Potential for Energy Savings by Using Daylighting and Hybrid Ventilation in Brazil

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ABSTRACT: The objective of this paper is to estimate the potential for electricity savings with the use of daylighting integrated with the artificial lighting system and hybrid ventilation in commercial buildings located in Florianópolis, southern Brazil. Several models were analysed. Two cases were investigated: a reference case, operating only with air-conditioning system and another one with the use of daylighting integrated with the artificial lighting and hybrid ventilation. Annual electricity consumption of each model was obtained from simulations using EnergyPlus and Daysim computer programmes. The consumptions of the reference case were compared with the daylighting and hybrid ventilation case. As a result, the energy savings by using daylighting and hybrid ventilation were calculated for each model. The larger the window area, the higher the energy savings. North oriented models presented the higher energy savings. Smaller and narrower models showed the higher energy savings. The use of daylighting integrated with the artificial lighting system and hybrid ventilation presented significant energy savings of up to 64.9%. It can be concluded that daylighting and hybrid ventilation use in commercial buildings located in Florianópolis presented potential for electricity savings. Combining such strategies can be an alternative to promote energy efficiency in buildings.

Keywords: daylighting, hybrid ventilation, potential for electricity savings, computer simulation

INTRODUCTION

Daylighting and hybrid ventilation have been used as alternatives to reduce the electricity consumption in buildings.

Researches to estimate the potential for energy savings by using daylighting integrated with artificial lighting have been developed [1, 2, 3, 4]. For example, a simplified method to evaluate the potential for energy savings by using daylighting integrated with artificial light system in a commercial building located in Hong Kong was developed by [1]. The global electricity consumption considering the cooling and the artificial lighting consumption was evaluated. The authors concluded that the potential for energy savings reached values up to 48.4%.

A comparison among different configurations of windows, with different types of glass, to assess their impact on the electricity consumption of commercial buildings located in Belgium was conducted by [2]. Superlink program was used for daylighting simulation and to complete the thermo-energetic analysis the TRNSYS programme was used. The authors concluded that the use of daylighting represented an average potential for energy savings of 39.0%.

The potential for energy savings by using daylighting in commercial buildings located in Athens, Brussels and Stockholm was assessed by [3]. Different types of control of artificial light were considered by the authors. Daysim computer programme was used for daylighting simulations. The potential for energy savings varied between 45% for an office with north orientation at Stockholm and 61% for an office with south orientation in Athens.

Likewise, the potential for energy savings by using hybrid ventilation has been evaluated in different climates [5, 6, 7].

Hybrid ventilation systems were studied in residential buildings by [5]. A mechanical system (reference) and a hybrid ventilation system (operating with two control strategies: presence of occupants and CO_2 concentration) were modelled. A single-family house located in four European cities was simulated: Trappes (France), Stockholm (Sweden), Athens (Greece) and Nice (France), including temperate (Trappes), cold (Stockholm) and hot (Athens e Nice) climates. The SIMBAD Building and HVAC Toolbox programmes were used. The indoor air quality, thermal comfort, energy consumption and stability of control strategies were considered in the analysis. Results showed that the hybrid ventilation system improved the indoor air quality, reduced the fan consumption (up to 90%) and maintained the same consumption for heating, when compared to the reference system.

A study of hybrid ventilation in a low energy building in south China (Hangzhou) was carried out by [6]. The mechanical system operates during summer and winter, and the natural ventilation in the other periods of the year. The natural ventilation system was modelled in ANSYS CFX programme and the thermal performance was evaluated by IES Virtual Environment programme. Results showed potential for energy savings (cooling) ranging between 30-35% for the hybrid strategy, in comparison with the mechanical system operating the whole year.

The works mentioned demonstrated that there is potential for energy savings by using daylighting or hybrid ventilation. In such a way, this work has the intention to collaborate for this research field, estimating the potential for energy savings by using daylighting and hybrid ventilation simultaneously.

OBJECTIVE

The objective of this paper is to estimate the potential for electricity savings with the use of daylighting integrated with the artificial lighting system and hybrid ventilation in commercial buildings located in southern Brazil.

METHOD

The study is based on computer simulations of room models of commercial buildings using EnergyPlus 6.0 and Daysim 3.0 programmes.

Chosen city, Simulation Models and Case Studies

The chosen city was Florianópolis (latitude: -27º 36', longitude: -48º 33' and altitude: 7m), located in the state of Santa Catarina, southern Brazil. The TRY (Test Reference Year) climate file of Florianópolis [8] was used for the simulations in both programmes.

For the simulations, the models were considered to have adiabatic ceiling, floor and interior walls. The models were studied considering different geometries and sizes. The model sizes are based on the room index (K), defined by Equation 1, as used in lighting manuals. The overall height of the rooms was taken as 2.80m and the working surface as 0.75m above floor level.

$$K=\frac{W.D}{(W+D).h} \qquad \text{Eq. 1}$$

where K is the room index (non-dimensional); W is the overall width of the room (m), D is the overall depth of the room (m) and h is the mounting height between the working surface and the ceiling (m).

Three geometries (Width:Depth) of 2:1, 1:1 and 1:2 were studied. Three room sizes per geometry were studied as shown in Table 1. For each case, window areas were varied, ranging from 0% to 100% at increments of 10%; and four solar orientations (north, south, east and west) were simulated. The window area is the total area of the façade that can be glazed. The window is located below a 60cm beam and has the width of the façade.

Table 1: Room dimensions for each room index and geometry.

Room index - K	Geometry - Width (W):Depth (D)					
	2:1		1:1		1:2	
	W (m)	D (m)	W (m)	D (m)	W (m)	D (m)
0.8	4.92	2.46	3.28	3.28	2.46	4.92
2.0	12.30	6.15	8.20	8.20	6.15	12.30
5.0	30.75	15.38	20.50	20.50	15.38	30.75

Each room model was investigated considering two case studies: a reference case (Case 1), operating with artificial lighting and air-conditioning system, and another case (Case 2) operating with the integration of daylighting with the artificial lighting system and with hybrid ventilation.

Parameters for simulation – Cases 1 and 2

The internal loads were taken as shown in Table 2. These loads were considered during occupation of the building, i.e., 8am-6pm, from Monday to Friday. The lighting power density (LPD) was estimated for each room by making a lighting design, which was performed by using the lumen method. Fluorescent tube lamps (TL5-28W) and recessed luminaries were used. The occupation and the equipment power density are based on the study of [9], developed for 35 commercial buildings located in Florianópolis. The metabolic activity was taken from [10].

The building components (Table 3) were also based on [9], with the exception of glass (single glass, 6mm, 88% of light transmission) that was based on [11].

Table 2: Internal thermal loads used for simulations.

Parameter	K	Geometry (Width:Depth)		
		2:1	1:1	1:2
Lighting power density (W/m^2)	0.8	13.9	15.6	13.9
	2.0	9.6	9.2	9.6
	5.0	8.1	8.0	8.1
Occupation (m^2/person)	14.7			
Activity (W/m^2)	65.0			
Equipment (W/m^2)	9.7			

Table 3: Properties of building components.

Component	Material	Conductivity (W/m.K)	Density (kg/m^3)	Specific heat (J/kg.K)	Thickness (m)	Total thickness (m)
Walls	Plastering mortar	1.15	2000	1000	0.025	0.200
	Ceramic 6-hole brick	0.90	1600	920	0.150	
	Plastering mortar	1.15	2000	1000	0.025	
Floor	Concrete slab	1.75	2200	1000	0.150	0.185
	Plastering mortar	1.15	2000	1000	0.025	
	Ceramic floor	0.90	1600	920	0.010	
Ceiling	Ceramic floor	0.90	1600	920	0.010	0.185
	Plastering mortar	1.15	2000	1000	0.025	
	Concrete slab	1.75	2200	1000	0.150	

The air-conditioning system consists of a split hi-wall, which was modelled in EnergyPlus considering an air change rate of 0.0075 m^3/s/person and a COP (Coefficient Of Performance) of 3.28 W/W. The air-conditioning set-point temperature was taken as 24ºC, during occupation. The air-conditioning system was used for cooling only, because in Florianópolis air-conditioning is not usually used for heating [9].

Daylighting simulations – Case 2

The daylighting simulations were performed using Daysim. The Daysim was used to simulate the daylighting because some authors indicate that the daylighting algorithm used in EnergyPlus overestimates indoor illuminances [12, 13].

The schedule of lighting control on an hourly basis was the report generated by Daysim that was used in this work. This schedule was used as input data to EnergyPlus. In the models, the daylight sensors were kept 0.2m away from each other, creating a grid of equidistant points. The reflectances of internal walls, ceiling and floor were defined as 80%, 50% and 30%, respectively. The lighting control of artificial light was performed by a photosensor controlled dimmer system based on daylight illuminances, providing a minimum illuminance of 500 lx at the work plane throughout working hours.

Hybrid ventilation simulations – Case 2

In order to incorporate the hybrid ventilation, control schedules of air-conditioning and control schedules of natural ventilation were created using spreadsheets and then used as input data to EnergyPlus. The control schedule of air-conditioning is the opposite of the control schedule of natural ventilation, i.e., when the natural ventilation is allowed, the use of air-conditioning is not-allowed and vice versa. These schedules were performed on an hourly basis for the whole year. Procedures "a" to "c" were created for the determination of these schedules during periods of occupation of the building (8am-6pm, from Monday to Friday).

a) Simulation of natural ventilation: The multi-zone Airflow Network model was used for the simulation of natural ventilation and the wind pressure coefficients were calculated by EnergyPlus. The windows were considered operable and were opened and the air-conditioning turned off when three requirements were satisfied: (1) the zone temperature was greater than the outdoor temperature, (2) the zone temperature was greater than the set-point temperature of natural ventilation and (3) the schedule control of natural ventilation allowed ventilation. The set-point temperatures for natural ventilation were 22ºC (autumn and winter, from March 21 to September 20) and 20ºC (spring and summer, from September 21 to March 20). The air mass flow coefficients and exponents when opening is closed and the discharge coefficients of openings used for natural ventilation simulations are based on [14] (Table 4). The schedule control of natural ventilation allowed ventilation from 8am-6pm, from Monday to Friday. For each model, indoor dry-bulb temperature (DBT), absolute humidity (AH) and relative humidity (RH) were obtained on an hourly basis.

Table 4: Parameters for natural ventilation simulations.

Field	Windows
Component description	Metal window, 1 leaf - horizontal sliding
Air mass flow coefficient when opening is closed (kg/s.m)	0.00010
Air mass flow exponent when opening is closed (dimensionless)	0.66
Numbers of sets of opening factor data	2
Opening factor 1 - Opening closed (dimensionless)	0
Discharge coefficient for opening factor 1 (dimensionless)	0.001
Opening factor 2 - Opening opened (dimensionless)	1
Discharge coefficient for opening factor 2 (dimensionless)	0.6

b) Comparisons of DBT, AH and RH with the method to asses thermal comfort: Indoor dry-bulb temperature, absolute humidity and relative humidity, obtained from the natural ventilation simulations, were compared with the upper accepted limits of thermal comfort zone of Givoni's chart [15]. The method of Givoni was chosen based on a previous study [16] that indicates this method as the most suitable to be used in hybrid commercial buildings located in Florianópolis. Thus, the upper accepted limit of relative humidity is 80%. Up to dry-bulb temperature of 27ºC, the upper accepted limit of absolute humidity is 17 g/kg. Between dry-bulb temperature of 27ºC and 29ºC, the upper accepted limit of absolute humidity is given by Eq. 2. This equation was obtained based on the Givoni's chart.

$$AH=-2.25 \times DBT + 77.75 , 27^{\circ}C < DBT < 29^{\circ}C \quad \text{Eq. 2}$$

where AH is the absolute humidity (g/kg); DBT is the dry-bulb temperature (ºC).

c) Allowing natural ventilation or air-conditioning: The air-conditioning system was turned on when the values of DBT, AH and RH were above the upper accepted limits described previously. Otherwise, if the values of DBT, AH and RH were below such upper limits, the natural ventilation was allowed.

In the other hours of each weekday, natural ventilation was allowed, if the three requirements described in "a" were fulfilled. On weekends, natural ventilation and air-conditioning were not allowed.

Potential for electricity savings

Annual electricity consumptions for each room were obtained from the simulations. The potential for electricity savings by using daylighting and hybrid ventilation was obtained by comparing, through Equation 2, the electricity consumptions for the reference case (Case 1) with the case using daylighting and hybrid ventilation (Case 2).

$$PES=\left(1-\frac{C2}{C1}\right)x100 \quad \text{Eq. 3}$$

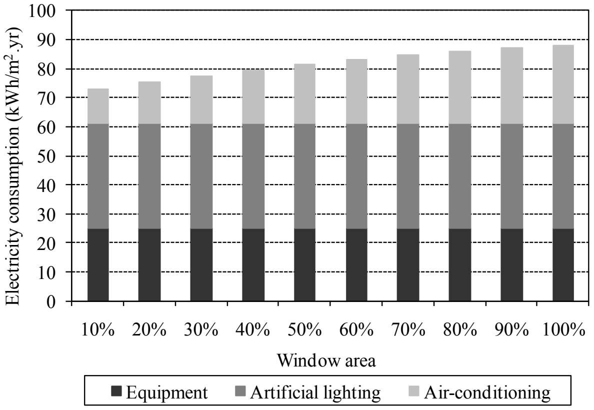
where PES is the potential for electricity savings by using daylighting and hybrid ventilation (%), $C2$ is the electricity consumption of Case 2 (kWh/m^2) and $C1$ is the electricity consumption of Case 1 (kWh/m^2).

RESULTS

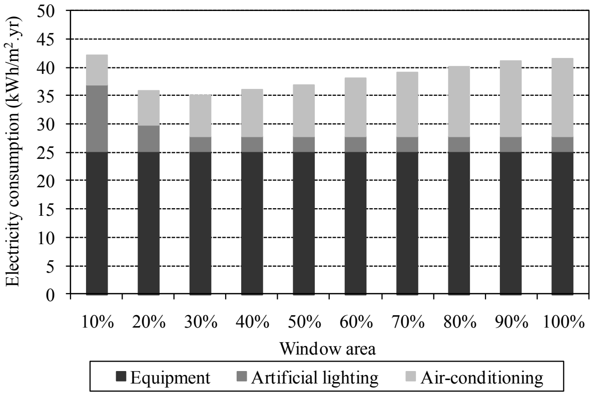
The results obtained by the application of the method described above are presented in this section.

The electricity consumptions for the reference case (Case 1) varied from 61.53 kWh/m^2.yr for model with geometry 2:1, room index equal to 5.0, 10% window area, south-oriented, to 120.47 kWh/m^2.yr for model with geometry 1:1, room index equal to 0.8, 100% window area, west-oriented. For daylighting and hybrid ventilations case (Case 2) the consumptions varied between 34.02 kWh/m^2.yr for model with geometry 1:2, room index equal to 0.8, 30% window area, south-oriented, and 62.73 kWh/m^2.yr for model with geometry 1:2, room index equal to 0.8, 10% window area, west-oriented.

Figure 1 shows, as an example, the annual electricity consumption by end-use as a function of the window area, for Case 1 and Case 2, models with geometry 2:1, room index equal to 0.8, south oriented.



(a) Case 1



(b) Case 2

Figure 1: Annual electricity consumption by end-use as a function of the window area, for Cases 1 and 2, models with geometry 2:1, room index equal to 0.8, south oriented.

For Case 1, the electricity consumption of artificial lighting and equipment are constant. The air-conditioning consumption varies according to the heat gain through the window. Thus, the greater the window area, the higher the electricity consumption.

For Case 2, only the equipment consumption is constant. The artificial lighting consumption varies depending on the use of daylighting; this also led to a reduction of the internal thermal load due to heat dissipation of lamps. The air-conditioning is dependent on the internal thermal load reduction due to the use of daylighting and due the use of hybrid ventilation. Through hybrid ventilation (alternating between natural ventilation and air-conditioning), the number of hours of air-conditioning use is reduced compared to Case 1. Furthermore, the use of natural ventilation removes part of the internal thermal load.

The potential for electricity savings by using daylighting and hybrid ventilation for north-oriented models are shown in Table 5. In this table, artificial lighting (AL), air-conditioning (AC) and the total potential for electricity savings for three geometries, three room indices per geometry, ten window areas and one orientation are presented. In general, it can be noticed that the larger the window area, the higher the energy savings. Smaller models (room index equal to 0.8) showed the highest energy savings. Models with geometry 2:1 and 1:1 (narrower rooms) presented the highest energy savings. These behaviours were also observed in the other orientations.

Table 5: Potential for electricity savings by using daylighting and hybrid ventilation for north-oriented models.

Window area	C	Potential for electricity savings (%)								
		Geometry 2:1			Geometry 1:1			Geometry 1:2		
		K=0.8	K=2.0	K=5.0	K=0.8	K=2.0	K=5.0	K=0.8	K=2.0	K=5.0
10%	AL	78.9	19.9	0.0	60.2	9.4	0.0	28.8	0.0	0.0
	AC	67.9	54.2	67.8	68.7	67.8	68.2	61.5	67.6	64.5
	T	50.9	20.4	17.1	43.7	20.3	17.6	27.0	16.9	17.0
20%	AL	90.3	51.3	1.5	88.8	27.2	0.0	51.2	3.9	0.0
	AC	70.8	68.0	56.8	73.3	65.9	51.6	70.4	60.4	40.5
	T	57.7	36.9	16.4	59.4	27.6	13.7	40.6	18.0	10.7
30%	AL	93.3	70.7	5.9	90.8	41.7	0.0	70.9	12.5	0.0
	AC	72.0	73.4	65.8	74.5	71.2	62.2	75.1	68.7	55.8
	T	60.0	46.5	21.3	61.3	35.4	18.0	51.4	24.4	15.4
40%	AL	93.3	83.8	11.7	92.9	53.6	1.0	81.7	16.8	0.0
	AC	73.1	73.8	69.6	74.9	73.1	67.9	76.5	71.6	63.3
	T	61.0	51.9	25.2	62.9	41.0	20.9	57.1	27.8	18.1
50%	AL	93.3	85.3	16.8	93.3	71.4	3.1	84.5	23.9	0.0
	AC	73.2	74.1	71.2	75.3	74.1	70.1	77.1	73.1	67.9
	T	61.6	53.2	28.0	63.6	47.9	23.1	59.0	31.5	19.9
60%	AL	93.3	89.7	20.9	93.4	75.5	6.3	89.0	29.1	0.0
	AC	73.2	74.1	72.0	74.8	74.9	71.6	77.4	73.4	69.7
	T	62.1	55.2	30.2	63.9	50.1	25.1	61.3	34.1	20.9
70%	AL	93.3	91.1	26.1	93.4	80.5	8.4	89.7	32.8	0.0
	AC	73.1	73.6	72.4	74.8	75.3	71.8	77.1	73.8	71.1
	T	62.5	55.9	32.5	64.3	52.4	26.4	61.9	36.1	22.0
80%	AL	93.3	91.1	29.6	93.4	82.9	10.6	90.8	34.6	0.0
	AC	73.1	73.6	72.7	74.9	75.0	72.4	76.7	74.1	71.9
	T	62.9	56.3	34.2	64.6	53.5	27.8	62.6	37.4	22.7
90%	AL	93.3	92.1	32.1	93.4	84.4	13.1	90.8	36.8	0.0
	AC	73.2	73.4	73.0	74.5	75.3	72.5	76.5	74.1	72.2
	T	63.2	56.9	35.6	64.8	54.4	29.1	62.8	38.7	23.7
100%	AL	93.3	92.1	32.1	93.4	84.4	13.6	92.0	38.1	0.0
	AC	73.1	73.2	73.2	74.5	75.4	72.7	76.4	74.5	72.7
	T	63.3	57.1	36.0	64.9	54.7	29.6	63.3	39.5	24.2

Table 6: Maximum, minimum and average potential for electricity savings by using daylighting and hybrid ventilation for all models.

Orientation	PES	PES - Potential for electricity savings (%)								
		Geometry 2:1			Geometry 1:1			Geometry 1:2		
		K=0.8	K=2.0	K=5.0	K=0.8	K=2.0	K=5.0	K=0.8	K=2.0	K=5.0
North	Max	63.3	57.1	36.0	64.9	54.7	29.6	63.3	39.5	24.2
	Min	50.9	20.4	16.4	43.7	20.3	13.7	27.0	16.9	10.7
	Avg	60.5	49.0	27.6	61.3	43.7	23.1	54.7	30.4	19.5
	σ	3.6	11.2	7.0	6.1	11.6	5.2	11.4	7.9	4.0
South	Max	54.8	48.6	28.0	57.9	45.8	22.8	57.3	44.8	21.7
	Min	42.2	16.7	13.6	32.2	15.1	12.6	39.2	15.3	9.7
	Avg	52.5	41.5	22.0	54.2	34.7	18.6	54.7	35.0	17.8
	σ	3.5	10.4	4.9	7.5	10.0	3.2	5.3	9.5	3.5
East	Max	57.4	52.8	34.7	60.5	51.2	29.1	58.5	37.5	22.1
	Min	49.0	23.4	8.7	39.3	16.2	4.8	25.3	12.4	4.4
	Avg	56.2	46.7	26.9	57.6	40.3	21.4	51.2	29.4	17.1
	σ	2.5	9.0	7.6	6.3	11.0	7.4	10.4	7.3	5.6
West	Max	58.1	54.5	35.5	61.0	52.5	28.5	60.4	37.9	23.3
	Min	48.9	18.3	7.1	32.4	13.2	4.2	20.8	15.5	10.0
	Avg	56.8	46.7	25.6	57.3	40.4	20.6	51.1	28.5	18.6
	σ	2.7	11.1	8.5	8.4	12.4	7.2	12.6	7.7	4.1

Considering the results of all models, the potential for electricity savings reached values of up to: (a) 93.6% in relation to artificial lighting consumption, for model with geometry of 1:1, room index equal to 0.8, 100% window area, east oriented, and (b) 77.4% in relation to air-conditioning consumption, for model with geometry of 1:2, room index equal to 0.8, 60% window area, north oriented.

Results on the potential for electricity savings in relation to the total consumption can be seen in Table 6. Table 6 shows the maximum, minimum and average (with the standard deviation-σ) potential for electricity savings by using daylighting and hybrid ventilation in relation to Case 1, for all models. The use of daylighting integrated with the artificial lighting system and hybrid ventilation presented significant energy savings of up to 64.9%, for the model with geometry 1:1, room index equal to 0.8, 100% window area, north oriented. The higher energy savings were achieved by north oriented models and the lower for south oriented models (both in percentage and in kWh/m^2).

The energy savings of the air-conditioning is higher due to the influence of the use of hybrid ventilation, because the use of daylighting only reduces the heat gain generated by lamps. Otherwise, the total energy savings are higher due to daylighting in most cases. In models with geometry 1:2, room indices equal to 2.0 and 5.0, oriented north, east and west there is no energy savings due to daylighting. Thus the hybrid ventilation is the responsible for the energy savings in these models.

The use of daylighting and hybrid ventilation in commercial buildings located in Florianópolis can be used to promote energy efficiency in buildings.

CONCLUSION

The method used in this work can be applied anywhere in the world to estimate the potential for electricity savings when daylighting and hybrid ventilation are used in commercial buildings. The input parameters for simulation need to be adapted to the climate of interest. However, the conclusions of this work are limited to the climate of Florianópolis.

The potential for electricity savings by using daylighting and hybrid ventilation in commercial buildings located in Florianópolis was evaluated. It can be concluded that the use of daylighting and hybrid ventilation in commercial buildings located in Florianópolis presented potential for electricity savings. A potential for electricity savings of up to 64.9% was achieved, when compared to buildings using artificial lighting and air-conditioning system. Smaller and narrower models showed the higher energy savings. North oriented models presented the higher energy savings.

This work reinforced the good potential for electricity savings by using daylighting and hybrid ventilation in commercial buildings, as seen in the introduction of this paper. Combining such strategies can be an alternative to promote energy efficiency in buildings.

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