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Numerical study of the thermal characterization of transparent envelopes for buildings with high energy impact

Estudio numérico de la caracterización térmica de envolventes transparentes para edificaciones de alto impacto energético

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Abstract

This research article presents the results of the energy simulation of a computer room with transparent windows located in the “Y” building of the Technological Institute of Pachuca. To carry out the energy simulation, the EnergyPlus program was used, which is a program to find the energy consumption of buildings. The methodology took into account the real operating conditions of the Computer Center, it was found that it has 20 desktop computers for students with computer spaces of 0.8m x 0.5m for each computer and the space for the teacher and his computer of 1m. x 1.3m, two office computers, an air conditioner with basic level climate control characteristics that ensures an average temperature between 64.4 degrees Fahrenheit and 86 degrees Fahrenheit, with variations of less than 4.1 degrees Fahrenheit per hour. The climate data of the City of Pachuca de Soto Hidalgo were taken into account. In this study the methodology is described, an achievement of a significant decrease in energy expenditure was shown.

Energy plus, Energy efficiency, Envelope, Building

Resumen

En el presente artículo de investigación se presentan los resultados de la simulación energética de una sala de cómputo con ventanales transparentes localizada en el edificio “Y” del Instituto Tecnológico de Pachuca. Para realizar la simulación energética se empleó el programa de EnergyPlus, que es un programa para encontrar el consumo energético de edificios. En la metodología se tomó en cuenta las condiciones reales de operación del Centro de Computo, se encontró que tiene 20 computadoras de escritorio para estudiante con espacios de las computadoras de 0.8m x 0.5m de cada computadora y el espacio del profesor y su computadora de 1m x 1.3m, dos computadoras de oficina, un aire acondicionado de características de nivel básico de climatización que asegura una temperatura promedio comprendida entre los 64.4 grados Fahrenheit y los 86 grados Fahrenheit, con variaciones inferiores a 4.1 grados Fahrenheit por hora. Se tomaron en cuenta los datos del clima de la Cd. de Pachuca de Soto Hidalgo. En estes estudio se describe la metodología, se mostró un logro de la disminución significativa del gasto de energía.

Energy plus, Eficiencia energética, Envolvente, Edificio

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Introduction

What is energy efficiency?

Overheating in buildings with transparent building envelopes is a growing problem in many countries with different climates, improving the thermal performance of buildings during the heating season has led to overheating problems, making it increasingly important that buildings are optimised for heating and cooling efficiency [1].

As society is advancing at a high speed, the production of all kinds of products is increasing day by day and although it is now becoming a habit to recycle, there is another method of contributing to the sustainability of the planet: energy efficiency. We are not fully aware of how much energy we waste on a daily basis and where this energy comes from. However, we are aware of how important it is to reduce our consumption in general and how much we humans pollute.

Figure 1 World Energy Efficiency Day
Source: Mutua Universal

Technological advances have changed the way human beings work in general. In the past, all procedures had to be carried out personally and took a long time, but with the evolution of the computer, it has been possible to minimise the effort and time required to carry out tasks and processes. In recent years, important experiments have been carried out to incorporate technology in education, with the aim of improving the teaching-learning process, which is one of the essential variables to take into account when we want to achieve significant learning in students, and it is important to be aware that the classroom is one of the most important factors that will greatly influence whether the objective is achieved or not. When planning a class or designing a syllabus, the available infrastructure must be taken into account, because without it there is no point in having the best syllabus.

To such an extent, it can be affirmed that there are very few institutions, both public and private, where computers are not at the service of teaching practice.

And because computers have become an indispensable tool for any professional and even for everyday life, as well as the importance of computer centres in any educational institution, there are also several problems in these computer centres, as the cost of having a computer centre in optimal conditions is currently very high. Periodic updates and maintenance of the equipment are required, as well as having a person who is continuously performing these functions, which leads many educational centres to offer slow and obsolete equipment to the student. Another very important expense is the use of electrical energy; on average, a CPU uses 500 W, which has a considerable impact on the electricity bill, as well as the acclimatisation and uniformity of the interior temperature of some schools.

The temperature uniformity inside some computer centres, which is necessary for the proper functioning of the computer equipment, should ideally have equipment that is not noisy, with a capacity to support the heat produced by all computers, as well as the occupants to have and thus have a certain degree of thermal comfort.

Figure 2 School control system
Source: SisteMéxico

Therefore it is very important to take into account the Energy Plus software as it gives details of the thermal behaviour in a building and thus it is possible to avoid overheating by reducing the thermal loads and to obtain energy efficiency.

Theoretical framework

In the following, we are going to present several studies that have been found in the literature that are related to the topic of this research report. The first article shown is the one reported by Xie, et al. [2], in which they show a method to simulate occupancy and air conditioning that integrates the occupant behaviour model with a modified distributed air conditioning system in Energy Plus.

They used the Markov Chain method and a stochastic Monte-Carlo model to simulate occupancy and set-point adjustment. The results of their study show that significant differences (7.86%) in energy consumption results can be observed between the original and the modified model.

In the study by Uribe et al. [3], they investigated that in an academic building of a higher education institution they carried out a detailed study of lighting intensities or the correct location of the intensities, so an architectural survey of the building was carried out in order to analyse it through a simulation. The lighting intensities were found in all areas of the academic building using the luminaire simulation program. The results showed that energy consumption could be reduced by 15%. This represented a large reduction in electrical energy consumption.

In the case of Nelson et al. [4] they studied the Energy Initiative for Sustainability at the University of Coimbra, Portugal. They conducted a monitoring campaign to measure and disaggregate electricity consumption. It also evaluated natural gas and water consumption. They also evaluated the building envelope and the heating and lighting systems. They investigated some patterns of environmental energy behaviours of the academic community through a web-based survey. The results showed a reduction in consumption of about 26,123 kWh/year, avoiding the emission of 3,704 $kgCO_2$/year, with an initial cost of 9,920 euros.
In the study by Lores et al. [5] they analysed multi-way principal components. This approach allows defining simple statistical indices T2 and SPE to be used in monitoring charts. These indices are used to detect abnormal behaviour on time scales.

After detection, a contribution analysis is performed to isolate the variables responsible for the misbehaviour. The exploitation of such models, obtained under normal operating conditions, can be used to detect both sensor failures and misbehaviour in energy consumption patterns in the case study focused on academic buildings located on the University of Girona Campus.

The need to reduce the energy requirements of lighting systems should provide engineers with a more mature and conscious vision during planning and this means that their main objectives should be visual comfort and energy efficiency. In the study by Ferdinando et al. [6] he examines the case study of a classroom located in the Faculty of Engineering of the Sapienza University of Rome and, in order to evaluate the possibility of combining natural and artificial light, he focuses on the realisation of a new lighting system. This new solution is made up of LED sources and control systems, resulting that there are payback periods that justify the higher costs presented by the electronics that characterise the control logic system.

Researchers Amy et al. [7] in their study comment that educational buildings, the third largest consumer of energy in the United States, provide significant opportunities to reduce greenhouse gas emissions by increasing energy efficiency because heterogeneous buildings consume a lot of energy, such as laboratories, medical research facilities, sports facilities and food. They deduced that there is a great opportunity to conserve energy by retrofitting these buildings. They concluded that through content analysis of the data they identified decision factors that fall into five main categories: economic feasibility, environmental impact, institutional characteristics, occupant impact and technical practicality, for retrofitting these buildings.

In the study of Joonho et al. [8] they estimated the energy efficiency of educational buildings with the case study of buildings in City University of Hong Kong by constructing a stochastic frontier model of energy demand. The model was estimated using university statistical data from 2011 to 2015.

For a constant data frequency among the variables, they adopted the quadratic sum method to convert the annual university report data into a monthly dataset. With results showed that the average energy efficiency is 0.87, which implies that 13% of the total energy consumption can be saved.

Indoor air quality is an issue of great concern for human health, as people spend most of their lives indoors in the study by Ayesha et al. [9] aimed to investigate and compare the air quality and thermal comfort in classrooms of four buildings of an educational institute that have different types of heating, ventilation and air conditioning systems. Through simultaneous measurements of outdoor temperature and relative humidity and statistical analysis. As a result, it was found that the exceedance in CO2 levels of ASHRAE standards was higher in buildings with non-centralised systems compared to buildings with centralised systems during the occupational period. In addition, it found that thermal comfort parameters are influenced by outdoor climatic conditions and building orientation.

In the work of Mohd et al. [10] he presents the potential savings for achieving energy efficiency in academic building through optimisation and operational strategies. He used several existing analytical tools, such as ASHRAE CLTD/CLF, lumen method, net present value and cost benefit ratio. Its results showed that the use of air conditioning, lighting and appliances can be reduced by 12%, 52% and 40%, respectively.

Energy efficiency has now become one of the most challenging tasks for academic and commercial organisations, and this has prompted research in novel fields. In the study by A. De Paola et al. [11] they addressed the issue of timely and ubiquitous monitoring of building complexes, in order to optimise their energy consumption, with an intelligent user-driven system, and concluded with a design of a three-tier architecture to detect the user's presence of inhabitants in the building and understand their preferences regarding environmental conditions in order to optimise the overall energy efficiency of buildings.

In research by Mehreen et al. [12] conducted a pilot study to analyse the relationship between electricity demand profiles and the activities of the users of a university building. To obtain information on how the building is used, operated and managed on a daily basis, an online questionnaire was distributed to staff and students, as well as interviews conducted with key management personnel. And conducted an analysis of half-hourly electricity demand data for the case study building to identify key trends and patterns in energy use. It concluded that detailed information on occupancy patterns could help the management team redesign control strategies for optimal building energy performance.

Energy efficiency as a concept brings together actions that are taken on both the supply and demand side, without sacrificing welfare or production, allowing for improved security of supply. It also achieves savings both in energy consumption and in the economy of the general population. Simultaneously, reductions in greenhouse gas emissions and improvements in the finances of energy companies are achieved [13].

The researchers A. Boyano, et al. [14] presented energy usage figures and gave a potential energy saving strategy for office buildings. By simulating various scenarios. With their results of Energy Plus simulations of an office building which can be considered as a representative office building in the whole of Europe.

According to the mentioned research a good energy efficiency study can give a certain % of savings and this percentage can be higher by using, implementing passive elements and a % in decreasing the 〖CO〗_2. Also, it could be observed that in the analysed works, some strategies are proposed to improve the efficiency of HVAC systems such as the use of energy technologies, the improvement of control systems, the use of energy efficiency control systems and the use of passive elements.

Energy Plus Methodology

In academic institutions there are buildings that consume more energy, for example, computer centres, in most cases there is no adequate study to have the highest energy efficiency of these facilities therefore there is a certain deficit in electricity consumption and at the same time thermal comfort. In the present research report, the aim is to reduce the energy consumption in the study laboratory and to improve the thermal conditions of the space occupied by the students, as well as the office attached to the computer centre.

Several computational energy tools have been found that allow the energy consumption of buildings to be established from detailed architectural models, taking into account information on equipment including computers, air-conditioning, lighting, etc. In this way, it is possible to modify the models for more efficient operation of the buildings prior to their construction.

One of the best computational tools used for this purpose is Energy Plus, which has been found to be a whole-building energy simulation program that is used by various professionals such as engineers, architects and researchers to model energy consumption for heating, cooling, ventilation, lighting, process and unregulated loads as well as water use in buildings.

What is Energy Plus?

The Energy Plus software is a calculation engine used to run energy simulations of buildings, it is a structured collection of analytical modules that evaluate the different associated models of a building, the analytical modules were developed by researchers for private and governmental institutions worldwide, through these procedures it is possible to take highly detailed descriptive input data of a building and generate data of the thermal conditions of the building and its surroundings, Energy Plus performs 2 types of simulations the simulation of mass and heat balance and simulation of building systems as shown in figure 3.

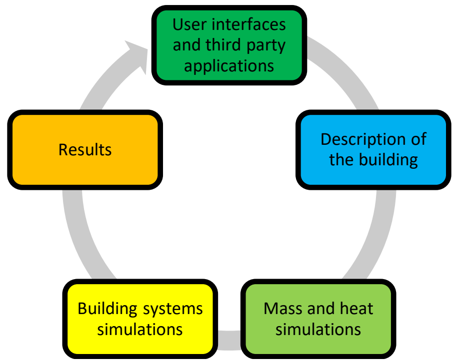

Figure 3 Energy plus simulation types
Source: (own figure)

Energy Plus is for modelling both the energy consumption of heating, cooling, ventilation, lighting, process and unregulated loads and water use in buildings of its most widely used and notable capabilities:

Simultaneous and integrated solution for heat zone conditions and HVAC system response.

Solution based on thermal balance of radiant and convective effects producing surface temperatures, thermal comfort and condensation calculations.

Combined heat and mass transfer model that considers air movement between zones.

Lighting and glare calculations to inform visual comfort and driving lighting controls.

Component-based HVAC that supports standard and novel system configurations.

Energy Plus is a console-based program that reads its input data and writes the results (output) via text files. In addition, it uses the Garbage in, Garbage out philosophy, which refers to the fact that the quality of the output depends on the quality of the input data. Thus, for example, if a program is fed with incorrect information, it is unlikely that its output will be useful or even informative.

Study geometry

The geometry should be built in 3D using the tools of Open Studio and Energy Plus through the software Sketch Up in this study should be made of a computer centre for academic purposes in which should have 20 computers 8 windows and have an office and have 2 computers, as well as having a HVAC system.

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At the beginning, the computer centre space should be 10m x 6m and the office space should be 3m x 3m.

With the Open Studio tool, the elevation is made by selecting the area of the computer centre and the office and indicating that it should be 3m high.

We start with the computer centre and select to build the main door of 2.5m x 1m with the Sketch Up tool and in turn the 8 windows of 1m x 2m, as well as the door to the office of 2.5m x 1m and the computer spaces of 0.8m x 0.5m for each computer and the space of the teacher and his computer of 1m x 1.3m as shown in Figure (4).

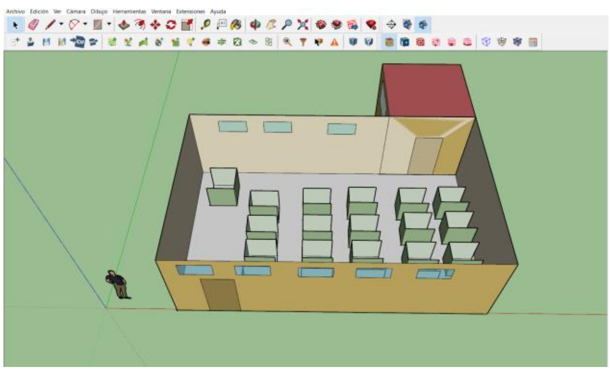

Figure 4 computer room space

In the office part of the office, the surfaces must first be matched with the Energy Plus tools so that the software takes into account the interaction of the door between the computer area and the office and does not take it as if it were outside, then the two windows of 2.5m x 2m are added with the Open Studio tools and the space of the two computers of 1m x 0.8m as shown in figure (5).

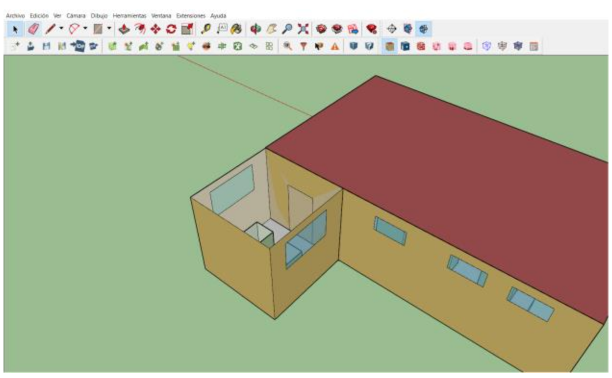

Figure 5 office space

Figure 6 shows the complete geometry as seen from the outside of the analysis building.

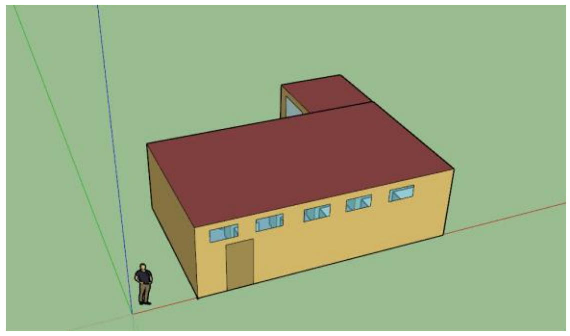

Figure 6 Complete geometry

Supplementary data for the simulation

The program is run with the climate data for the year in the desired region and displays the series of calculations in the form of tables and graphs of the 3D geometry, as well as the data entered.

Climate file

First you must add the desired climate data in an annual period in epw format as shown in figure 7, in this case the climate data for Pachuca de soto, Hidalgo for the year 2020 was used.

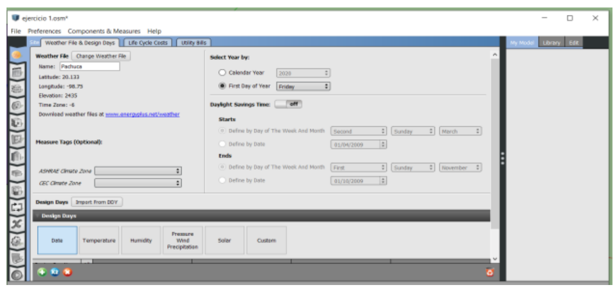

Figure 7 Climate Data Archive Addendum.

Input data

For electrical equipment, the data should be inserted either in general or per unit for the consumption of the computers, which is approximately 500w per computer, as well as for the luminaires, HVAC, etc. As shown in figure 8.

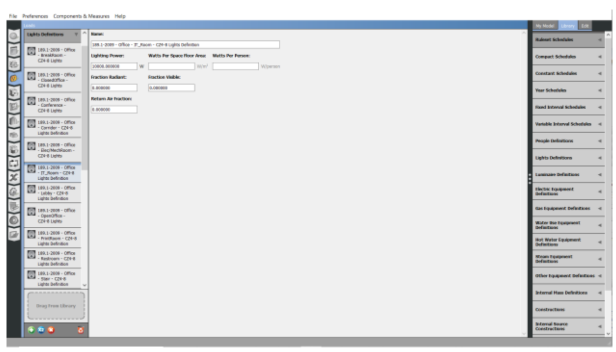

Figure 8 consumption data of computers in the computer room and in the office

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Analysis of results

Once the simulation is finished and verifying that there is no error, we will obtain a report of the geometry performed, as well as detailed graphs.

The first graph in figure 9 shows the behaviour of the air temperature in the student area of the computer centre during the period from January to December 2020 in Pachuca de Soto Hidalgo. It is worth mentioning that this area is conditioned with an HVAC. In the side section of figure 9, the range of temperatures reached is shown, which varied from approximately 71.5°F to 73.3°F and it can be observed that in some weeks, in March and May, the maximum temperature was obtained.

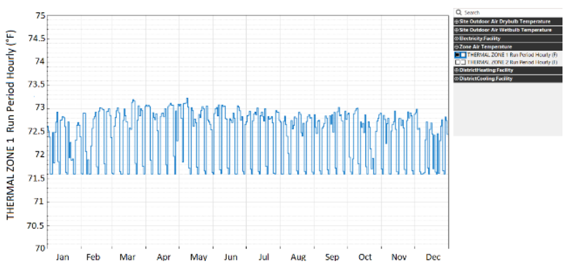

Figure 9 Approximate air temperature in the computer centre on a weekly basis

In figure 10, the behaviour of the air temperature in the student area of the computer centre is presented in a monthly average and it is worth noting that in the year 2020 in the computer centre the highest temperatures were in April and May with an average temperature of 72.6 degrees Fahrenheit and it can be observed that January and December were the months with the lowest average temperature with 72.3 degrees Fahrenheit.

Figure 10 Approximate air temperature in the computer centre on a monthly basis

As can be seen in figure 11, it gives the data in the form of a graph of the air temperature in the office attached to the computer centre, this office is not air conditioned, so it can be seen that there is a much more significant variation in the weekly temperatures of approximately 59.8 degrees Fahrenheit to 78 degrees Fahrenheit over the period January to December.

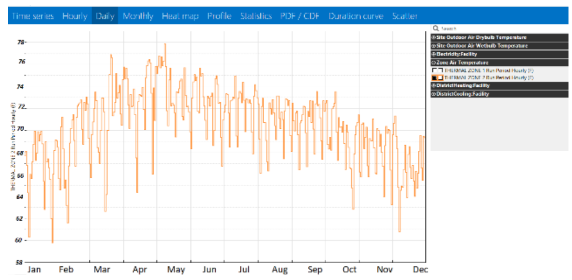

Figure 11 Approximate office air temperature on a weekly basis

With the graph in figure 12, the monthly temperatures were arranged and it was observed that the month with the highest temperature in the office was May with an average temperature of approximately 73.5 degrees Fahrenheit, while January and December had the lowest temperature with an approximate 66.9 degrees Fahrenheit.

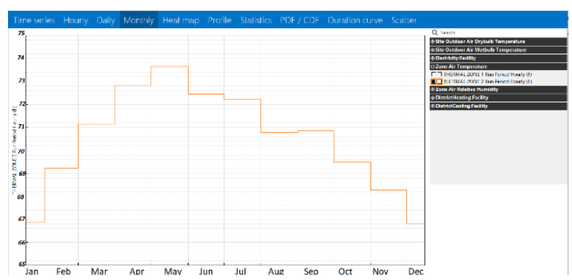

Figure 12 Approximate office air temperature on a monthly basis

As you can see in Figure 13, and Figure 14, a 24-hour heat map for the period January to December 2020 yielded an image in which it is possible to distinguish different shades of colour depending on the relevance of the area.

Normally, warm colours are always used for their representation, which usually follows the following criteria:

Red, orange and yellow tones for the areas with the highest temperature. The higher their intensity, the higher the temperature at that time of day.

Green and blue tones for areas with lower general temperature.

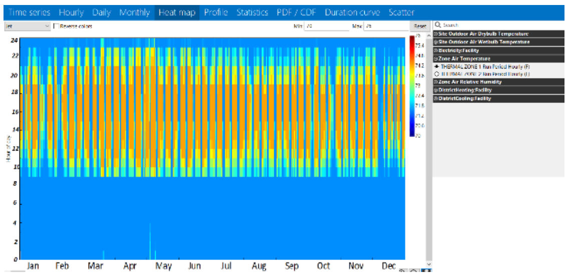

Figure 13 computer centre heat map.

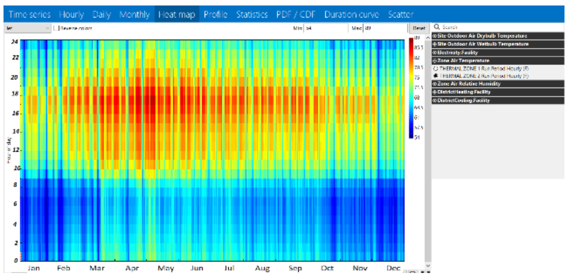

Figure 14 office heat map.

In figure 15, the total average weekly energy consumption of the building in the period January-December can be observed and can easily be seen to vary from 4500 Wh to 16100 Wh.

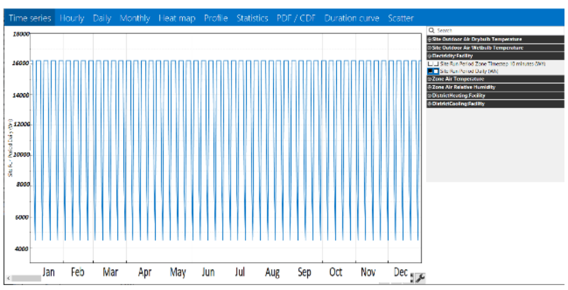

Figure 15 total average weekly energy consumption of the building

Figure 16 shows the total monthly average energy consumption of the building and shows that the month of May together with July, which had the highest temperature, had the highest consumption with an average of 13600 Wh and the lowest consumption was June with an average of 12,900 Wh.

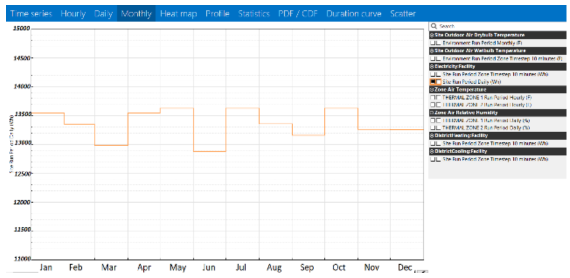

Figure 16 total average monthly energy consumption of the building

Proposed improvement

In figures 17 and 18 we added 4 small windows that can be opened to the computer centre and 2 to the office to add more ventilation and by being close to the floor we can have some ventilation near the CPUs of the computers and therefore avoid that they heat up and that the internal fans of each computer do not work at their maximum power.

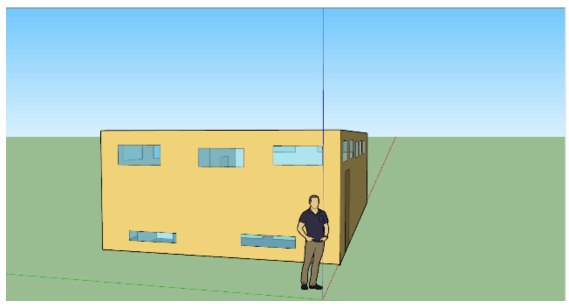

Figure 17 view of 2 additional windows to the computer centre.

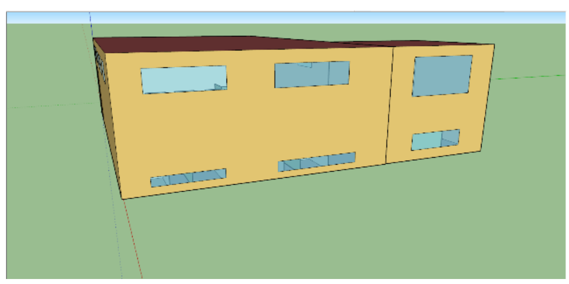

Figure 18 view of the extra windows in the computer centre and the office

Analysis of the results of the improvement proposal

Figure 19 shows the graph of the energy consumption with the extra windows per week in total for the building in the period from January to December and shows that it ranges from 4400 Wh to 14900 Wh on average.

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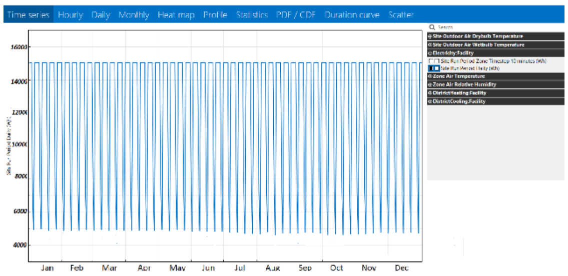

Figure 19 energy consumption with the extra windows weekly in total building

Figure 20 shows the energy consumption with the extra windows on a monthly basis and shows that there is a small but significant reduction in the hottest months and where the most energy was consumed now on average was 12800 Wh and the months with the lowest consumption was 12000 Wh on average for the total building.

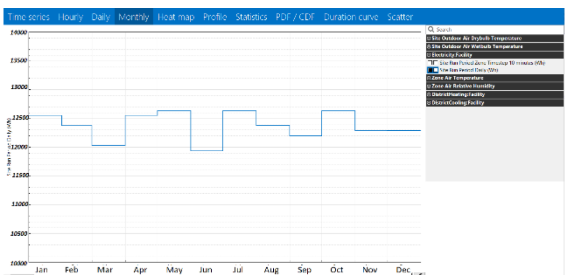

Figure 20 energy consumption with extra windows per month

In figure 21, a comparative graph of the monthly energy consumption of the study building can be seen on the left side the consumption of the building without the proposed improvement and on the right side the consumption with the proposed improvement of the extra windows for better ventilation and it is shown that there is a reduction of 1000Wh per month with the improvement.

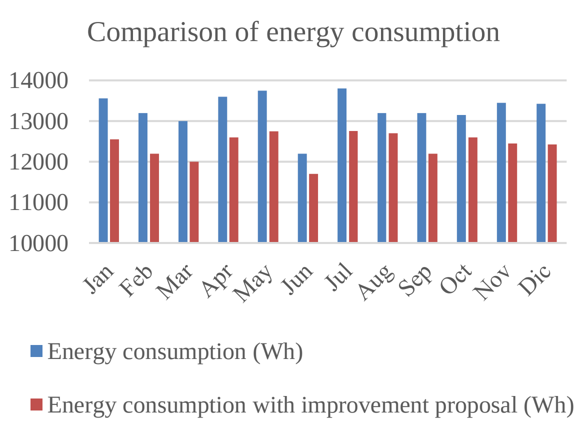

Figure 21 Comparative graph of energy consumption on a monthly basis

Conclusions

With the above studies, the use of the Energy Plus software becomes relevant as it showed that there are reductions in energy costs and significant savings, as well as a detailed demonstration of the behaviour of air conditioners and transparent envelopes as they affect thermal comfort.

The hottest month was May in both the computer centre with 73.3 degrees Fahrenheit. In the office with 78 degrees Fahrenheit. The total consumption was 13600 Wh. And the month with the lowest temperature was December with 72 degrees Fahrenheit in the computer centre and 66.9 degrees Fahrenheit in the office, with a total consumption of 12,900 Wh. The computers as a whole have the highest consumption at 500W per computer.

There are different ways to reduce the energy consumption, for example, if possible add more windows, change the windows for double glazed ones, change the lighting for the latest LED technology, change the old computer equipment, usually basic computer equipment, for better equipment with good internal ventilation systems. All this reduces energy consumption during periods of use.

This was demonstrated with the proposed improvement by adding extra windows, which provided better ventilation to the CPU's of the computers and prevented them from heating up to the point where the internal fans had to work at maximum power and a reduction of 1000 Wh per month was observed.

Acknowledgements

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