thirteen buildings in Germany with simple and double facades displays optimum daylight coefficient in the areas near to windows. Work places away from the facade must be artificial lighted resulting in a higher energy consumption and a visual discomfort for the users [29];
3. The lost of daylight contact during the day affects the body's circadian rhythm. This process influences the metabolic heat exchanges between the human body and environment around. This theory can be compared in [30];
4. The main acoustic problems in landscape offices, with workstations and half-height partitions, are the lack of privacy by users and the speech intelligibility to develop their activities [31];
5. In [32], studies about sound propagation in landscape offices, show that large rooms, require high levels of acoustic treatment with the absorption coefficient higher than 0.7.

Thus, the modification of the variable height (h) implies an additional volume for mechanical conditioned environments, increasing the cooling energy demand. A third supplementary methodology, varying height (h) as a function of depth (D) and width (W) could be applied and new results presented to assess the energy demand as a function of room ratios and room sizes considering also the holistic perspective.

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