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Selecting automation techniques of lighting and air conditioning for inner enclosures considering warm tropical climate: a case study

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Abstract. Overall, the intervention on buildings on university facilities presents a lack of design criteria oriented to the rational use of energy (RUE), which can reduce electricity consumption between 20% and 40%. In particular, the selection of lighting and air conditioning systems in buildings is limited to the choice of efficient equipment. A process of classification of control and automation techniques have developed as a base for the computing of the electrical load associated with lighting and air conditioning systems. This article presents an interface based on Microsoft Excel® for evaluation, classification, and validation criteria for the control and automation of RUE-oriented applications. In particular, the results of the implementation of the software are set to evaluate different inner spaces like classrooms, offices, and auditoriums, among others. As a case study, several techniques of control and automation for lighting and refrigeration are analyzed for a classroom and an office considering specific warm tropical microclimate, physical characteristics, operation schedules, and operation characteristics.

Keywords: Rational use of energy, lighting, air conditioning, automation system.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) emphasizes the need to halve the quantity of the emissions of greenhouse gases (GHGs), to prevent this climate change that would affect all living beings in the world [1]. A common scenario of analysis is a building since is permanent roofed constructions [2], where occupants spend up to 80% of their time. The energy component of a building becomes a factor of high impact on the environment and its inhabitants, in particular the contributions associated with lighting systems and air conditioning [3]; which about 60% is due to consumption generated by air conditioning (cooling and heating) [4] and 20% is by lighting [5].

Currently, the use of building automation systems - BAS is a global trend that tends towards the RUE during the operational phase of buildings [6]. BAS provides advanced functionality control and monitoring of mechanical and electrical systems of a building. These systems reduce energy consumption without affecting the functionality and comfort of the inhabitants [7].

In general, the comfort of the inhabitants in buildings is determined by three factors: thermal comfort, visual comfort, and indoor air quality (IAQ) [8]. Thermal comfort is defined as the neutral thermal sensation of the inhabitants, such as expressing no feeling of heat or cold. Visual comfort is determined by the level of illumination and glare. Proper lighting allows to distinguish shapes, colors, objects, and all are easily performed without causing eyestrain [9,10].

The buildings present on the campuses of universities can form small cities because of its size, users, and complex mixed activities [11]. Power consumption of the campus at universities has reached 8% of the total energy consumption in society [12].

In recent years, the management of lighting and cooling systems on college campuses presented difficulties by requiring users to access, verify, and change the operating parameters of devices [12–14]. Therefore, the energy and environmental impact of universities could be significantly reduced by implementing organizational and technological measures, and energy optimization [11], which would be based on the concept of sustainability that integrates environment, economy, and society [10,13,14].

In short, the university campus suffer from the following [10–14]: 1) lack of RUE criteria for design automation lighting and air conditioning, 2) few or no means to adjust automatically the lighting and temperature according to each space, 3) exclusive use of efficient devices as an energy management strategy, and 4) failure to take advantage of natural conditions of the enclosure, as daylighting and natural air stream.

Therefore, it is appropriate to define a mechanism for evaluation and validation of design criteria for energy automation applications oriented to RUE, which is addressed for lighting and air conditioning systems in university buildings. This work proposes a tool developed on Visual Basic for Microsoft Excel®, which is a functional tool for implementing a method for sorting automation and control techniques for lighting and air conditioning systems on campuses, focusing on energy consumption.

This document presents the method for estimating the electrical load of an indoor enclosure (Section 2); then it is defined the requirements for computation (Section 3); subsequently, the software is described and two cases of study are illustrated (Section 4), and, finally, conclusions of the research are showed (Section 5).

2. Proposed method

The method starts by coupling two systems for calculating load, one for light and another for cooling, by adjusting its basis to hourly calculations. Second, it was defined and integrated the operations of air conditioning and lighting systems for each control technology. Third, integrated variables such as location, working hours, function, dimensions, characteristics of doors, windows, and walls, among other characteristics of the enclosure. Fig. 1 summarizes the information required for the calculation of the total energy and classification techniques according to saving energy, given by the integration of control techniques in the enclosure.

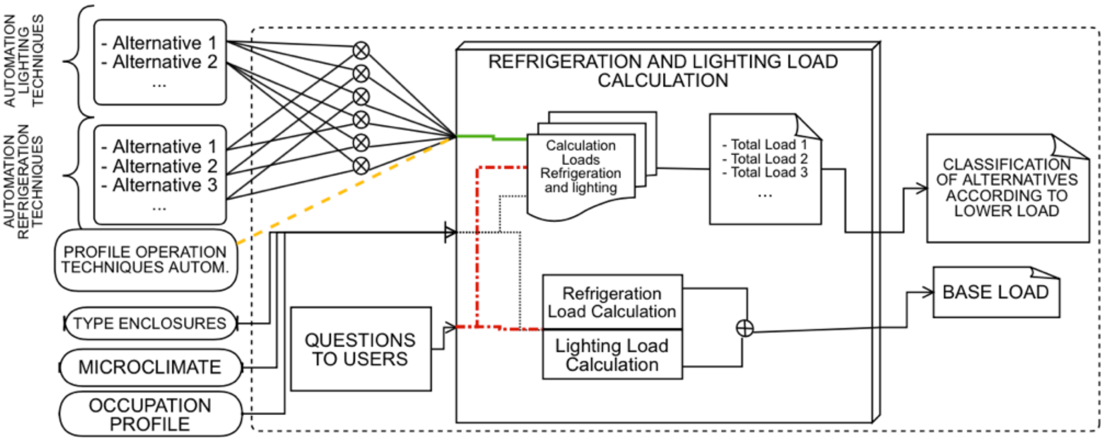


Fig. 1. Estimation method of electric charge.

3. Requirements for calculating the electric charge

A computational tool was created for computational purposes, which was based on the above parameters. Table 1 shows the relationship between each part of the lighting calculation and cooling with the required information to the user and the microclimate of the enclosure.

Table 1. Load calculation parameters versus user requirements.

		Cabinet Type	Schedule	Solar irradiation	Room temperature	Work temperature	Room Relative humidity	Work Relative Humidity	Dimensions of the enclosure	Orientation of the enclosure	Area windows	Window Type	Wall type	Roof	number of people	Business people	Number doors	lighting power	Number of Skylights	Lighting level	Type of luminaire and lamp	Obstructions
Air conditioning	Heat sensitive due to solar radiation through windows	X	X	X						X	X	X										
Air conditioning	Heat sensitive due to radiation and transmission through exterior windows	X	X		X	X			X				X									
Air conditioning	Heat sensitive due to radiation and transmission through external ceilings	X	X		X	X								X								
Air conditioning	Sensible heat transmission through walls because no external	X	X		X	X			X				X									
Air conditioning	Heat sensitive due to air infiltration	X	X		X	X									X		X					
Air conditioning	Sensible heat generated by people	X	X												X	X						
Air conditioning	Sensible heat generated by lighting	X	X															X				
Air conditioning	Latent heat generated by people	X	X												X	X						
Air conditioning	Latent heat due to infiltration air	X	X												X	X						
Air conditioning	Sensible heat from ventilation air	X	X		X	X																
Air conditioning	Latent heat from ventilation air	X	X				X	X														
Illumination	Lighting power	X		X					X												X	
Illumination	Lighting constant factor	X	X																		X	
Illumination	Load factor	X	X													X						
Illumination	Natural light dependency factor	X		X						X	X	X	X	X		X			X	X		X
Illumination	Parasitic energy	X	X																			

In general, solar irradiance, temperature, relative humidity, and occupancy represent the greatest accumulation of information required for calculating the total charge, cooling and lighting. Also, it is necessary to consider the influence of the type of strategy for air conditioning or lighting and the type of enclosure on all parameters required.

The methodology provides to the user with the three greatest energy savings techniques, among 40 possible scenarios, could be implemented in the evaluated enclosure. For this, the set of techniques are classified according to the energy demand and compared with respect to base scenario, which does not include the application of automation techniques on the evaluated enclosure.

In general, the software initially computes the base energy load of the enclosure based on the micro-climatic information, the operating profile of the control techniques, the occupation characteristics, and information provided by the user like the architectural and electric characteristics of the enclosure. Then, the software computes the energy load for the 40 combinations of control and automation techniques. Finally, this tool supplies the classification according to the energy savings obtained.

A. Microclimate

The parameters supplied by a weather station installed on rooftop of Electrical Engineering Building of the Universidad Industrial de Santander (Bucaramanga, Colombia) are condensed in Fig. 2, highlighting the ambient temperature, humidity, and solar irradiance [13,14].

The average solar irradiance is 416.5-441.5 W/m^2 between 6 a.m. and 6 p.m. in Bucaramanga. The average ambient temperature and relative are 23.4-24.0 ºC and 81.1- 79.8%, respectively. These levels are due to the geographical position and climatic conditions of the university campus.

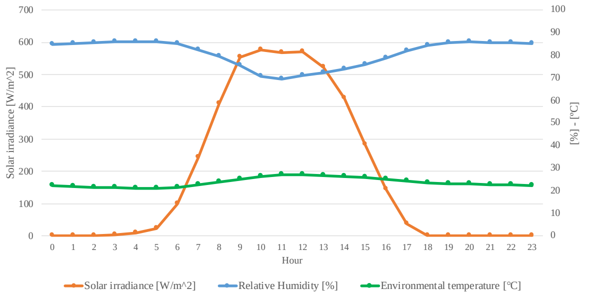


Fig. 2. Behavior of microclimate conditions in Bucaramanga.

B. Technical control and automation operation

The operation of various control and automation techniques are associated with the on/off operation of the lighting and cooling systems on an hourly basis, Fig. 3, as well as the value of their setpoints (illuminance and temperature). Table 2 shows the operation of 14 studied techniques, where *DO = Depends on Occupation, *DRS = Depends on Solar Irradiance, and *TT = Working Temperature.

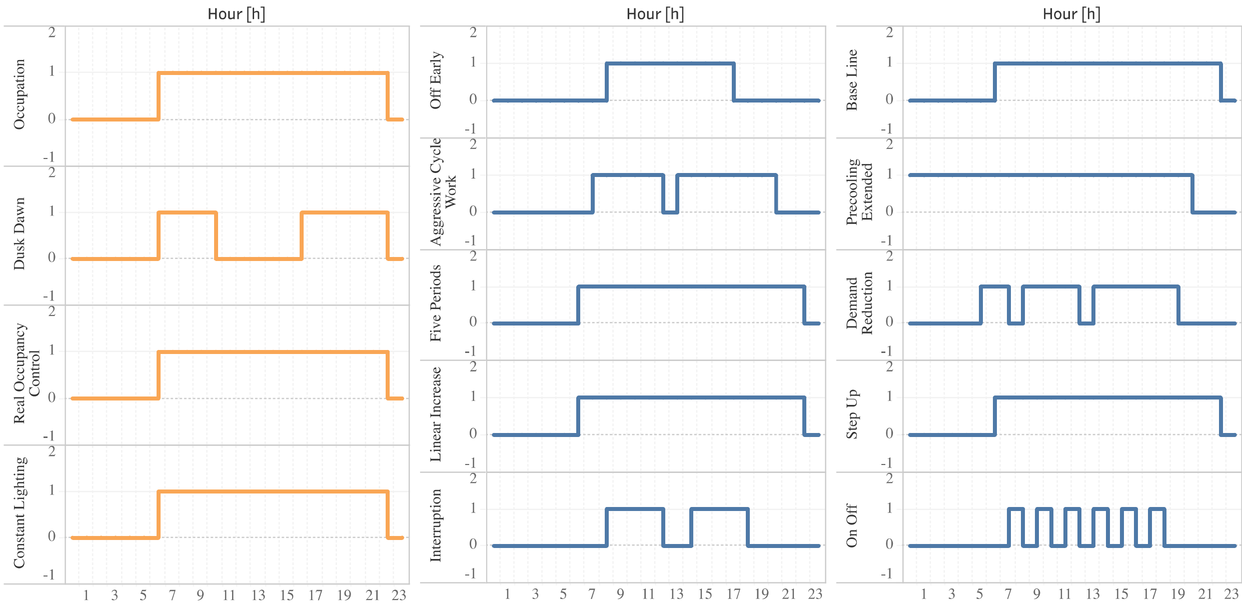


Fig. 3 Control techniques operating hours.

Table 2. Variation of setpoint of control techniques.

Time	Occupation	Dusk dawn	Real occupancy control	Constant lighting	On off	Off Early	Interruption	Demand reduction	Aggressive cycle work	Base line	Step Up	linear increase	Precooling extended	Five periods
0	0%	0%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	32	32	32	*TT-2 ° C	32
1	0%	0%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	32	32	32	*TT-2 ° C	32
2	0%	0%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	32	32	32	*TT-2 ° C	32
3	0%	0%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	32	32	32	*TT-2 ° C	32
4	0%	0%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	32	32	32	*TT-2 ° C	32
5	0%	0%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	32	32	32	*TT-2 ° C	32
6	100%	100%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	32	32	32	*TT	32
7	100%	100%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	*TT	*TT	*TT	*TT + 0.22 °C	*TT-2 °C
8	100%	100%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	*TT	*TT	*TT	*TT + 0.44 °C	*TT-2 °C
9	100%	100%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	*TT	*TT	*TT	*TT + 0,67 °C	*TT-2 °C
10	100%	0%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	*TT	*TT	*TT	*TT + 0.89 °C	*TT- 2 °C
11	100%	0%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	*TT	*TT	*TT	*TT + 1,11 °C	*TT
12	100%	0%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	*TT	*TT	*TT	*TT + 1.33 °C	*TT
13	100%	0%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	*TT	*TT + 2 °C	*TT + 0.33 °C	*TT + 1.56 °C	*TT
14	100%	0%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	*TT	*TT + 2 °C	*TT + 0.66 °C	*TT + 1.78 °C	*TT + 2 °C
15	100%	0%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	*TT	*TT + 2 °C	*TT + 1 °C	*TT + 2 °C	*TT + 2 °C
16	100%	100%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	*TT	*TT + 2 °C	*TT + 1.33 °C	*TT + 2 °C	*TT + 2 °C
17	100%	100%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	*TT	*TT + 2 °C	*TT + 1.66 °C	*TT + 2 °C	*TT + 2 °C
18	100%	100%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	*TT	*TT + 2 °C	*TT + 2 °C	*TT + 2 °C	32
19	100%	100%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	32	32	32	*TT + 2 °C	32
20	100%	100%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	32	32	32	32	32
21	100%	100%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	32	32	32	32	32
22	0%	0%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	32	32	32	32	32
23	0%	0%	*DO	*DRS	*TT	*TT	*TT	*TT	*TT	32	32	32	32	32

C. Enclosure Occupancy

Some of the techniques depend on occupation data, for this reason Fig. 4 shows occupation profiles for several areas.

This profile considers the hours of operation of both, the university and analyzed enclosure since those vary according to the characteristics of their occupants (e.g., students, professors, administrators, and general public) and the length of stay.

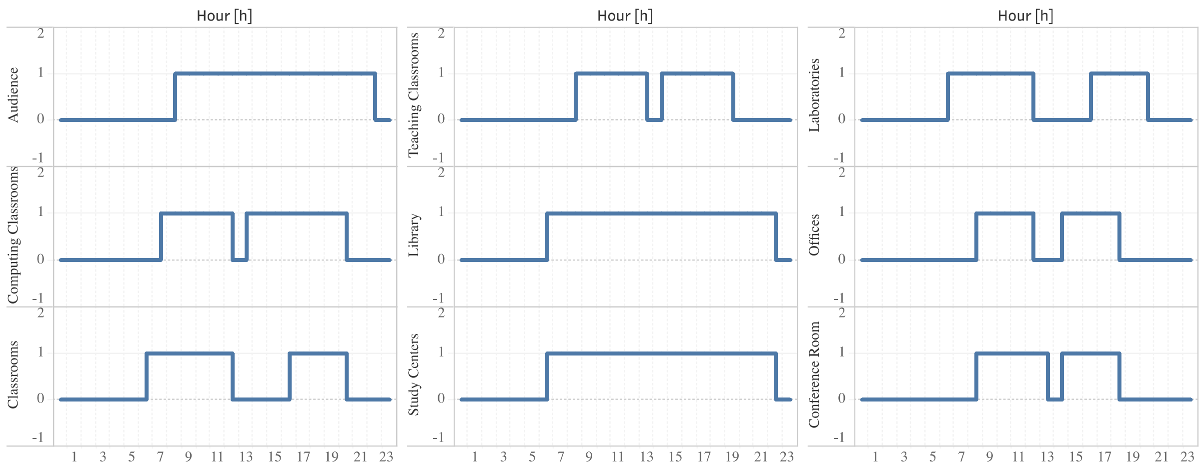


Fig. 4. Occupancy profile by indoor enclosure.

4. Description of the application

The application is based on Visual Basic for Microsoft Excel, which allows the user to enter the information required to compute the total energy load, specially lighting load and the cooling load of an enclosure (designed or existent). As result, this tool delivers the classification of the air conditioning/lighting strategy set that offers greater energy savings to the enclosure evaluated by the user, compared to the energy consumption of the same enclosure without the application of automation strategies.

The developed form consisting of five tabs is presented below. The first three tabs, Fig. 5, allow the collection of information related to the enclosure; the last two tabs, Fig. 6, present the comparative results of the base load (room load without implementation of automation techniques) with respect to the best three energy saving scenarios due to the implementation of automation techniques.

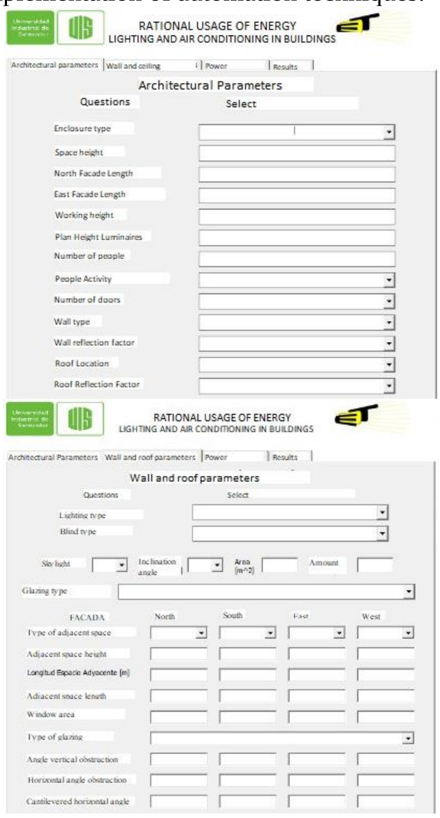


Fig. 5. Section of questions for the user.

As a use case, energy consumption was calculated for two recurring university environments, a classroom and an office, the parameters requested from the user are shown in Table 3.

Table 3. Data entered by user.

Questions	Enclosure 1	Enclosure 2
Type of space	Classroom	Office
Space height [m]	3	3
North or South facade length [m]	11	5
East or west facade length [m]	5	7
plane height [m]	0.85	0.85
Luminaire plane height [m]	0	0
Number of people	40	2
Activity by persons	Sedentary	Seated
Number of doors	1	1
Wall type	Exterior	Exterior
Wall reflection factor	0.5	0.5
Roof	Inside	Exterior
Ceiling reflection factor	0.75	0.75
Lighting type	Fluorescents	LED
Blind type	ordinary	ordinary
Inclination angle skylight [°]	N/A	0°
Skylight area [m^2]	N/A	1
Skylights amount	N/A	3
Skylight glazing type	N/A	Ordinary
Facade opening	South	North
Type of adjacent space	Playground	Playground
Adjacent space height [m]	10	0.1
Adjacent space length [m]	20	100
Wide space adjacent [m]	30	100
Window area [m2]	15	10
Type of glazing	Simple	Simple
Angle vertical obstruction [°]	5	0
Horizontal angle obstruction [°]	45	15
Cantilevered horizontal angle [°]	0	0
Temperature [° C]	24	22
Relative Humidity [%]	60	60
Additional equipment power [W]	N/A	1000
Additional equipment efficiency [%]	N/A	95

As a result, it was obtained that the classroom has a daily energy consumption of 955.4 kWh without the implementation of automation techniques; the effect of implementing the Nightfall / Sunrise-On / Off techniques generates a saving of 84%, such as Fig. 6 shown.

On the other hand, for the office the energy consumption without automation techniques is 583.6 kWh and the implementation of Constant Lighting - On / Off generates an energy saving of 89%.

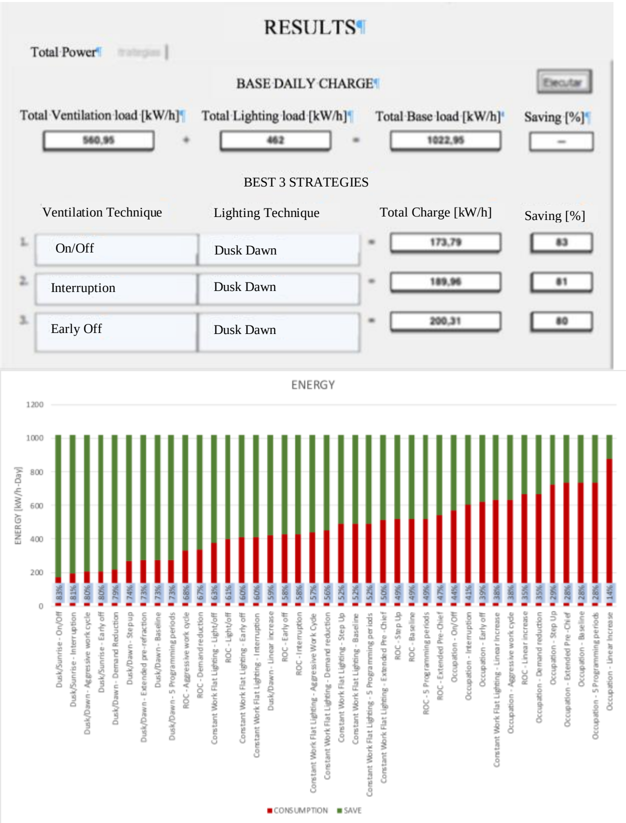
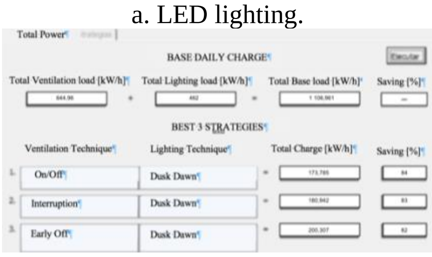


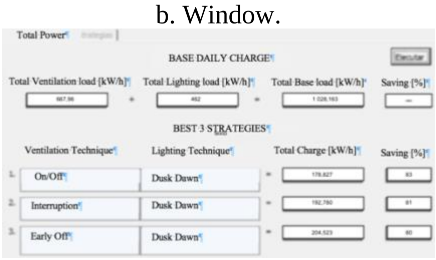
Fig. 6. Load calculations for the classroom.

In the same way, the following specific modifications were evaluated under the same conditions of the classroom, change to LED lighting, increase in the area of windows to 22 m^2, increase in the number of doors to 2, inclusion of 3 skylights, decrease in temperature of work at 18 ºC, change of function of the enclosure to computer room and auditorium, Fig 7.

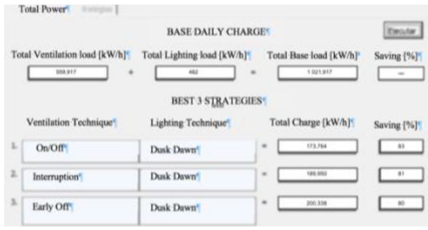
a. LED lighting.



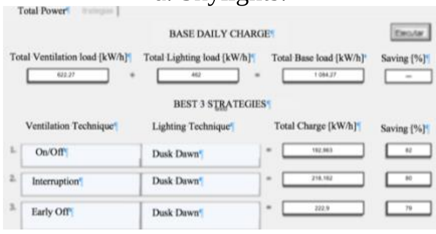
b. Window.



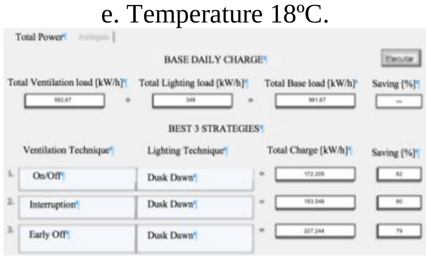
c. Doors.



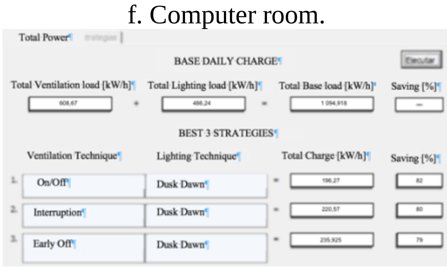
d. Skylights.



e. Temperature 18ºC.



f. Computer room.



g. Auditorium

Fig. 7. Results to specific modifications for a classroom.

Each of the previous modifications changes the total calculated load (see Table 4). Therefore, the change related to the LED lighting shows 16.06% of total load reduction. Similarly, implementing 3 skylights reduce the total load in 2.5%. On the other hand, the resizing of the windows and add doors produced an increase of 8.2 % and 0.5% in the enclosure total load respectively.

The result obtained by the decrease in the working temperature is highlighted; the change of this setpoint incremented the total load in 5.99%. Besides, the purpose changing of the enclosure to computer and auditorium rooms shows both gains and loss in the total load, these changes are more related to the number of occupants and functionalities of the enclosure.

Regarding the automation techniques, they show invariance since the architectural and envelop conditions of the enclosure are maintained. The techniques On-Off for ventilation and Dusk-Dawn for lighting could produce load savings between 82-84% with a similar location, dimensions and characteristics. In short, the envelope of the enclosure is a relevant feature, that directly contributes to the total energy load, following for the equipment's level of efficiency and the kind of control and automation system implemented.

Table 4. Results of specific modifications in the classroom.

Parameter Change	Old classroom		New classroom			Load Change [%]
	Total base load [kWh]	Saving technique	Total Base load [kWh]	Saving technique	Savings for control [%]	
LED lighting	1 022.95	On-Off / Dusk-Dawn	858.57	On-Off / Dusk-Dawn	82	- 16.06
Window to 22 m^2	1 022.95		1 106.96		84	+ 8.21
2 Doors	1 022.95		1 028.16		83	+ 0.5
3 Skylights	1 022.95		1 001.9		83	- 2.05
Temperature 18ºC	1 022.95		1 084.27		82	+ 5.99
Computer room	1 022.95		981		82	- 4.1
Auditorium	1 022.95		1 094.91		82	+ 7.03

5. Conclusions

The application presented in this article is a useful design tool to identify and quantify the effects produced by the implementation of RUE techniques on university campuses. Likewise, the application facilitates the development of sensitivity studies on the total electrical charge of a room, the adjustment of architectural design parameters, the variation of control and automation techniques, the change in the room's microclimate and the application of new technology for the RUE.

Regarding the results obtained after the analyzes carried out in a classroom-type enclosure. It is evident that the implementation of control and automation techniques allows generating energy savings of over 50%. Likewise, factors like place, area, envelope, and orientation of the enclosure represent the greatest contribution to total energy consumption. following for the features of the technology implemented and its controls process.

The variables with greater sensitivity are the physical dimensions, components of the envelops, temperature and relative humidity operation. The optimization of these variables could lead to finding the largest energy consumption savings.

The differences in energy savings between the different control and automation techniques in cooling and lighting systems can be overcome by implementing more efficient equipment and processes.

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