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Impact of the Thermal Load for a Library Model in a Rural Region of Tropical Climate in Mexico

Cesar A. Ramirez[a,*], Gerardo Alcala[b], Jorge A. Andaverde[c], Maria D. Cardona[d], Dario Colorado[b]

[a]Fac. De Ingeniería, Universidad Veracruzana, Av. Universidad km. 7.5, Coatzacoalcos, Veracruz 96538, México.
[b]Centro de Investigación en Recursos Energéticos y Sustentables, Universidad Veracruzana, Av. Universidad km. 7.5, Coatzacoalcos, Veracruz 96538, México.
[c]Fac. De Ciencias Químicas, Universidad Veracruzana, Av. Universidad Km. 7.5, Coatzacoalcos, Veracruz 96538, México.
[d]Programa de Posgrado en Mantenimiento Industrial y Técnicas de Diagnóstico, Facultad de Ingeniería Mecánica y Fabricación, Universidad de Sevilla, Camino de los Descubrimientos s/n, Isla de la Cartuja, Sevilla 41092, España.
ramirez_cesard@hotmail.com

The evaluation and results of a thermal balance is presented for a building located at latitude 18° N, in an intercultural university community in the "Sierra de los Tuxtlas" (Tuxtlas Mountains), southeast of Mexico. The case study corresponds to the main building of the Intercultural University of Veracruz "Las Selvas" which is able to house the library, a center for learning native languages and a computing. In order to maintain thermal comfort conditions in this space, the use of an air conditioning system is required, which works at its maximum capacity, implying high consumption of electrical energy, as well as important maintenance expenses. The objective of this work was to evaluate the thermal load of the building considering the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) methodology in order to reduce the consumption of the electric energy required for the use of air conditioning, which is of vital importance in this tropical zone. In the first stage of evaluation, the following assumptions were considered: (a) the loads related to the glazed enclosures (radiation, conduction and infiltration of air), (b) the effect of the surface of the windows of the different orientations of the building and, (c) the use of solar control films to decrease heat gains. Special care was taken not to make alterations on the infrastructure of the physical space and to not compromise the external environment. In the building that was under evaluation it was found that by reducing the enveloped area of the north and south sections, heat can be minimized and the transmitted visible light required for the development of the occupants' activities is not affected. However, if the enveloped area on the west side is modified, visible light would be compromised. The use of solar control films provides significant benefits because the heat gained by radiation can be minimized by more than 60 %, this is achieved without obstruction the view to the outside nor the visible light required by the occupants to maintain an adequate performance in the development of their activities. If these strategies are implemented, the consumption of electrical energy can be reduced considerably.

1. Introduction

The construction and operation of buildings contribute to a large proportion of the final use of energy in the world; as a consequence, reducing energy consumption in the design and refurbishment of buildings offers opportunities to contribute significantly in savings both economically and reducing emissions of greenhouse gases (Valerie and Guedi, 2009). In fact, one strategy to ensure sustainability is through the increase of actions and techniques of energy efficiency in existing buildings (Abidin et al., 2017). Ma et al. (2012) establish that only in the construction sector, most of the energy is consumed in existing buildings however the total volume of energy has yet not been assessed. Most of the buildings in the world are spaces of excessive energy consumption, either they make an irrational use of it or were conceived with an erroneous design. As an immediate solution to this problem, various scenarios that favor the rapid increase of energy efficiency in existing buildings have been proposed (Roslan et al., 2015), this kind of alternatives are essential for a timely reduction

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of global energy consumption and preservation of the environment, considering this an action that prioritizes the foundations of sustainable development. Several research results converge on the idea that the energy used in the needs of buildings can be significantly reduced, this can be achieved by identifying different areas of opportunity, such as the use of high-efficiency electrical equipment, by the implementation of ground-air heat exchange systems in order to reduce the use of mechanical cooling systems, the use of renewable energies, roofs and green walls, as well by the diagnosis and proper refurbishment following the basic principles for the correct functioning of passive systems, which take into account innovative construction materials for the architectural envelope and the glazed area of the buildings (Griego et al., 2015). The latter is the objective of this research, which is focused on the development of recommendations for the retrofitting of existing school buildings in a rural area of tropical climate, without sacrificing the architectural design on which the original construction was conceived. The authors have focused on the search for solutions to reduce heat gains on the glazed areas of the building, paying special attention in the summer season.

1.1 Case study

The building selected as the study case is located in the municipality of Mecayapan, in the state of Veracruz in southeastern Mexico. Its geographical location is at 18° 9' North latitude and 94° 47' West longitude. Mecayapan is a rural region that has a warm and humid climate with temperatures that reach a maximum of 30 ° C and abundant rainfall in the summer, the climate is influenced mainly by the trade winds of the northern hemisphere being the cause of summer rainfall. This region is characterized by having a clear sky with high solar radiation most days of the year (Gutierrez and Ricker, 2011).
The construction of the building, has an area of 411.97 m^2, consists of concrete blocks, flattened cement and sand, and vinyl paint on the outside and inside the walls. The roof has steel sheets on the outside and thick wood inside the building (typical rural educational construction of Mexico). The study includes the determination of the contribution of heat that is gained through the glazed windows and doors for different configurations, as well as the estimation of the thermal load using solar control protections. The windows of the building are horizontal sliding glass 6 mm thick with a U value of 5.52 W/m^2 °C. The glazed area (windows and doors) is 26.90 m^2 for the north of the building, 44.97 m^2 for the south and 4.24 m^2 for the west, the windows do not have typical solar protections in the interior such as Venetian blinds and fabric curtains. It is important to emphasize that due to characteristics of this type of climate it is difficult to maintain an optimal level of thermal comfort inside buildings without having to resort to artificial ventilated and cooling systems.

1.2 Energy evaluation of the building

In the initial phase of this study, simulations were carried out to determine the heat transfer by conduction and radiation in the glazed areas, later the optimal areas of windows that allow the least heat gain were determined, in the final phase heat gains were determined again considering the optimal area and the use of solar control films. The study has been developed using the energy equations and ASHRAE tables for the solar heat gain and the glass cooling load factor (Hassouneh et al., 2010). The heat gain from radiation phenomena and solar conduction through windows and doors is shown in Eq(1) and Eq(2) respectively.

$$Q_{rad} = (SC)\ (SHGC)\ (CLF)\ (A) \tag{1}$$

For Eq(1), SC represents the shadow coefficient, CLF is the cooling load factor, A is the glass area (m^2) and SHGC is the solar heat gain coefficient (W/m^2) which depends on the orientation, latitude and month of study, this factor is shown in Table 1 according to the ASHRAE Tables.

Table 1: Solar Heat Gain Coefficients for sunlit glass at 18° north latitude May month

Orientation	SHGC $\frac{W}{m^2}$
North	156.06
South	130.83
East	680.94
West	680.94

$$Q_{cond} = (U)\ (A)\ (\Delta T) \tag{2}$$

In the Eq(2) U stands for the global heat transfer coefficient (W/m^2 °C), A for the glass area (m^2) and ΔT is the temperature gradient (°C) between the outside and inside of the physical space. The glazed area variations were made depending on the section that allows the greatest heat gain inside the building, in this case the area of the northern section is ideally reduced by 5 %, in comparison to the southern section which is increased by the same amount, in order to maintain a constant total area that does not affect the light transmitted to the interior. When using solar control films, the energy equations should be used in the same, however when determining the heat gains by radiation in glazed areas it is important to consider the $SHGC_a$, which corresponds to the value granted by the manufacturers (Table 2 for the case presented), in order to obtain the new $SHGC_{II}$ (Eq(3)) in order to perform the relevant calculations.

$$SHGC_{II} = (SHGC)\ (SHGC_a) \quad (3)$$

Table 2: Performance thermal of solar control film

Performance	%
IR Rejection	97.00
U value	1.02
$SHGC_a$	0.39
Total solar energy rejected	61.00

2. Results and discussion

The prevailing climate in the area favors the use of air cooling systems because there is no significant change in temperature and humidity throughout the year (Gutierrez and Ricker, 2011). The gain of heat of greater record is due to the glazed area of the building, the building was evaluated considering the temperature to conditions of the month of May being this the hottest month in the region. The behavior of the increase of heat is observed by means of the glazed areas in the daytime of summer which is 12 h of solar presence in this latitude of the planet.

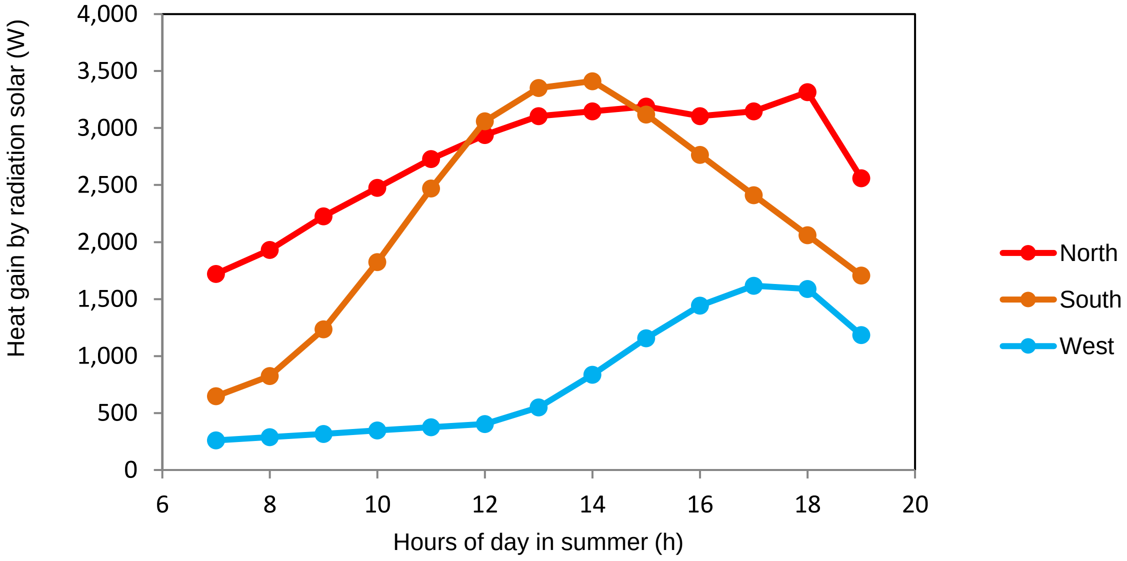

Figure 1: Heat gain due to the solar radiation phenomenon in the building.

Based on the results, the total heat gain by radiation on a summer day has been estimated at 74,848.93 W, in the north and south sections of the building the highest heat gains were quantified, this is due to the larger glazed area, while in the west it was quantified a 29.11 % heat gain compared to the gain of the north. The highest heat gains in the building, where reached at different hours, depending on the orientation of the façade and glazed area. For the north section it occurred at 18:00 h, having a value of 3,316.19 W, for the south section it was at 14:00 h with a gain of 3,412.35 W and for the west section at 17:00 h 1,616.82 W.

For the study case variations were made in the glazed area, it was found that for each 5 % of area that decreases in the north side and increases in the south area, a saving of 915.84 W can be obtained, only for the radiative contribution. The area reductions described were ideally carried out, however, it has been considered that they do not affect the actual proportion of the glazed area of the building or the visible light transmitted so as not to alter the performance of the occupants and the visual comfort (Fasi and Budaiwi, 2015). Table 3 shows the total heat gains in the physical space with variations from 5 to 50 % of the area in the northern section.

Table 3: Heat gains varying the glazed area of the building

Variation of the area (%)	Solar heat gain (W)
5	73,936.49
10	73,017.24
15	72,091.57
20	71,185.56
25	70,237.12
30	69,353.87
35	68,457.75
40	67,522.19
45	66,606.25
50	65,690.50

Taking into account the use of a solar control film, the heat gain can be decreased without the need to reduce the glazed area as the first option when adapting the building due to the significant reduction of SHGC and the overall heat transfer coefficient (U value).
Table 4 presents the results that derive from the effect of the use of solar control films, in comparison when there is no protection against this solar phenomenon in the windows, by showing the highest heat gains in the building for the original configuration.

Table 4: Higher heat gains in the building without solar protection VS with solar control film

Section of the building	Hours (h)	Heat gain by radiation without protection (W)	Heat gain by radiation with protection (W)	Heat gain reduction using solar control film (W)
North	18:00	3,316.19	1,293.31	2,022.88
South	14:00	3,412.35	1,330.82	2,081.53
West	17:00	1,616.82	630.56	986.26

The data shown in Table 4 only represent a sample of all the values previously calculated in the energy evaluation. These values were obtained for each daytime of the summer and for each half hour using polynomial regressions. It is important to note that with the proposed solar control film, 39% of the heat gain in each glazed section of the building would be rejected.
Figure 2 presents the behavior of heat gains by solar radiation using control film in the glazed area of the building and, the case when there is no sun protection comparing the situations of the evaluation and its tendency.

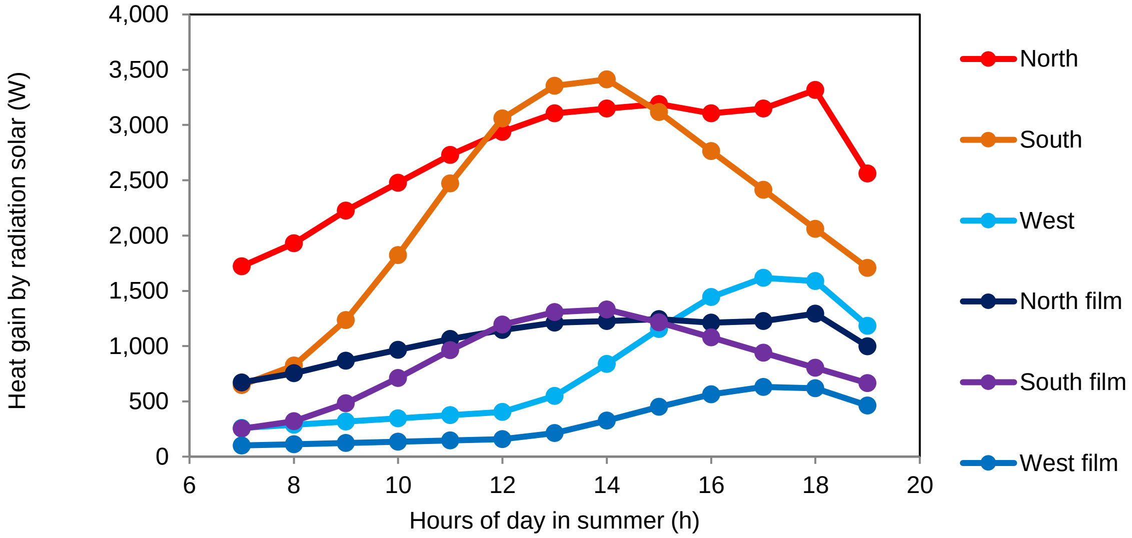

Figure 2: Heat gain by solar radiation solar control film.

The results of the heat gains by means of the windows of the evaluated building are presented in Table 5, at the end the total sum of the heat gains is presented, corresponding to the original configuration of the glazed area of the building.

The southern side is the one with the highest heat gain, however, when the gain is determined with the solar control film, a favorable reduction percentage is observed. This result is important because it was not necessary to reduce the glazed area to obtain a positive value.

Table 5: Results of total heat gain

Concept	Heat gain (W)
Conduction	588.51
Radiation	74,848.93
Infiltration	516.93
Total	75,954.37

The heat gain of the radiation phenomenon is the one that provides the greatest increase in heat within the physical space evaluated, the values of SHGC and the glazed area in the south orientation of the building are two important factors in the result of the heat gain shown in Table 5 and affect the thermal comfort of the occupants, followed by the increase of heat by the conduction that depends directly on the glazed area, the difference of temperatures between the outside and inside of the physical space, the U-value characteristic of the type of glass and finally the infiltration of air, it is important to note that several studies ignore the values of air infiltration due to its low influence on the energy balance of buildings.

Air infiltration can represent 30 % or more of the cooling costs of a constructed space and contributes to problems of humidity, noise, dust and contaminants. To reduce the energy losses due to air infiltration, it is recommended to reduce the glazed area or implement windows that reduce the infiltration or exfiltration rate (Hassouneh et al., 2012).

The results indicate that the heat gains are high in the summer season at the study site, however when implementing control films the heat gains are significantly reduced, as shown for the case of the south and north side which is in where the glazed area is larger and when determining the heat transfer with the control film the results are reduced considerably this implies a benefit in thermal comfort.

3. Conclusions

In this paper, we present a methodology based on the energy equations and ASHRAE tables that allows us to make estimates of heat gains and detect opportunities to implement techniques to reduce thermal load a library scholar rural. The library taken as case study it was built in a rural area where the tropical climate prevailed during most of the year, the presence of temperatures and humid relative high is common a the four stations. Considering the view of Fasi and Budaiwi (2015) and Ma et al. (2012) this research was conducted in a site built taking into account the largest number of real variables.
The results of the study show that the influence of the thermal load inside the library is prevalent in the summer season. It was determined that at least for the studied case by reducing the glazed area of the north section and increasing it on the south, significant energy saving can be obtained in the summer season. This alternative and the use of a solar control film could significantly diminish the thermal load of the building, promoting longer hours of thermal comfort and reducing the use of mechanical cooling systems, as well as the consumption of electrical energy and emissions of greenhouse gases. According to the results obtained, proposals have been made to the directors of the institution as an alternative to a) employ techniques that reduce thermal loads and as a result decrease the consumption of electrical energy and can preserve the thermal comfort of the occupants without damaging the infrastructure of the building, b) the work done can be replicated in various campuses of the Universidad Veracruzana in order to assess the conditions of the buildings and detect areas that reduce thermal loads and make efficient use of both electrical energy and physical spaces taking advantage of the climatic variation of each region of the state of Veracruz to propose alternatives to each region.
It is important to note that although there are several studies on the modernization and conversion of buildings to low-energy criteria in developing countries, comprehensive campaigns between government and society have not yet been carried out, as is the case in Mexico where It attributes to the buildings 19 % of the total energy consumption of the country and it is foreseen a rapid increase due to the social growth and the construction sector (Griego et al., 2015).

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