Promotion of Energy Efficiency Measures in EB23 Conde de Oeiras School

Luigi Tedesco

luigi.tedesco@tecnico.ulisboa.pt

Instituto Superior Técnico, Universidade de Lisboa – Portugal

November 2019

Abstract

The present study aims to identify a systematic approach to promote adequate energy efficiency measures for *Escola Conde de Oeiras,* a lower secondary school (5th and 6th grade) sited in Lisbon district. To pursue this purpose, it was carried out the detailed study of its principal facilities in three main phases, namely: *creation of the geometrical model* with *Google SketchUp* and *OpenStudio*, *dynamical thermal simulation* of buildings with *Energy+*, *results analysis*. Outcomes proved that thermal discomfort is mainly induced by excess of solar gains and poor insulation degree caused by glass surfaces. Therefore, it was shown that all the thermal zones do not comply with comfortable acceptability limits provided by ASHRAE-55 2017 standards. Once assessed the performance of three new type of double-glazing systems, it was identified as the best option the installation of *selective low emissivity* glass with a *thermal break aluminium frame.* Indeed, with this new type of fenestration it was estimated an average of 30% less time of discomfort in four of the six buildings examined. In addition to this first measure, it was study, for various thicknesses of expanded polystyrene (EPS), whether the realisation of thermal coat could provide benefits or not. What emerged was that only for one type of building, namely pavilions A,B, C, it was advantageous to install 12cm of EPS insulating layer. Finally, it is proposed a simplified business plan of a long-term investment which targets to achieve the condition of energy independence. This includes the design of a 150-kW photovoltaic plant that could supply 261 MWh per year, enough to satisfy the 95% of the future school needs.

Keywords: School buildings, energy efficiency measures, Energy+ simulation software

1 Introduction

Despite being apparently in good condition, *Escola Conde de* Oeiras, a lower secondary school in Lisbon district, has some critical inefficiencies which affect significantly thermal comfort of students, employees, staff members and electricity and gas consumption. As a prevailing aspect, many constructive elements have never been replaced since 1982, year in which the school complex was built, and they are now facing their natural decay. The most practical example is represented by doors and windows: poor sealing, low degree of insulation and sometimes their complete inoperability are the most are the most frequent cause of uneasiness. Besides, glass surfaces are obsolete and therefore the excess of solar gains may be unbearable during the hottest months. All these factors converge towards the main issue that is, essentially, thermal discomfort. Aiming to provide reasonable options to enhance the current condition, it was planned a systematic path which consisted in three phases:

1. Development of the virtual geometric model of the buildings which are part of the school complex through the collection of all the most useful pieces of information regarding: materials of the constructive elements, people activity in the facilities, presence of electric equipment etc.
2. Exportation of the created geometry into a thermal simulation software environment.
3. Outcomes analysis and comparisons.

Thus, all the possible options were assessed both in a thermal comfort enhancement and economic perspectives.

2 Methodology

In this passage, are presented tools and models which characterized the methodology adopted to carry out simulation of buildings thermal performances.

Phase 1 - Geometry creation and workflow description

In the initial phase it was indispensable to reproduce the geometry of the school buildings in a virtual environment. To accomplish that it was made use of *SketchUp*, a 3D modelling computer program with an extremely intuitive interface (Fig. 1).

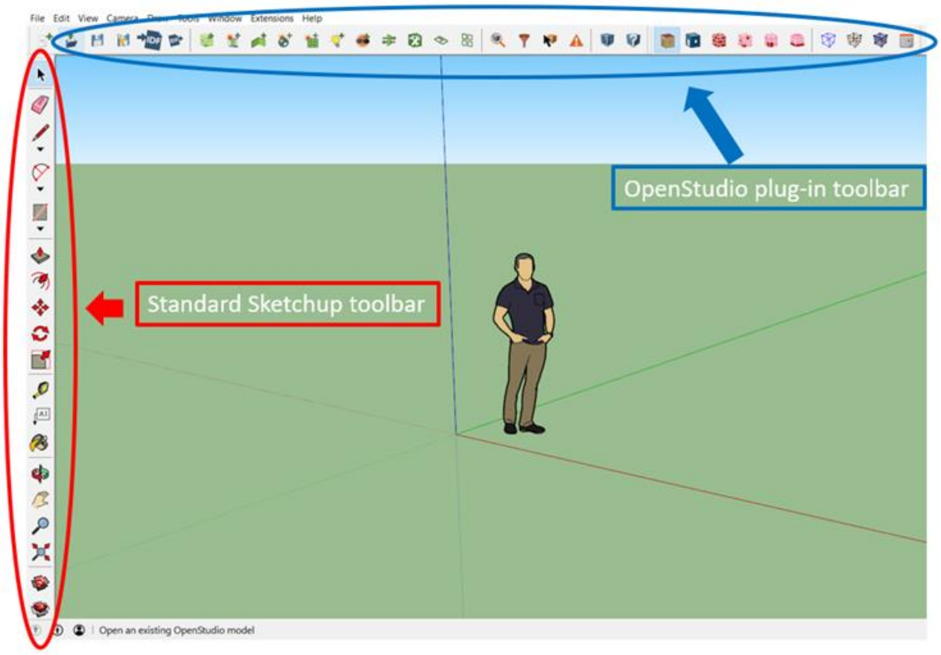

Figure 1 - Google *SketchUp* interface with its OpenStudio plug-in.

Among the advantages offered by this 3D modeler, there is the possibility to interact with *OpenStudio*, which is one of its numerous plug-in. It works as a link between *Energy+* (the fundamental software adopted for the thermal simulations) and *SketchUp.* In particular, it allows the user to input several parameters like materials, constructive elements and schedules, directly from *SketchUp* environment.

To give a more practical explanation of the workflow, its main steps are summarised as follow:

1) Geometry is created within *Sketchup* environment (buildings arrangement, walls, windows disposition etc.);
2) All the enclosed spaces become *thermal zones*. This is done with the proper function available in OpenStudio plug-in toolbar present in Sketchup environment;
3) *Construction names* are assigned to the surfaces. All the thermal zones have at least 3 types of surfaces (ground, walls and roof). To do thermal simulation is fundamental to assign to every surface his construction name. A construction is an ordered set of layers each representing a material.
4) Once the thermal zones and the related surfaces are defined, it is possible to export the model as a file with .idf extension. This is the final file that will be processed with Energy+ software.

Phase 2 – Thermal balance in *Energy+*

Once the geometry was completely defined, the model created on *SketchUp* was exported as an .idf file. Hence, it is possible to open it in the *Energy+* environment and enter all the parameters needed. This software will compute the thermal balance for each room of each building in a certain period, set by the user. To give accurate results, the simulation requires several inputs which must be consistent with each other. In this regard, the logic adopted for the definition of the parameters required by Energy+ was based on the idea of computing a thermal balance on very simple control volumes, like a small isolated room. Hence, according to [1], four mechanisms were considered:

- heat gains/losses through the envelope due to conduction, convection and radiation.
- air mass balance influenced by natural ventilation and infiltration;
- solar gains, which intensity varies with seasonality;
- internal gains related to people occupancy and presence of electric and gas equipment.

Data about materials, activity schedules, and equipment energy use, was obtained through measurements and observations carried out *in situ*.

Having the four mechanisms defined, the weather file was selected and then the simulation was ready to be finalised through the *Energy*+ launch menu.

Phase 3 – Selection of thermal comfort assessment model

Since one the main purposes of the study was to promote measures that could enhance the current thermal discomfort status, the last phase consisted in the selection of the most adequate model to assess the ongoing conditions.

Two models, referenced by ISO and ASHRAE standards, were compared, namely: *Predicted Mean Vote* (PMV) and *Adaptive*. As various authors [2] sustain, the latter should be preferred to the former because it takes into account the human body adaptation to climate and for this reasons it tends to guarantee more accurate previsions. Given these premises, adaptive model was chosen. Successively, in each of the thermal zone defined in the reproduced geometry of school facilities was verified the presence of discomfort conditions. This was done defining the *People* object in *Energy*+ environment.

Once set the field *Thermal Comfort Model* to *AdaptiveASH55*, the software gives as output the number of hours that are outside 90% and 80% acceptability limits according to ASHRAE-55 2017 standard.

3 Case study

Built in 1982, *Escola Conde de Oeiras* (Fig. 2) is a lower secondary school complex of 6 buildings located in Lisbon district, consisting in: *Administrative pavilion* hosting offices and library (P.A.), *Canteen*; *Gym* (not treated in this study); *Pavilions A, B, C* with classrooms.

Figure 2 - *Escola Conde de Oeiras* view 1. Source: Google Earth Pro; year: 2018

Each of these facilities was examined in terms of people occupancy, scheduled activities (lectures, working hours, dining time) and energy use. Successively, data on Specific Energy Consumption of the entire complex was gathered and compared with the benchmark [3] discussed in section 2. A summary is provided in table 1.

Table 1 - Specific Energy Consumption comparison.

	Escola Conde		Reference(***)
Year	2017	2016	2008
Electricity billed consumption [kWh]	155250	160998	/
SECelectricity [kWh/m2/year](*)	28.37	29.42	16.18
Avg. n° of students (**)	787	809	1179
SECelectricity per student [kWh/student]	197.3	199.0	286.5

(*): *Escola Conde* Gross Floor Area = 5473m2; including all the facilities (also the gym and football pitch)

(**): Calculated averaging data of two consecutive school periods

(***): Average values for the 57 schools discussed in chapter 3, before their complete refurbishment

4 Outcomes of simulations

In the initial set of simulations were compared the performance of the buildings before and after they were subjected to roof cover replacement[1], in August 2019. Results highlighted a modest percentual reduction of discomfort time, especially in pavilions with classrooms (Fig. 3). This was mainly due to the improved airtightness of the roof and to its better degree of insulation.

Similar improvements in the of 2-3% range were observed in *Administrative pavilion.*

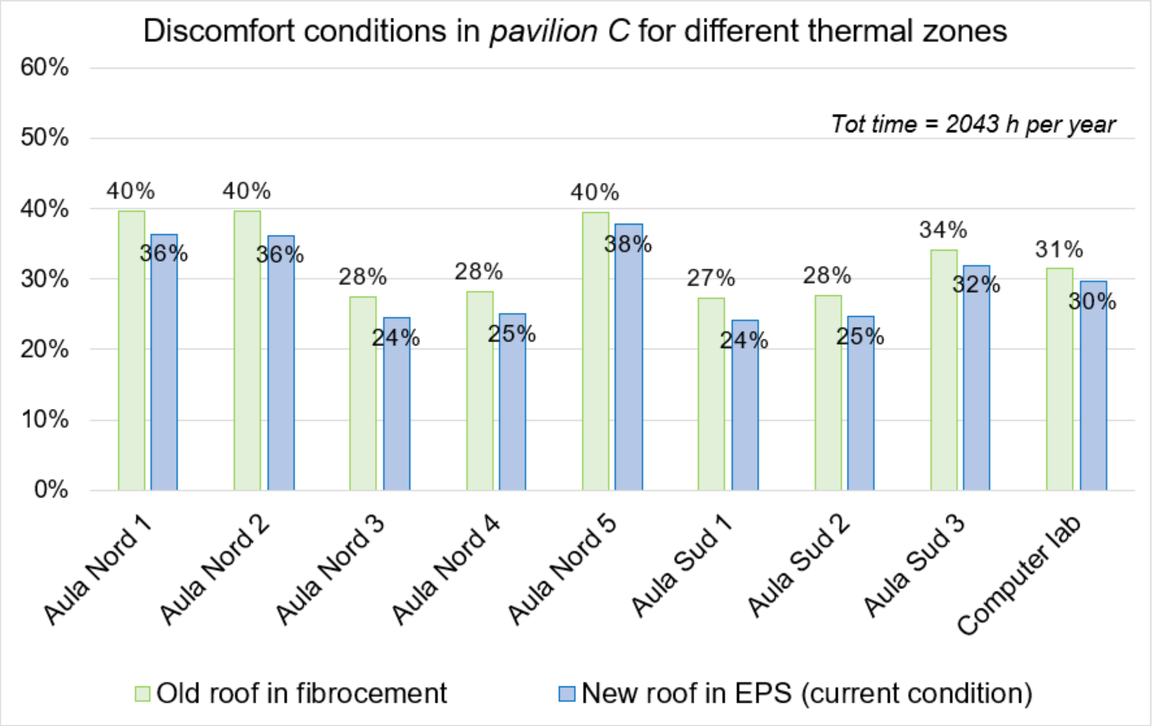

Figure 3 - % of time out of 80% acceptability limits defined by ASHRAE-55 2017 standards.

---

[1] Old roof covers of *P.A.* and *pavilions A, B, C* in fibrocement were replaced with a new one made with 6cm expanded polystyrene. Replacement did not occur in *Canteen* building.

In any case, the most valuable information was found consulting the annual thermal balance of each buildings. In fact, it was proved that factors with the greatest influence in the balance are _heat addition/removal through the windows_, _Infiltration heat removal_ and _Conduction heat losses_. The example of *pavilion C* is reported below.

Table 2 - Extract form *pavilion C* annual thermal balance.

Extract from *pav. C* annual thermal balance	
HVAC Zone Eq & Other Sensible Air Heating [kWh]	0
HVAC Zone Eq & Other Sensible Air Cooling [kWh]	0
People Sensible Heat Addition [kWh]	23821
Lights Sensible Heat Addition [kWh]	1181
Equipment Sensible Heat Addition [kWh]	10089
Window Heat Addition [kWh]	116565
Infiltration Heat Addition [kWh]	905
Opaque Surface Conduction and Other Heat Addition [kWh]	1153
Window Heat Removal [kWh]	-33659
Infiltration Heat Removal [kWh]	-61428
Opaque Surface Conduction and Other Heat Removal [kWh]	-58627

Since these were suspected to be the principal causes of thermal discomfort, it was consequently decided to define some countermeasures to tackle the problem.

In the first place, were examined three different alternatives of argon-filled double-glazing systems to replace the current windows in all the facilities. Among all, the one that could provide either a thermal comfort condition enhancement or an economic[2] benefit was the *selective low emissivity double glazing system*[3]. Results are shown in Fig. 4, 5 and 6.

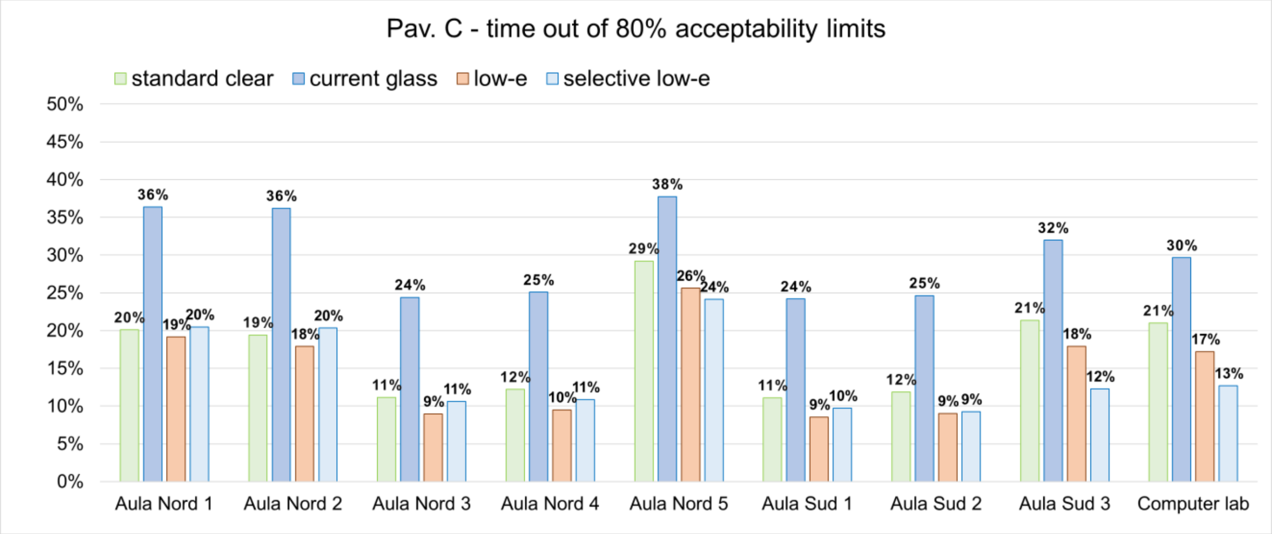

Figure 4 - Thermal discomfort condition in *Pav. C* thermal zones for the examined double-glazing systems

---

[2] Quantified through savings due to reduced cooling and heating needs.

[3] *Selective Low e* presented the following characteristics: Solar Heat Gain Coefficient = 0,4; Visible Transmittance 0,6; U=1 $W/m^2/K$. Source: Pilkington catalogue.

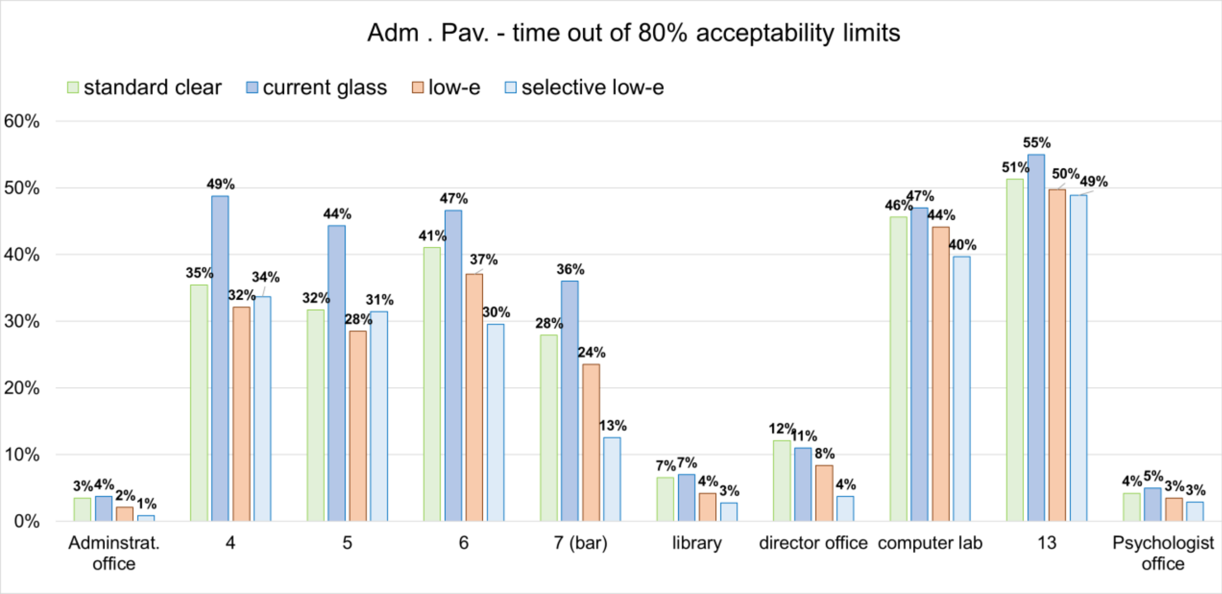

Figure 6 - Thermal discomfort condition in *Adm. pav.* th. zones for the examined double-glazing systems.

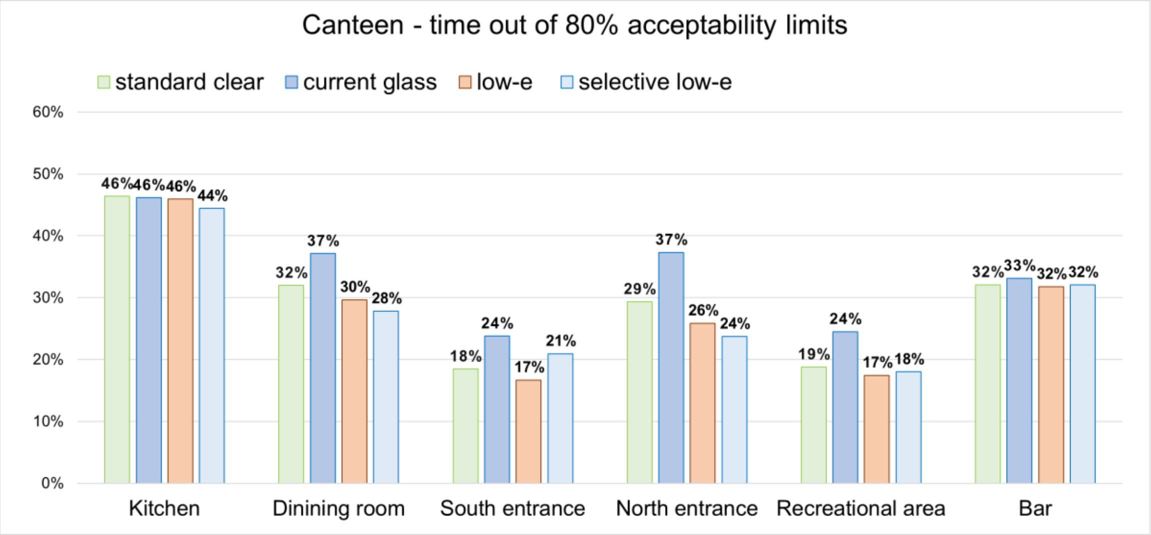

Figure 5 - Thermal discomfort condition in *Canteen.* th. zones for the examined double-glazing systems.

As it can be noticed in Fig. 4, 5, 6, benefits were not equal for all the buildings. This was expected to be due to:

- diverse window/wall (w/w) ratio: *pavilion C* which have the largest advantages, has the highest (w/w = 44%) whereas *administrative pavilion* (35%) and *canteen* (28%) registered more modest improvements;
- different windows location; *administrative pavilion* has just two windows on the north façade while most of *pavilion C* classroom are north exposed;
- heat generated by electric and gas equipment. For *canteen* building a considerable amount of heat is provided by cooking device in the kitchen. Hence windows replacement has a smaller impact on thermal comfort in zones like dining room and, obviously, the kitchen.

Nevertheless, project evaluation confirmed that replacing all the current windows in each building would still be convenient (Investment period: 40years; NPV: 57281 €; PBP: 24 years).

The other proposed energy efficiency measure consisted in the realization of EPS[4] thermal coat in all the facilities. This time though, results highlighted the fact that only *pavilions with classrooms* would have received benefits both in terms of thermal comfort and heating/cooling needs reduction. Figure 7 provides a visual explanation.

According with these results, the most convenient alternative is only the installation of 12cm EPS insulating layer only in the pavilions with classrooms.

Finally, it was intended to evaluate an additional measure[5] in which both the previous measures are employed. Hence, it has been simulated the implementation of a selective low-e double glazing system for every fenestration combined with the installation, only for pavilions with classrooms, of 12cm EPS insulating layer. Through the increased buildings efficiency achieved is possible to limit the school total annual consumption due to space heating and cooling from 129 MWh to 91,5 MWh per year, hence by 29%. However, it is important to remark that these ‘potential’ savings do not represent an actual positive income, since presently the school do not provide heating or cooling services. They should be interpreted as ‘future’ savings obtainable in case the school will provide each facility with HVAC systems.

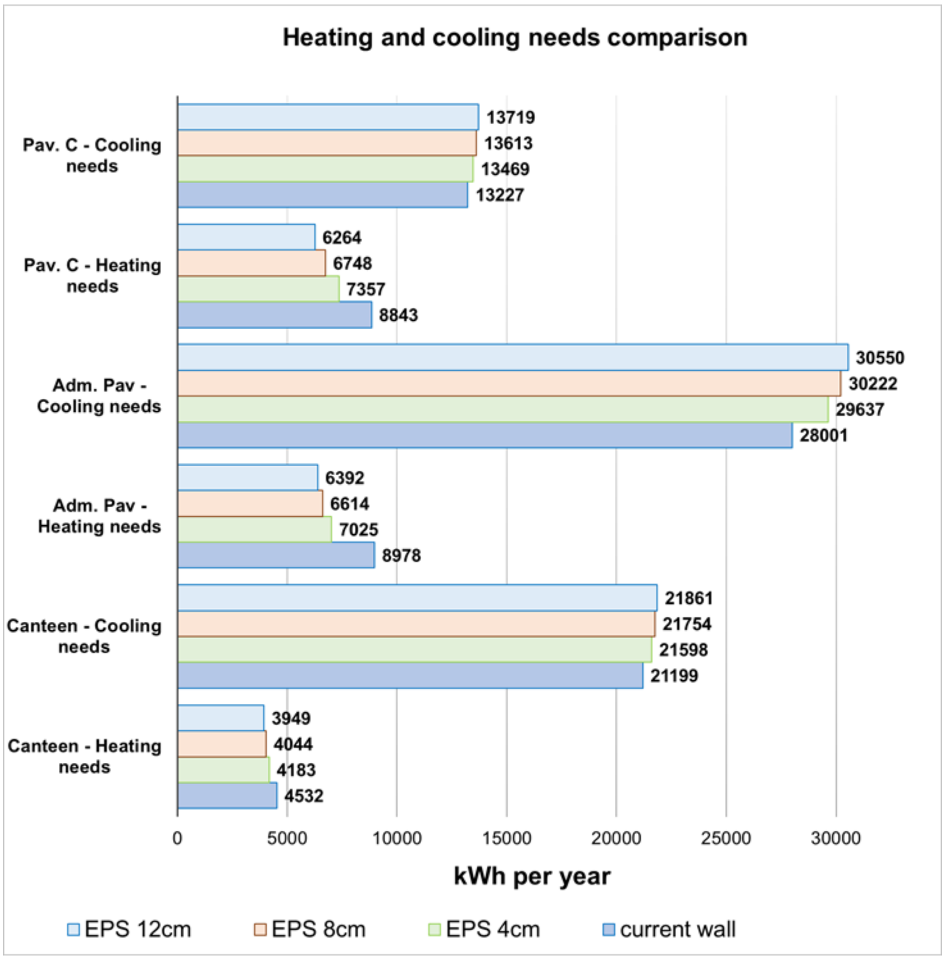

Figure 7 - Heating and cooling needs comparison for the examined EPS thicknesses.

---

[4] Effectiveness of various thicknesses was assessed.
[5] Named: Energy Efficiency Measure C (EEM-C).

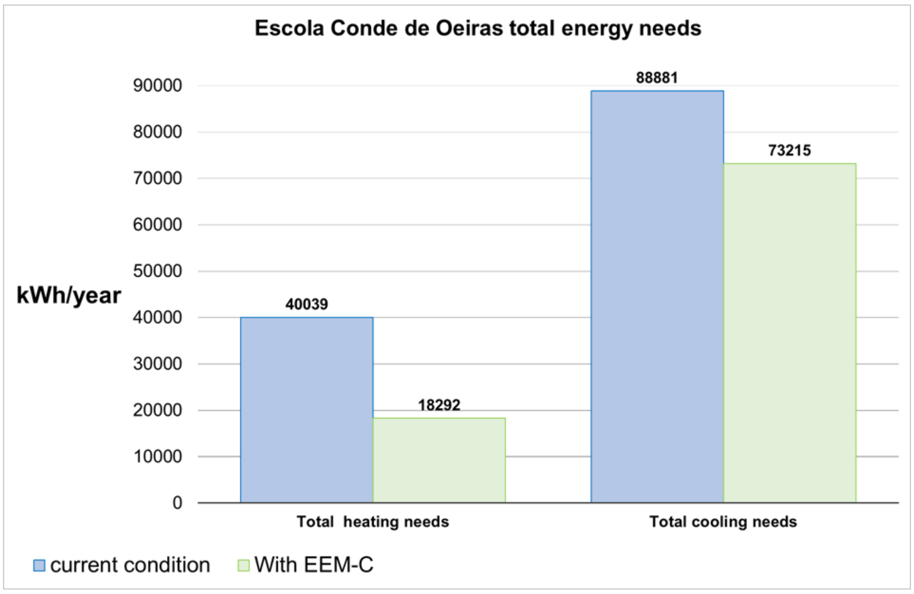

Figure 8 - Total heating and cooling needs including all the school facilities.

From the thermal comfort analysis of the singular buildings emerged the urgent necessity to guarantee better conditions for the students and employees. As demonstrated before, the current state of fact can be improved through an enhanced insulation of the building envelope which also leads to a reduction of energy needs. Nevertheless, considering the absence of space heating/cooling services, all the measures analysed in the present study may not be sufficient to guarantee acceptable conditions for 96% of the time inside the thermal zones. For this reasons, windows replacement and thermal coat must be included in a more wide investment plan which includes the design of efficient HVAC systems able to supply the required needs and a photovoltaic plant that is able to develop enough power to satisfy the energy requests of the entire school. Thus, the total demand will be disaggregated into three voices:

- energy to supply HVAC system, currently estimated in 151 MWh per year but reducible to 108 MWh per year with EEM-C;
- energy required from ordinary electric equipment, assessed around 155 MWh per year;
- energy required from gas equipment, assessed around 13,5 MWh per year

With information above it was intended to provide the reader with a final business plan of 150 kW grid-connected PV plant that can satisfy the total demand. The simplified approach used to carry out this investment plan may imply low accuracy in the results; however, the scope was essentially to acknowledge the order of magnitude of the capitals involved. A higher interest rate was adopted due the unpredictable time required for the installation of all the new structures and because of their risk of damage throughout the years. In the table that follows are summarised the most meaningful pieces of information regarding the project evaluation of the investment.

Table 3 - Final business plan.

Final business plan	
Tot gross investment (PV plant + HVAC +EEM-C) [€]	**800'000**
Net investment (-60% due to tax deduction) [€]	**320'000**
Investment period [years]	**40**
1st year cash flow due to energy savings [€]	**74'379**
estimated annual energy cost inflation	**2%**
Interest rate	**15%**
NPV [€]	**247'430**
PBP [years]	**7**

5 Experimental data feedback

To assess model accuracy, experimental data on indoor air temperature was collected in the second decade of October 2019 during three regular weekdays. It would be appropriate to clarify that this experimental data have no claim to validate the model 100%, but it is believed that they may represent an acceptable feedback for the work carried out in this study. To evaluate the validation of a model, there are some variables which quantify model accuracy, which would determine how well simulated data would match real data during a certain time-frame. [4]. From these variables, statistical indices have been recommended by three main international bodies [5]:

- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Guidelines 14 (St.14);
- International Performance Measurements and Verification Protocol (IPMVP);
- M&V guidelines for the US Federal Energy Management Program (FEMP).

The statistical indices used herein will be the Mean Bias Error (MBE) and the Coefficient of variation of the Root Mean Square Error (CvRMSE), defined by Equations (1-4):

$$MBE(\%) = \frac{\sum_i^n (S_i - M_i)}{\sum_i^n M_i} \times 100\% \tag{1}$$

$$RMSE_{period} = \sqrt{\frac{\sum_i^n (S_i - M_i)^2}{n}} \tag{2}$$

$$A_{period} = \frac{\sum_i^n M_i}{n} \tag{3}$$

$$Cv(RMSE)(\%) = \frac{RMSE_{period}}{A_{period}} \times 100\% \tag{4}$$

For a model to be considered calibrated, the mentioned international bodies define limit values for the previous statistical indices. For an hourly calibration, St.14 and FEMP consider a range of ±10%, while IPMVP considers a range of ±5% for the MBE. For the CvRMSE index, St.14 and FEMP consider a max limit value of 30%, while IPMVP considers a max limit value of 20%.

Comparing the average measured data with the model results, shown in Figure 9, an MBE value of 2.95% and a CvRMSE value of 4.29%, which are within the limits established above.

The equipment adopted to meter the temperature consisted in a standard thermocouple positioned inside one of the north exposed *pavilion C* classrooms, namely Aula Nord 3. Temperature was registered with a 5 second timestep whereas for *Energy+* the minimum timestep possible is 1 minute.

As can be noticed in Fig. 9, peak temperatures are achieved around 15, 38 and 60 hours hence approximately midday. The slight drops visible on all the peaks of the orange line and a little on the first peak of the blue line are probably due to people occupancy. Indeed, in the model it was scheduled that students start to leave the classroom at 1pm. This makes the indoor temperature decrease. In the reality, this type of event does not occur systematically every day.

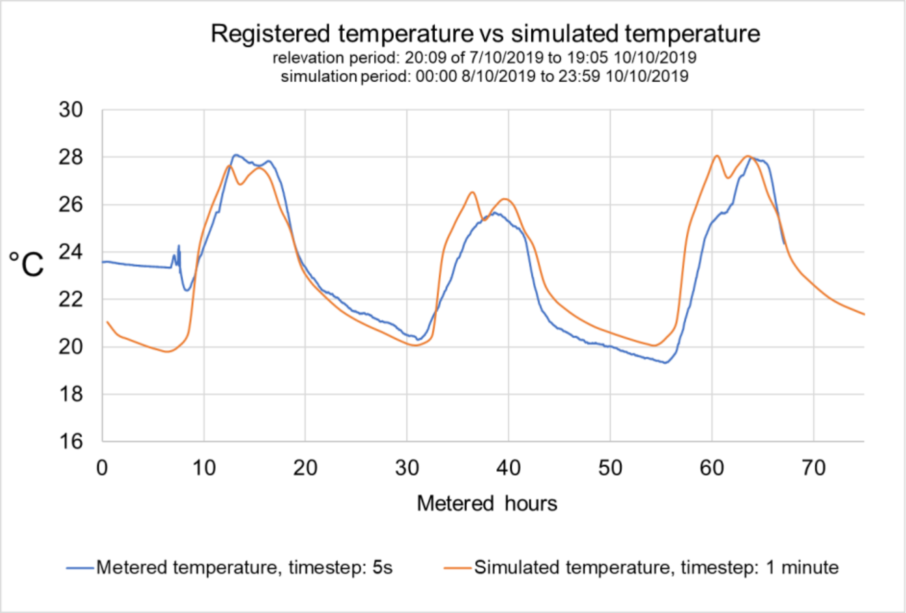

Figure 9 – Metered *vs.* simulated indoor temperature of classroom ‘Aula Nord 3’ in *pavilion C*.

6 Conclusions

Already after the first visits to *Escola Conde de Oeiras*, it was recognised, as probable causes of discomfort, the poor insulation degree and the excess of solar gains due to the old glass surfaces. To prove this hypothesis, it was computed the percentage of time out of acceptability limits for every thermal zone of each facility. With the thermal simulations of the school buildings it was highlighted a diffused presence of discomfort in most of the spaces with averages of 32% in pavilions with classrooms, 33% in Administrative pavilion and 34% in the canteen, even considering less strict acceptability limits of 80% provided by ASHRAE-55 2017 standard. Among the various alternatives compared, a *selective low emissivity double glazing system* provided the best results. With this new windows configuration, it was estimated that the average percentages of discomfort time would reduce up to 14% for pav. with classrooms, 21% for adm. pav. and 28% for the canteen, without installing any HVAC systems. Finally, hypothesizing to include these energy efficiency measure in a more ambitious and long term investment plan it is expected not only to reduce school environmental impact, but also to have the complete return of capital after 7 years and a Net Present Value of almost 250’000 € after 40 years, even assuming an interest rate of 11%.With the achieved results, it is intended to promote a detailed feasibility study to be carried out in the near future.

7 References

[1] **MOOC** Carlos Santos Silva; , «MOOC- Energy Services,» Instituto Superior Técnico, 2018. [Online]. Available: https://courses.mooc.tecnico.ulisboa.pt.

[2] **Paper** T. Cheung, S. Schiavon, T. Parkinson, P. Li e G. Brager, « "Analysis of the accuracy on PMV – PPD model using the ASHRAE Global Thermal Comfort Database II,» pp. 205-217, April 2019.

[3] **Conference Paper** Gameiro da Silva, M.; Antunes, C.H.; Bernardo, H.; Jorge, H.; Cruz, L.; et al. A preliminary assessment of energy performance in refurbishedschools. In Proceedings of the 1st International Congress on Energy & Environment (ICEE): BringingTogether Economics and Engineering, Porto, Portugal, 9–10 May 2013

[4] **Phd dissertation** R. Gomes, *A multidisciplinary approach for building retrofit driven by thermal comfort,* Lisbon: IST, 2019.

[5] **Paper** E. Fabrizio e V. Monetti, «Methodologies and Advancements in the Calibration of Building Energy Models,» *Energies,* pp. 2548-2574, 2015.