Improving schools performance based on SHERPA project outcomes: Valencia case (Spain)

Víctor Manuel Soto Francés[a,b,*], A. Begoña Serrano Lanzarote[a,c], Vera Valero Escribano[d], Miriam Navarro Escudero[d]

[a] *Universitat Politècnica de València. Camino de Vera S/N. 46022 Valencia (Spain)*
[b] *Departamento de Termodinámica Aplicada. ETSII. Edificio 5J.*
[c] *Departamento de mecánica de los medios continuos y teoría de estructuras.ETSA.*
[d] *Institut Valencià de l'Edificació (IVE).C/Tres Forques 98.46018 Valencia (Spain)*

Abstract

The European SHERPA project aims to share knowledge for energy renovation in buildings by public administrations. The EU Energy Performance in Buildings Directive (EPBD) recast, indicates the necessity of transforming EU buildings into Nearly Zero Energy Buildings (nZEB). Each Member State transposes differently the EPBD, usually based on European norms like Spain did. The generated knowledge about improving performance and transforming public buildings into nZEBs, is applied here to schools, according to the Spanish transposition.

SHERPA, among other buildings, has audited four schools sited in the Valencia Region (Spain, Southern European Country). The paper starts describing, briefly, the general auditing protocol devised by SHERPA. Particularly, one school was chosen out of the four to illustrate the protocol and was converted into a nZEB. This school led to the most unexpected and outstanding results, although the trends were shared among all the audited schools.

Finally, based on the results, the paper suggests some recommendations to the policy makers about the practical definition of nZEB and financial instruments to engage this nZEB challenge for schools.

*Corresponding author
Email address: vsoto@ter.upv.es (Víctor Manuel Soto Francés)
URL: www.five.es (Miriam Navarro Escudero)

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Nomenclature

$C_{ep,nren}$ Non-renewable primary energy consumption $[kWh/m^2/yr]$

$C_{ep,tot}$ Total primary energy consumption $[kWh/m^2/yr]$

CFI Internal loads intensity $[Wm^{\cdot 2}]$

G_{July} Building solar heat gain during July $[kWh/m^2/July]$

U Overall heat transfer coefficient $[W/m^2/K]$

U_g Global or building overall heat transfer coefficient $[W/m^2/K]$

NZEB Nearly Zero Energy Building

Subscripts

max Maximum allowed value by Spanish building code CTE-DB-HE 2019

1. Introduction

The SHERPA project [1], SHared knowledge for Energy Renovation in buildings by Public Administrations, is a Testing and Capitalising EU project financed by the Interreg Med Programme under Specific Objective 2.1 (to raise capacity for better management of energy in public buildings at transnational level). The project objective is the following:

"It aims to reinforce the capacities of public administrations at regional and sub-regional level to improve Energy Efficiency in public buildings so as to address difficulties related to EEB (Energy Efficiency in Buildings) projects in the Mediterranean area. One of the key objectives of the project is to set up 200 project proposals for Energy Renovation in Public Buildings. One hundred energy renovation proposals, to be identified according to specific selection criteria, will be carried out on public buildings in the Mediterranean regions involved in

the project. Another amount of proposals will be selected in the municipalities of these regions. All these projects will be implemented according to specific findings, guidelines, tools and strategies. They will be associated with public-private investments worth around 300 million Euros and producing thousands of new jobs."

The crucial phrase is *"... according to specific findings, guidelines, tools and strategies."*. This paper represents a research effort in that direction. Additionally, at the project's completion:

"... a Joint Action Plan will be produced. It will have a wider Mediterranean scope on Energy renovation in buildings (ERB) and will look at the potential for future interventions at transnational and regional/local level taking into account governance aspects, shared information systems, training and awareness raising as well as innovative financing schemes."

At the conclusions section of the paper, some recommendations are collected about the future Action Plan, based on our results.

1.1. The national Spanish context

This paper deals with one type of the overall public buildings analyzed, the schools. On October 2019, the newspapers published articles about overheating problems in the schools, due to the increasing frequency of heat waves during school time periods. Dry-bulb temperatures of $34[°C]$ inside the classrooms at the end of September are now common. During May and June schools report outside temperatures above $38[°C]$ or even $40[°C]$. The schools usually lack of cooling systems in classrooms. At most they have fans, but the students complain of suffering: lack of attention to the lessons, headaches, nose bleeding and faints. The higher impact relies on young children who are in the range between 3 and 11 years old. The local government proposal in these cases was to pick up the kids earlier, at $13:00$ pm. Nevertheless, this provoked bad reactions from the parents due to the conflict with their work time-schedule. Some of the building schools mentioned in the newspapers are less than nine years old, some even with an architecture award. The gross amount of schools are around 40 years old and are not ready for the climate change. Spain has around 30000 public schools and now, this thermal stressful events, are not exclusive of southern regions. In the north of Spain, during 2019, there were reports about babies and professors fainting in classroom during a heat wave in July. The Valencia region has planned to invest 1000 million Euros in 5 years for renovation actions, affecting one half of its public schools (≈ 1420). One explicit target is decreasing the internal temperatures without installing air conditioning, since it is economically unfeasible. Moreover, local governments do not want to see their electric bills rising. The problem is even worse in northern Spanish cities, where historically, cooling is not needed but now, singular extreme events, spark unusually high peak cooling loads. This is a challenge for engineers and architects. Some school headmasters express their surprise when internal temperatures are above $27[°C]$ very early in the morning after the school opening at $9:00$am. In Andalucía (the most southern Spanish region) has appeared a new social phenomenon: the creation of new associations of parents named Heat Schools. They lobby the regional government to legislate in favor of, at least, a bio-climatic control of the internal conditions of the schools.

It is quite obvious, therefore, that there is an urgent need to improve the performance of our schools because, unfortunately, the climate change has already impacted on the health and interfered with the learning capacity and social lives of students and their families.

1.2. The European context

The European Parliament declared the "Climate and environmental emergency" (resolution 2019/2930RSP) on the 28^{th} of November 2019.

On one side, the SHERPA project represents the regional/local governments approach to act on the issue described previously in §1. On the other, the global European action plans are transmitted through Directives which each member State (MS) must transpose at national level. The first Directive about Energy Buildings Performance [2] dated in 2002, was recast in 2010 introducing the 'nearly zero energy buildings (nZEB)'. However, both regional and global plans should converge or even merge their objectives and policies. It is our hope to contribute here to this goal.

In an interesting paper, Attia et al. [3] made an overview of the challenges of nZEB in southern Europe. Their study was based on interviewing national experts from seven South European countries. In §4.3 of [3], they stated : *"... our analysis and recommendations are experience based working hypothesis but need to be enriched and confirmed with further analysis."* This paper supports partly their findings, based on real school buildings audits. Our conclusions are in line with their statement: "The challenge of embracing the nZEB concept is technical, societal, and organizational before being economical." Moreover our results, confirm the following findings of [3]:

1. There are no clear functional concepts of nZEB that can help to set up a definition and implementation strategy (although practical research efforts are ongoing [4]).
2. Insufficient funding of human infrastructure (professionals).
3. Financial barriers related to the cost-optimality.

The European Union research program has non-local projects like ZEBRA2020 [5] devoted to help implementing their Directives. Lessons learned in ZEBRA2020 about nZEB which are confirmed by SHERPA results are:

1. "The absence of accessibility of key data concerning the buildings stock and in particular *non-residential and existing buildings as well as renovations* remains an important obstacle to policy planning. There is a strong need for European harmonization for solid cross-country comparisons and tracking of the transition to nZEBs. The revised EPBD should include unambiguous, clear definitions of terms and thresholds. Notice that this point agrees with the previous item 1 from Attia et al. .

   Specially, our SHERPA project results, are in line with the following statement from ZEBRA2020, as it will be shown later: "*Further, it is important to distinguish between new buildings and renovations despite of a common nZEB definition for both cases.*"

2. “Moreover, `energy poverty` and vulnerable consumers are a European-wide issue and need further attention. Shifting from fuel subsidy to energy efficiency support is required.”.
3. “ Financial matters (additional costs), low awareness, bureaucracy and issuing *unreliable energy performance* certificates were the main obstacles reported in our real estate agents survey.” These last two points are also related with the previous items 2, 3 from Attia et al. .

1.3. Previous research on schools performance in Southern European countries

Gaitani et al., in [6](2015), described the work done, by the ZEMedS project, in Spain, Greece, Italy and France. It was devoted to create a road-map for the renovation of schools towards nZEBs. The paper declares that there is not a clear definition of the nZEB concept. They point out that: “The lack of data as to energy performance of current buildings is an important barrier when it is to renovate the built stock”. The SHERPA project tries to fill this gap analyzing several, very common, school typologies as representatives of a great number of schools.

Unfortunately, there are just a few previous studies on transforming school buildings into nZEB, in Southern European countries. For example, [7] is one such interesting study, performed in Xanthi (Greece) on a single school. It is uncommon, in technical research papers, to include economical discussions, but [7] does. None of the energy measures proposed were economically cost-effective (over a period of 30 years), despite of the bad initial thermal conditions of the school. Only when the actions were combined with photo-voltaic panels, the measures were cost-effective, i.e. the school became an energy producer. Corrado et al. presented in [8](2017), another example about the nZEB transformation of a school built in the 1940s in Torino (Italy). Their conclusions agree with the previous ones, from [7]. Unfortunately, the work focuses, exclusively, on the cost-effectiveness of the energy-saving measures. The Italy’s nZEB definition is different from the Spanish one. Corrado’s methodology follows these steps: a school audit, a model calibration based on the audit and an (energy) evaluation of the proposed energy-saving measures using standard Italian weather conditions. However, its details show noticeable differences with our proposal. For instance, the building thermal model is static (based on heating degree-days) and the calibration is performed using one weather variable, the monthly average dry-bulb temperature. An overlooked work by Watson [9], proposed a method to easily decide, beforehand, the expected accuracy from a dynamical/statical simulation. His method is just based on simple weather statistics and building indoor temperature set-points. According to his method, the building energy storage dynamical effects for both, Torino and Valencia, are important in winter. This might explain the degree-days corrections employed by Corrado [8]. Additionally, we analyze also the increasing school cooling needs, due to climate change. Another discussion, on energy performance strategies applied to eight existing schools in Matera city (Southern Italy), can be found in [10]. This paper does not include an economical study of the strategies. Nevertheless observing Table (9) in [10], it can be clearly seen that the same strategy applied to different schools has different impact on the energy savings. This characterizes existing schools. Additionally, we have observed a similar trend but from the occupants comfort perspective: the same strategy applied to different schools has a different impact on the comfort.

For the southern Spanish climates (Andalusia), Gil-Baez et al. [11] (2019) studied a linear-shaped school inside the ClimACT Project (SOE1/P3/P0429EU), which resembles the typology of the one presented here. The Gil-Baez's conclusions, although not explicitly stated so, reinforce one of our findings: the measures are hardly cost-effective from the economical perspective. However there are important differences with our work. On one side, they did not use a general purpose energy simulation software-tool but a specific one. The Spanish Official software-tool devoted to the energy labeling of buildings (or energy performance certificates), named LIDER. Due to its legal character, the internal loads and schedules are fixed and predefined. Therefore they cannot be modified or tunned to fit the actual occupation activity of a concrete school. This can be easily appreciated by looking at the school annual schedule §2.3 and Figure

(4) of [11], where July and August have no occupation. However §3.1 and Figure (6) of [11] display a cooling demand during those months. Moreover, their model was calibrated with energy consumption bills from other similar schools whereas we have dealt with several years of actual consumption of the audited school. On the other, despite they mention the importance of enhancing the indoor comfort with the passive measures, there is no estimation of their actual impact.

Finally, the work by López-Ochoa et al. [12], contains an analysis of transforming a school into a nZEB, but for northern Spanish regions. They performed a parametric study. Different energy saving strategies were applied to the same school placed in eleven cities, but without any reference to the actual performance of the school. Their interest was centered on the reduction of: non-renewable primary energy consumption ($C_{ep,nren}[kWh/m^2/yr]$) and fossil $CO_2[kg/m^2/yr]$ emissions. Unfortunately they did not evaluate the comfort or the economic feasibility of the studied strategies.

Summarizing, the original state of the four audited schools by the SHERPA project, were not so bad as the aforementioned Greek school and closer to the Italian schools. Regarding cost-effectiveness, SHERPA outcomes are also negative and in close agreement with those of the Greek paper. Perhaps, even worse because of the better initial state of our buildings. This finding is also reinforced by results from other EU-countries (like Italy, France) and even non-EU countries, with similar climates, like Israel (see for instance [13]).

Therefore, since cost-effectiveness seems not to be a driving force for nZEB transformation, the paper focuses on the ultimate goal: the comfort. However the EU-Directive main concern is energy consumption while comfort is mentioned only three times and taken for granted. Thus our objective was readdressed to study how both goals may interact or reconcile with each other. In doing so, for clearness, we present the most outstanding results by their unexpectedness, just for one of the SHERPA audited schools which is also the architecturally simpler. However similar trends have been found in the other three schools not presented here. Before proceeding, we would like to show how the EU nZEB concept, the CEN standards and the Spanish building code CTE-DB-HE ~~2018~~ 2019 [14], intermingles since these are the boundary conditions of the building agents. Secondly the paper describes the audit protocol devised by SHERPA, for any public building. Finally, for one particular school, a Spanish nZEB transformation was tried based on the audit outcomes. The issues which showed up, during the process, are throughout discussed.

2. Review of the nZEB EU Directive and its Spanish transposition

~~La~~ The Directive 2010/31/EU (EPBD) on the 19th of May [15], at art.9 indicates that EU Member States (MS) must ensure that by 2021 all new buildings and already by 2019 all new public buildings, are nearly Zero Buildings (nZEB). It adds that MS should draft plans and "... encourage best practices as regards the cost-effective transformation of existing buildings into nearly zero-energy buildings". The nZEB concept as defined by the Directive states:

"Nearly zero-energy building means a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby."

Regarding performance, Annex I of the Directive makes a reference to a calculation of the energy performance of the building:

"The energy performance of a building shall be expressed in a transparent manner and shall include an energy performance indicator and a numeric indicator of primary energy use, based on primary energy factors per energy carrier, which may be based on national or regional annual weighted averages or a specific value for on-site production."

Every Member State is allowed to make his own interpretation of these two important concepts: nZEB and building performance. The Spanish dwelling Ministry has published the technical bases of the new Building Code (CTE-

DB-HE ~~2018~~2019) [14] in order to comply with this Directive. The new code relies, in turn, on the norm ISO $52000-1$ (2019) [16] to answer both questions: what is a nZEB? and how to measure the building performance?. In annex H of this ISO there is an informative proposal of indicators for the assessment of nZEB which has been adopted by Spain. The indicator suggested is the primary energy consumption/use C_{ep} expressed in $[kWh/(m^2yr)]$. Notice that the reference area is subtly placed at the denominator. It is easy to be careless about the square meters used, but this measurement has obviously very important implications (see [17]) on the indicator. According to the ISO, the usable floor area must be the reference, not the conditioned, area. Therefore the indicator is not aware about the presence or not, of heating and cooling systems on those square meters. The ISO norm, in annex H, describes an approximation to a nZEB which goes through three sequential steps:

1. *Building fabric (Energy needs/demand)*. Here it encloses: thermal quality of building envelope, bio-climatic design (solar gains, natural lighting), inertia and zoning. It includes also a remark: "the need to guarantee adequate indoor environmental conditions in order to avoid possible negative effects such as poor indoor air quality (due to lack of *ventilation*) or hygrothermal problems (such as *mould*)"
2. *Total primary energy use*. It states: "...reflecting the performance of the technical building systems (HVAC installation, domestic hot water supply, built-in lighting installation)"
3. *Non-renewable primary energy use without compensation between energy carriers*. Finally a by-product step is: *taking into account the compensation.*

The Spanish CTE-DB-HE ~~2018~~ 2019 states that nZEB would be any building which satisfies the new requirements enclosed in the code for new buildings (including existing ones). The CTE-DB-HE ~~2018~~ 2019 is split into four sections and, beneath the wording, follows the ISO:

- HE0: Limiting the energy use (corresponds to ISO items (2) and (3)).

For tertiary buildings (like schools) the non-renewable $C_{ep,nren,max}$ and total $C_{ep,tot,max}$ primary energy limits, depend on the internal heat gains $CFI[Wm^{-2}]$ and Spanish winter climatic zone $\{A, B, C, D, E, \alpha\}$. In concrete for a school in Valencia city (climatic zone $B3$) with $CFI \leq 6[W \cdot m^{-2}]$, which is considered low internal gains, the limits are: $C_{ep,nren,max} = 80[kWh \cdot m^{-2} \cdot yr^{-1}]$ and $C_{ep,tot,max} = 185[kWh \cdot m^{-2} \cdot yr^{-1}]$. These values will be used later on, for the described case. This indicator C_{ep} includes, for tertiary buildings, the services of: heating, cooling, ventilation, domestic hot water and lighting.

- HE1: Limiting the energy demand (corresponds to ISO item (1)). HE1 establishes the calculation requirements for the energy demand and consumption. The temperature schedule set-points are fixed only for residential buildings. It explicitly states that ventilation and air quality must be accounted for. Regarding comfort it only states: "The number of hours outside the set-point will be less than $350[hrs/yr]$". The reference area is the whole usable floor area. Each envelope element has a limiting U_{max}-factor, or overall heat transfer coefficient, as a function of the winter climatic zone and irrespective of the residential or non-residential use. Additionally there are two global restraints on the building; its maximum $U_{g,max}$ or global heat transfer coefficient, computed as the area-weighted sum of each envelope element U-factor and the global solar heat gain control in July, $G_{July,max}[kWh \cdot m^{-2} \cdot month^{-1}]$. By $G_{July,max}$, it is meant the overall solar energy entering the building along July. The limits to this latter are: $G_{July,max} < 2.0[kWh \cdot m^{-2} \cdot month^{-1}]$ for private residential buildings and $G_{July,max} < 4.0[kWh \cdot m^{-2} \cdot month^{-1}]$, for all other uses (i.e. tertiary, like schools). Mobile solar protection devices can be accounted for, such as blinds, screens, curtains, etcetera.

- HE2: Thermal technical facilities efficiency.(Indirectly affects ISO item (2)).

- HE3: Lighting efficiency.(Indirectly affects ISO item (2))

- HE4: Solar energy contribution for DHW.(Indirectly affects ISO item (3))

Regarding the buildings with different heating and cooling services per thermal zone, which the ISO norm in section §9 refers to as "mix of building services included in EPBD", it poses the following problem:

"Consideration shall be given for buildings that are not equipped with all services for which the energy performance shall be assessed (e.g. building without cooling systems when cooling is part of the energy performance calculation)".

The way this problem is solved affects the calculation of the indicator items (2) and (3) of the ISO's nZEB definition. Three *optional* principles are proposed, by ISO, as a solution:

1. *Assumed system*: Provide specification of a default technical system for each missing service.
2. *Presence of system*: Do not take into account energy use for a specific service if there is no technical building system present for that service.
3. *Other principle*: Principle not covered by the above listed two principles.

Spain has chosen the principle-(1) for dwellings and principle-(2) for tertiary buildings (like schools, offices, hotels, etc.). For the latter principle, the ISO norm warns: *" Consequence: a possibly better energy performance, for buildings missing some service, is accepted (violation of level playing field)."* Furthermore, it adds a note which states: *"NOTE: A possibility is to compensate this by highlighting the discomfort with a complementary discomfort indicator (example: hours of summer discomfort)."* However this is not done by the Spanish code.

Next sections illustrate the practical consequences of the previous discussion when applied to the audited school. In first place §3 shows the general protocol devised by the SHERPA project, to collect building state information. Then we proceed by showing the protocol outcomes for a real school sited in Valencia city (Spain). In second place, the upgrade of the school to a nZEB is analyzed and discussed.

3. General protocol for school building data collection. SHERPA project

The Spanish Royal Decree 56/2016, 12 of February, transposes another EU Directive 2012/27/UE, 25 of October 2012, on energy efficiency. This Decree deals with: energy audits, certification of energy and auditing companies as well as the promotion of energy efficiency at the supply side. The fulfillment of this Decree is compulsory. In its article 3 the Decree establishes the minimum requirements of an energy audit:

1. It must be based on updated operative data, measured and verifiable on the energy consumption and in case of electricity the load profiles if available. The building energy efficiency label should be included and can be used to fulfill the Decree, whenever it includes recommendations for energy saving.
2. The detailed analysis of the energy consumptions must include transport inside the building or even vehicles.
3. Whenever possible, it must be based on life cycle costs rather than on simple repayment periods.
4. Its scope must be proportional and representative enough to detect improvement opportunities.
5. It must contain detailed and validated calculations of the improvement measures, in order to show the energy saving potentials.
6. The data collected must be stored for back-tracing and historical-recording purposes.
7. It must not contain clauses which hinder the access to its conclusions by energy service companies. However the information can be considered as confidential.

Additionally, article 13, specifically deals with energy demand and efficiency, for cooling and heating. Every Member State, must gather these demands and make a forecast of their evolution within 10 years.

This section briefly explains the building audit procedure devised by the SHERPA-project, according to that Spanish Decree. ~~The protocol~~ It also follows the EU norm EN 16227-2:2014 as the Decree suggests. The throughout description of a concrete audit falls out of the scope of the paper and can be found in the SHERPA-project. The norm, apart from the management sections of the audit, has at its core, the following:

- Section 5.3: Data collection.
- Section 5.4: Fieldwork.
- Section 5.5: Analysis: calibration of models, evaluation of energy saving measures.
- Section 5.6: Report.

These could be considered as the stages of the audit procedure. The protocol to collect the data, has been divided into three~~sections~~: the architectural, the technical facilities and the energy carriers data. Each part includes both, norm sections 5.3 and 5.4, i.e., the data and their field verification. Each one is summarized in the following tables.

1. Table (1): split into two parts. The passive-architectural and the active-energy-consuming components. The first includes; geometry, thermal envelope properties, schedules (occupancy, lights, equipment), land register information, pictures,~~etc.~~ etcetera. The second includes the following services: domestic hot water (DHW), ventilation, heating and air conditioning (HVAC), lighting and *others*(kitchen equipment, computers,etc).
2. Table (2): the energy carriers, tariffs and supply conditions.
3. ~~Table (3): list of possible energy saving measures. Additionally, the auditing company must perform an economic evaluation for each proposal.~~

Besides ~~the collection of data~~ data collection, the audit-contract commits to include an energy simulation of the building. This belongs to section 5.5 of the norm. This computation is a helpful tool to find out some, possibly hidden, errors or flaws buried ~~in~~ into the audit data. An example of this fact, will be shown in the next sections. ~~Audit protocol. Data collected from the Architecture and the Technical facilities~~

Obviously, an easy way, and perhaps the only way, to get an estimation of the consumption is through the energy bills. However, using the bills, has a well-known drawback: the consumption of different services is aggregated, that is, the type of consumers cannot be distinguished. In any case, it is advisable to gather as many years as possible to get a representative mean. Table (3) also belongs to the analysis section. It shows a list of possible energy saving measures. Additionally, the auditing company must perform an economic evaluation of them. The indicators chosen for the analysis were mainly $C_{ep,tot}$ and $C_{ep,nren}$.

Finally the audit report (section 5.6 of the norm) must always follow the same index for comparison purposes:

1. Energy Saving measures.
2. Aim of the audit.
3. Methodology.
4. General Data of the building.
5. Current energy consumption of the building.
6. Description of the building and its technical facilities.
7. Energy analysis of the building.
8. Detailed description of the energy saving measures.
9. Energy certificate or labeling of the building (EPC).
10. Anexes: Pre-diagnosis, report summary, the collected energy bills and calibration certificates of the measurement devices.

Since the energy audit comes from an EU-Directive, the stages are broadly the same in any EU-Member State. However the protocols may differ in the details. An instance of another audit implementation can be found in [8]. Our procedure shows biggest differences within the analysis stage. Figure (1), shows a scheme about how we conceive the process. The building, as a technological object, evolves in time, forced by the climate and the users (internal gains). The audit is done at a certain point in time. It gathers the snapshots belonging to the building operation along several past years. These create a blurred image of the building operational behavior because of the lack or uncertainty of the data, aggregated data along the time, or even, aggregated values belonging to the consumption of several utilities. Therefore the reality is modeled based on averaged or expected input/outputs. The model has parameters, which can be tuned, to fit the computed to the measured outputs. This procedure creates a projection of the reality onto our model (see the *interface* in Figure (1)). However, the range of each parameter has boundaries associated to its intrinsic uncertainty. If the model cannot be fitted within these assumed ranges, then there must be very important aspects missing, or even, data errors. Hopefully, this may become a source of extra useful information, as it will be shown. While [8] includes also the climate as an object to be tuned, we prefer to use the *official* or standard weather files. In other words, we do not calibrate a *climate model*, instead we assume that the one provided by the government, is valid. The *standard* climate is supposed to be the expected weather. The reasons for this choice, will be discussed further, afterwards. As Figure (1), shows, the goal is to modify the building so that the new path ends at a nZEB. This would be confirmed by a future energy audit. However, the way the building may be modified is not totally free but depends on the constraints imposed by the Spanish code (this differs also with respect to [8]). The evaluation, or forecast, of the future operational performance of the building, is done on the *reality model* with the standard climate. We agree with [8] in this latter step. In short, our proposal and [8], roughly differ in how to get a *calibrated* model of the building. The *tailored* climate is used by [8], while here the standard one is employed. Moreover, in [8] the model is based on degree-days, while we perform a dynamical simulation.

Finally, there is another difference regarding the indicators. While [8] focuses exclusively on energy indicators, we have added the comfort (PPD, Percentage of People Dissatisfied). The constraints on the energy saving measures and

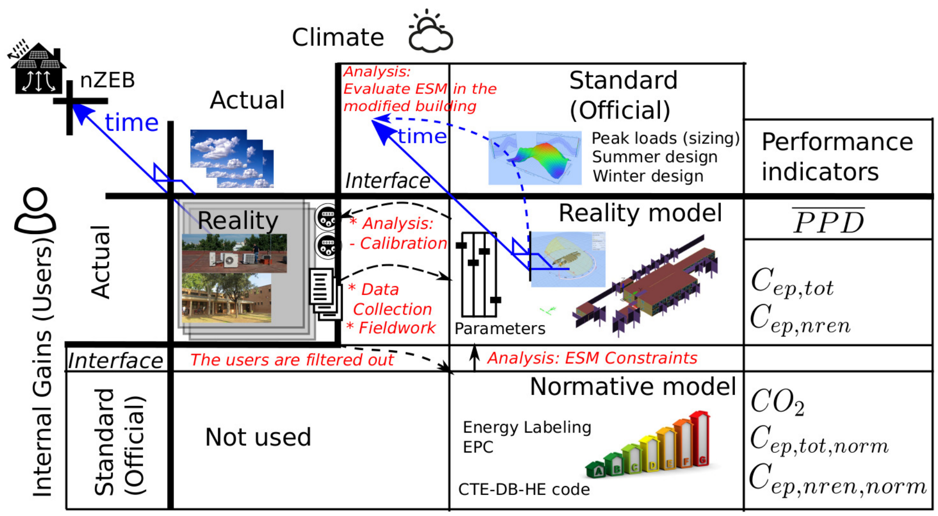

Figure 1: Audit map. Time-axis (in blue) is perpendicular to the plane of the paper. The other axis are two separated dimensions of reality. Standard means some *officially* established *objects*. $C_{ep,tot,norm}$ and $C_{ep,nren,norm}$ are the indicators obtained when standard objects are used. The *interface* indicates, with arrows, some kind of projection of data from one realm to another. Text in red indicates audit actions.

some unexpected results, led us to add the comfort, as a driving force for the investment in building retrofitting. Next sections describe and discuss in detail all these aspects, by using a concrete audit example.

4. Case study: a small-size school at the suburbs of Valencia city

Within the scope of SHERPA, several types of schools have been audited using the methodology described in §3. From big and complex to small and simple ones (see Figure (2)), in urban and non-urban environments. These schools have been chosen as proxies of their types. The target of the project was to obtain a mapping one-to-many, which covered as many schools as possible of the Valencia Region. Although similar general trends have been obtained for all of them, we have chosen a small one which holds the most outstanding and illustrative outcomes. The building is just a small part of a much bigger complex, which was not audited. In concrete, it is a professional school. In [18] Gómez-

Architectural data		Technical facilities	
- Land registry data (code)		- Lighting:	Luxes measurement
- Raw area [m^2]			Type: incandescent,led, …
- Built area [m^2]			Zone location
- Footprint area [m^2]		- DHW+HVAC:	Existence of a centralized control system. (Yes/No)
- Year of construction			On/Off depends on user (Yes/No)
- GoogleMaps ©			Type of system
- Pictures of the site			Boilers: Exhaust gas analysis
- Geographical orientation			Chillers & Heat pumps:
- Shading obstacles			+ Check one working point if possible
- Zone description:	Office,…		Ventilation: mechanical,exhaust,natural,…
	Area ([m^2]		+ Integrated with the cooling/heating?
	Have they heating/cooling?		+ Heat recovery? Type?
	Total useful area [m^2]		+ Economizer (free-cooling)?
	Occupation		+ Rated power of the fans?
	Schedules		+ Zones served
- Windows and opaque enclosures:	Design plans of the building		+ Control: Schedule,CO_2,…
	Otherwise infer from:	- Water circuits:	Thermal insulation & pumping power
	Year of construction	- Renewable :	Solar thermal collectors, PV panels
	Visual inspection		
- Visual inspection			

Remark:For any system an inventory of its components is performed
- Identification of existing equipment/components (photos are taken)
- Manufacturer declaration of the rated power
- Usage in order to estimate the simultaneity profiles
- Extra: Model and brand of each equipment

Table 1: Audit protocol. Data collected from the Architecture and the Technical facilities

Energy suppliers		
Electricity	Tariff type	
	Monthly energy consumption: active and reactive	
	Price of the energy according to tariff	
Natural gas	Tariff type	
	Monthly energy consumption	
	Prices:	special tax on hydrocarbons
		fixed term
		counter renting
		government tax

Table 2: Audit protocol. Data collected about the energy consumption.

Alfonso gathered data about the amount of schools of a certain typology in the Valencia region. Usually, many schools are built at the same time, due to local government policies, and share the same shape and constructive solutions. For instance, just for the Valencia province (Valencia region is made up of Valencia, Castellón and Alicante provinces) Gómez-Alfonso collected 34 schools very alike to the one studied here, which add up to 217 classrooms altogether. According to [18], linear-shaped schools are the most common type and therefore, in the whole region, the total amount could be easily three times higher than Valencia (adding up around 100 schools for the whole Region). Thus, the results presented here, are not just those from a singular case but have, in fact, a much wider scope.

4.1. Audit results

According to the methodology devised and exposed in §3 the data collected from the school was the following.

The passive-architectural data:

- Table (4): It shows general data and visual inspection according to Table (1).

Objective	Scope	Measure
Comfort	Architectural:	Fenestration renovation
		Improving the building envelope
	HVAC:	Adding cooling/heating systems in occupied zones
Cost	Environmental:	Solar thermal (DHW)
		Solar photo-voltaic panels
	Energy consumption:	Monitoring and control
		Improving HVAC/DHW whole system efficiency
		Improving lighting system
		Presence detectors in corridors/toilets
		Natural daylighting study
		Energy efficiency other equipment
		Installing a capacitor bank to reduce reactive power
	Monetary	Optimization of the electric bill

Table 3: General optimization measures proposed by the contracted engineering consultant company.

- Table (5): It is a two-floored buidling. Notice that some of the bottom zones have no cooling or even heating & cooling service. However, all top floor zones have both services but the teachers' room.

- Table(6): The envelope properties of the floors, roof and walls was not available to the engineers. Therefore according to the visual inspection, experience and year of construction, Table (6) was filled. It shows, along with the estimated heat transfer coefficient U, the limiting values U_{max} according to CTE-DB-HE ~~2018~~ 2019 code. Clearly, the school does not comply with the new Spanish code. Moreover, at the bottom of the table, it can be checked that the global value U_g and the building solar heat gains in July G_{July} are above their limits.

Figure 2: Examples of different types of audited schools. (a) Small one, at the suburbs, presented in this paper- (b) Big one at the city center.

4.2. Energy simulation calculations

Due to the complexities of the school surroundings, the auditing consultancy did not provided an energy simulation model for this school. Therefore an EnergyPlus [19] model was developed, independently, by using a building *model compiler* named Genera3D [20]. Figure (3) shows a picture of the ge-

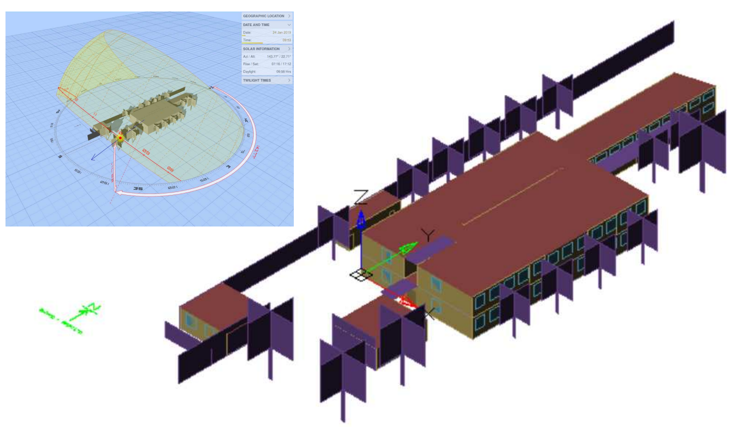

Figure 3: Geometrical input model to EnergyPlus.

ometrical model. The surrounding deciduous trees were modeled as shading devices with a seasonal solar transmittance schedule. The thermal properties obtained by the auditing company are gathered in Table (6). It was used just

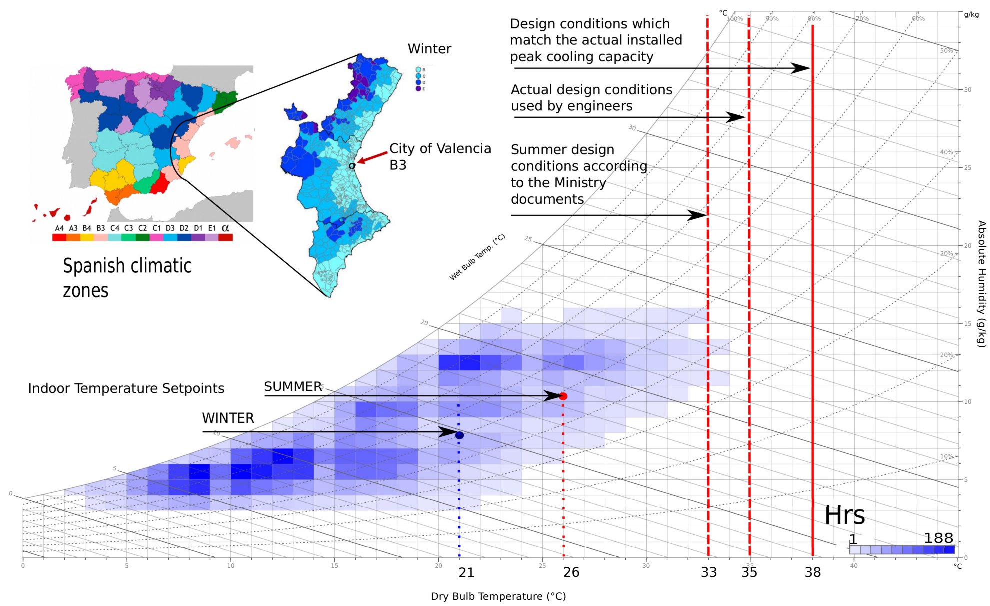

Figure 4: Representation in the psychrometric chart of the Valencia *official* weather conditions. These data have been used in the simulation runs. The building temperature set-points for winter and summer are shown along with the design temperatures for summer

for computing the energy demand for heating and cooling by using the ZoneHVAC:IdealLoadsAirSystem component of EnergyPlus. The energy consumption from HVAC components was not computed directly using E+, because the performance curves of the actual equipment are hard to obtain. The time step was $15[min]$. A discussion about why higher time steps are not advisable to estimate the energy demand can be found in [21]. At least for our purpose, audited seasonal efficiencies were enough. Thus, the computed energy consumption was based on the calculated energy demand and the audited outcomes for the seasonal efficiencies of the HVAC systems, which were 0.897 and 2.16 for heating and cooling, respectively.

According to the audit results, the internal loads were:

- The school has capacity for 50/60 students, and 15 staff workers.
- The occupancy schedule was (note: Christmas, Easter and local holidays, were also taken into account):
  - Classrooms: weekdays $9:15$ to $14:00$ and $15:00$ to $16:45$ (but July and August).
  - Administrative services and offices: weekdays $9:00$ to $14:00$ and $15:00$ to $17:00$ (but August).
  - Meeting rooms: weekdays $17:00$ to $18:00$ (but July and August), weekdays $12:00$ to $13:00$ (July).
  - Dining room: weekdays $14:00$ to $15:00$ (but July and August).
  - Kitchen: weekdays $13:00-16:00$ (but July and August).
- The lighting intensity was $7.66[W/m^2]$.
- The electric equipment had an average intensity ratio in classrooms of $3.83[W/m^2]$. However Studio-1,2 and 3 had higher intensity $6.22[W/m^2]$. Finally the computer room had the highest ratio $12.44[W/m^2]$.

The comfort was based on:

- Metabolic activity $138[W/person]$ which corresponds to $1.3[met]$ or sedentary activity (schools, office, laboratory).

- Radiant fraction 30%.

- Air velocity in the occupied zone: winter $0.13[m/s]$, summer $0.17[m/s]$.

- Clothes: winter $1.0[Iclo]$, summer $0.5[Iclo]$

The set-point dry-bulb temperatures were: winter $21[°C]$, summer $26[°C]$. There is no control of the relative humidity in winter. During summer it was assumed that 30% of the cooling load was latent (which is a common design of cooling equipment for the Spanish latitude). The ventilation was assumed direct into each zone as an infiltration (or uncontrolled ventilation). A real estimation of its value is difficult. Moreover, according to the audit data, the opening and closing of the windows is discretionary for the occupants. Therefore, it was decided to use the infiltration as a tuning parameter in order to match measured and computed energy consumptions. The infiltration was given as a flow per exterior wall area and during unoccupied hours it was assumed that the infiltration was 5% of its peak value. The value that fitted the measured energy consumption was: $0.004[m^3/(s \cdot m^2)]$ (applied at each external wall). This provides ventilation rates for the different school zones in the range $(0.003, 0.010)[m^3/(s \cdot person)]$. Section HE2 of the Spanish code suggests $0.0125[m^3/(s \cdot person)]$, therefore, the school has clearly insufficient ventilation.

Figure (4) shows the weather file for Valencia according to the Ministry official database. It shows the hourly frequency of the outside hygrothermal conditions. The building dry-bulb temperature set-points are also displayed for visual reference. The "officially" available weather data conditions for peak loads design, suggest a peak dry-bulb temperature of $33[°C]$ for Valencia (see Figure (4)). The peak load calculation, for the school, with this temperature gives a cooling power around $45[kW]$. However the engineers are aware of the earth global warming, and they discard that value and nowadays use $35[°C]$ instead (see Figure (4)). In this case the peak loads calculation provides a cooling power of $54[kW]$. However the installed cooling power is actually $59[kW]$ (see Table (7)). So, by solving the *reverse problem*, we got $38[^{\circ}C]$ as the correct design temperature which matches the installed cooling power ($60.6[kW]$) (see Figure (4)). In our opinion, this adds to the evidences on the schools overheating issue described in §1.1. In fact, nowadays it is not rare to achieve outdoor summer temperatures of $40[^{\circ}C]$ or even higher during 2 or 3 days. These extreme episodes also impose an additional stress on the cooling equipment which causes unexpected failures. Moreover a greater number of hours working at a higher partial-load, shifts its seasonal efficiency, down.

From the previous comments it can be concluded that though all the paper results are based on the *official* weather file shown in Figure (4), the summer conditions of the actual weather seem to be drifting to the right in that figure, i.e., to higher temperatures. Therefore, why using here the *official* weather file, instead of the actual one?. There are several reasons:

1. Obviously, it is costly or hard to get the hourly data for all weather variables for each building site and each analyzed year. This would prevent the widespread of the methodology employed by SHERPA.
2. Due to all the uncertainties in the model input data, a pragmatic method would just look for a reasonable approach between the expected measured and the computed values. An accepted relative error between the measurements and outputs from a model is between $\pm10\%$ and $\pm30\%$ (the upper limit can be decreased to around $\pm20\%$ by using actual weather data, see [22]). The better the relevant building physics are modeled the better the sensitivity of its subsequent predictions.
3. The professionals *must employ these official* files to design nZEB, according to the country normative.

The *official* file should represent an average expected weather. Winter prevails over summer conditions for schools, since during July and August, they are closed. Within winter, the model can match (with a reasonable uncertainty) the actual measurements. Nevertheless, our study reveals that, for summer conditions, there are deviations which cannot be explained by a reasonable adjustment of the model parameters within their range of uncertainty. Moreover, there is a mismatch between computed and audited cooling power. All these issues indicate that summer conditions are getting hotter and spreading into the school days. It would be advisable to upgrade the *official* weather files due to this climate change.

4.3. Energy simulation validation

The simulation model must be validated in order to make estimations about new strategies. While trying to fit the simulation to the measured energy consumption, some unexpected issues appeared.

Tables (8) and (9) show the monthly measured consumption of electricity and gas, respectively, along with the outputs from the simulation. We have detected a certain amount of electricity consumption which cannot be justified. According to the audit during July and August the activity at the school is usually very low. But the simulated and measured values do not match because there exist a non-negligible electricity consumption during these months. This *parasitic* consumption was estimated by averaging the two lowest values of July and August for two years (see $(*)$ in Table (8)). It amounts to $709[kWh/month]$ and it was assumed to be a constant value along the year.

At the bottom floor there are four showers which are used occasionally without a schedule. A quick estimation of domestic hot water daily consumption gives $75[l/day]$ at $50[^{\circ}C]$ and assuming that the mains water temperature is $12.3[^{\circ}C]$ and the heat loss rate from the storage tank is $31[W]$ leads to a year-round consumption $\approx 709[kWh/yr]$. Therefore this would justify only one moth of the *parasitic* electricity consumption.

With respect to the gas consumption, the problem of service aggregation showed up since there was just one gas meter for both the boiler and the kitchen. We assumed that the simulation values were correct and obtained the kitchen gas consumption as the difference between the metered value and the simulated heating consumption. Afterwards it was checked with the kitchen occupancy and schedule data from the audit, as a plausible value.

Natural gas consumption for heating is much higher ($26344[kWh/yr]$) than the electricity consumption for cooling. The latter, since the electricity is aggregated, has a simulated value of $1791[kWh/yr]$ (sum of the cooling column in Table (8)). The overall relative error between the yearly metered consumption values of electricity and natural gas are 4.61% and 4.73% respectively. However on a monthly basis, the relative error for the electricity consumption is bigger, in the range between -41.47% and 22.6%. These boundary error limits correspond to the most uncertain months, i.e., July and August. For the winter months the error is much smaller and for the intermediate months (those of spring and autumn seasons) the relative error increases. In our opinion, this discrepancy is caused due to eventual cooling needs because of the climate change. However, as was mentioned, the simulation weather file does not take this fact into account, but in our opinion, its effects are already embedded into the audit data.

Summarizing, it can be stated that energy simulation helped us to check the consistency of the audit data outcomes and to disaggregate or estimate the energy consumptions per service.

5. Upgrading the school performance

This section is split into two strategies. First, the energy saving measures proposed by the audit engineering company contracted by SHERPA. Second, the strategies to transform the school into a nZEB according to the current Spanish code.

5.1. Saving measures according to the audit

This section presents the economical evaluation of some of the energy saving measures proposed by the auditing company. Although the economic evaluation of any action is arguable, it is worthwhile to be included here since affects the decision-making process. The goal of the proposed measures was not to convert the school into a nZEB, but just to establish attainable options. The return period considered was $n = 20[yrs]$. The calculations were done according to the European Directive 2010/31/UE about energy efficiency in buildings. The interest and the inflation rates assumed were $i = 1\%$ and $infl = 2\%$ respectively. The economic indicators are computed as follows:

$$NPV_s = \text{Net present value of savings} = \text{cash-flow} \cdot \frac{1}{i - infl} \cdot \left(1 - \left(\frac{1 + infl}{1 - i}\right)^n\right)$$
$$NPV = \text{Net present value} = NPV_s - \text{Invested capital} \tag{1}$$

The discounted payback period DPP is the value of n in Eq. (1) which makes $NPV = 0$.

$$DPP = \frac{\text{Invested capital}}{\text{Yearly net cash flow}} \tag{2}$$

Finally, the internal rate of return IRR is the value of i in eq.(1) which makes (for $n = 20[yrs]$) $NPV = 0$. A subset of the most interesting energy saving measures are the following:

1. Optimization of electric tariff (peak vs off-peak): the current electric power contract is $P1 = 20[kW]/P2 = 20[kw]/P3 = 33[kW]$ a better distribution would be $P1 = 16.5[kW]/P2 = 16.5[kW]/P3 = 4.7[kW]$
2. Windows renovation: change the single pane glass with $U = 5.9[Wm^{-2}K^{-1}]$ by a double pane glass with $U = 2.9[W/m^{-2}K^{-1}]$.
3. Thermal insulation walls: add $7[cm]$ in thickness.
4. Upgrade heating and cooling facilities: replace the current systems by a variable refrigerant flow one. (SCOP=5.55, SEER=7.01).
5. Install solar radiation protections outside the windows.
6. Replace current fluorescent lights by their equivalent led: 18% computed lighting energy savings.
7. Occupancy detectors: based on previous experience the company assumes a 1% lighting energy savings.
8. Daylighting control: based on previous experience the company assumes a 3% lighting energy savings.

9. Monitor and control the energy consumption of HVAC equipment: 15%, not computed, based on previous experience.

At first sight, it might be shocking that one item is to install cooling/heating systems. In fact most of the Valencia region schools, as the SHERPA-project shows, lack of them or they are insufficient. The engineers main concern was to produce a realistic list. Whether they are technically feasible or economically cost-effective for each case, is another problem. The assessment and quantification work adds costs to the renovation budget which have not been taken into account. Table (10) shows the economical evaluation of the previous measures. A positive NPV means that the investment is profitable. Unfortunately, as Table (10) shows, the general trend, almost for any measure, is that the payback time DPP is long or the internal rate IRR is very low.

This is in agreement with other findings as mentioned in §1.3. Particularly, the study presented by Meron and Meir [13], for green schools in Israel, has as extra interesting feature: they included also the teachers satisfaction. Curiously, occupants satisfaction is frequently overlooked.

5.2. Towards a nZEB according to the new Spanish code

As §5.1 shows, the strategy of focusing on energy savings seems to be , in general, non cost-effective. Therefore, next step was to analyze what benefits could be obtained by transforming the school into a nZEB according to the Spanish transposition of the EU Directive, apart from complying with the code. In doing so, an unexpected result showed up that led us to explore, finally, an alternative in the direction pointed out by Meron and Meir.

5.3. Renovation strategies: Spanish nZEB and our alternative

This subsection shows three cases: (A) current state, (B) tailored renovation and (C) full renovation, in order to comply with the nZEB requirements of the new Spanish CTE-DB-HE ~~2018~~ 2019 code.

In concrete, case (C), represents the minimum amount of actions to be taken, so that it can be considered a nZEB. The code states that the building must comply with the limits as if it were new.

Starting at the school in its current state, while computing its primary energy indicators $C_{ep,tot}$ and $C_{ep,nren}$ (see Table (12)), it was surprisingly found that the school could already be considered a nZEB. However, it is not, because it fails to comply with the maximum U-values and solar heat gain constraint $G_{july,max}$ as if it were new.

One question comes up immediately: what force would drive the decision of transforming the school into a nZEB?, i.e., its transformation from state (A) to state (C). The school already satisfies the HE0 but violates HE1, hence it must upgrade the thermal performance of its envelop, but, what for?, what is the benefit?.

Therefore, it was decided to explore an alternative case (B) which represents a different situation from (C). In (B) the actions were consistently taken with the fact that the school is an old existing building. The alternative goal, was not to obey the CTE-DB-HE ~~2018~~2019, but to focus on feasibility and performance effectiveness: better comfort and greater energy demand reduction.

Table (11) summarizes what actions were taken in both cases (B and C). In case (C) the amount of thermal insulator and the quality of the windows are such, that the maximum U values allowed by the CTE-DB-HE ~~2018~~2019, are obtained. Since, perhaps, a more practical or intuitive magnitude is the thickness of thermal insulation employed, the table also displays it, inside the parenthesis for each envelope element. The solar heat gain coefficient SHGC of windows is, additionally, constrained by CTE-DB-HE ~~2018.~~ 2019. Cases (C) and (B) have in common that an automatic blind control is placed to control heat gains. However, there are important differences between the two:

- Heating and cooling services: if a zone had no cooling in case (A), then neither in case (C). In other words, it is not compulsory by the CTE-DB-HE ~~2018.~~ 2019. Notice that according to the option chosen by Spain (see

§2), the primary energy indicators are computed based on the whole useful area, regardless of the existence or not of heating/cooling service. In case (B), on the contrary, every occupied zone has both cooling and heating systems.

- Ventilation: in both cases (B and C) the air flow rate is increased according to the CTE-DB-HE ~~2018~~ 2019 at each zone. However, in (C), the ventilation is supplied directly into the zones, while (B) has an air handling unit (AHU). Therefore, case (B) has a centralized ventilation system. The AHU has two components : an economizer (also known as free-cooling) and sensible heat recovery system (70% efficiency).

- Windows: in case (B) the windows remain the same as the current ones.

- Insulation: in case (B) the insulation thickness has been chosen to get the best improvement in occupants comfort, regardless of the CTE-DB-HE ~~2018~~ 2019 constraints. In other words, more effort has been done on those thermally weak parts of the building.

At first sight, looking at the last two columns of Table (12), it seems, as was mentioned, that all three cases (A,B and C) are nZEB. Recall that the original school (case (A)) is included. Moreover it has primary energy indicators well below the nZEB thresholds established by Spain. Therefore, one might think that there is no need to act on the school. What Table (12) shows, in fact, is that all cases fulfill the chapter HE0 of the CTE-DB-HE ~~2018~~ 2019 (see §2). However as can be deduced from Tables (6) and (11), only case (C) fulfills the U and $SHGC$ constraints on the envelope elements, or in other words, complies with chapter HE1 (CTE-DB-HE ~~2018~~2019). The current school (A) is not a nZEB although it consumes as if it were so, or simply stated, its consumption is already low. This trend, although not so outstanding, was observed in the other schools audited by the SHERPA project. The reasons may be several-fold, just to mention a few: energy poverty, schools have not the occupant comfort as their main business goal (like hotels) and the calculation method of the primary energy indicator (as mentioned in §2) tends to indicate better performance than reality. Therefore, energy, and hence economic, savings from an hypothetical conversion into a nZEB, are likely to be non-profitable.

When a building is qualified as nZEB, occupants take comfort and air quality for granted. Since the nZEB mark is promoted from the EU, as good-quality and environmentally-friendly buildings, failing to come up to this expectation, would put in risk the nZEB quality. However as exposed in §2, comfort and air quality are treated as a kind of by-product in codes and norms. Therefore the thermal comfort attained in the school was targeted as our new main objective.

The use of adaptive or *PPD-PMV* comfort metrics, for southern European countries, is a controversial subject [3] [23]. In this work, the *PPD-PMV* method has been preferred. The *PPD-PMV* comfort model can be found in EN 16798-1:2019 [24] or ISO-7730 [25]. The PPD and PMV was computed by EnergyPlus as a time averaged value $\overline{PPD}$, for each zone, during occupied hours. Using just a single PPD indicator for the whole building, mainly for existing old ones, and for the entire year, may lead to wrong conclusions, since comfort is smoothed out among the zones and the seasons. Recently Enescu [26] reviewed comfort indexes for buildings, but we have preferred to use an area weighted averaged $\overline{PPD}$ index. For a certain time-span, the discomfort distribution through the building, is computed as a discrete set of values: $(A_{i-zone} \cdot \overline{PPD}_i)$, for each i-zone. The area averaged school discomfort is thus computed as:

$$\overline{\overline{PPD}} = \frac{\sum_{i-\text{Occupied zone}} (A_{i-zone} \cdot \overline{PPD}_i)}{\sum_{i-\text{Occupied zone}} A_{i-zone}} \tag{3}$$

By σ, we mean the standard deviation of the discomfort distribution. Tables (13),(14) and (15),(16) show the detailed distribution of $\overline{PPD}_i$ among the thermal zones, at the bottom and at the first floor respectively and per time-period ($Y \equiv$ year, $W \equiv$ winter and $S \equiv$ summer). Letters in the tables refer to the cases. The norm ISO-7730 establishes three thermal comfort categories based on the PPD (percentage of dissatisfied people):

- Category-I: High level of expectation. For sick, very young children and elderly persons.($PPD \leq 6\%$)

- Category-II: Normal level of expectation. For new buildings and renovations.($6\% < PPD \leq 10\%$)
- Category-III: Acceptable level of expectation. For existing buildings.($10\% < PPD \leq 15\%$)
- Category-IV: Only acceptable for short periods of time.($15\% < PPD$)

In order to make clearer the representation of these categories, instead of plotting directly the $\overline{PPD}_i$, the following linear mapping has been used, on the right hand side of Tables (13),(14),(15),(16):

$$\begin{aligned} &\text{Mapped} - \overline{PPD}_i = 1 + \tfrac{0-1}{15-6} \cdot (\overline{PPD}_i - 6) \\ &\text{If Mapped-}\overline{PPD}_i > 1 \text{ then Mapped-}\overline{PPD}_i = 1 \end{aligned} \tag{4}$$

By using equation (4) any acceptable comfort Category will have a positive Mapped-$\overline{PPD}_i$ value, while negative values are all, unacceptable, i.e. Category-IV. For the current state, case (A), it can be observed that the bottom floor of the school has serious thermal comfort problems since the minimum acceptable comfort is not attained, even in winter. The first floor shows a better performance, just the one expected from an existing building. This is because this floor is isolated from the ground and the roof receives solar radiation during winter. In general outside the winter season, the comfort is not very good. Nevertheless, recall that the school, from the point of view of energy consumption (HE0), would be a nZEB but it lacks the thermal upgrade of its envelope.

Then, how does the thermal comfort situation change, if the school is transformed into a nZEB by this upgrade according to HE1 (CTE-DB-HE ~~2018~~2019), i.e., case (C)?.

In this case, during winter, some zones of the bottom floor reach a normal comfort level, others still are out of comfort but the number of dissatisfied people is reduced. However, during summer comfort gets even worse than that of the original school. In passing, recall that case (C) has the same the cooling and heating services per zone than case (A).

Finally for the partial or tailored renovation case (B), the bottom floor (but the dining-room) attains normal comfort levels, similar to case (C) and sometimes even better. On the left side of Table (12), can be appreciated that case (B) achieves better comfort and less spread through the zones than case (C) for all the periods (year, winter and summer). Even the energy performance of (B) is better than (C), because the investment focused precisely on comfort and energy consumption. However, case (B) would not be a nZEB according to CTE-DB-HE ~~2018.~~2019.

Next section describes the political and practical implications of the results exposed in this section. Some recommendations to policy makers are also suggested.

6. Discussion

The previous §5.3 shows a trend shared by the schools audited within the SHERPA EU-project although, perhaps, not so clearly. In Southern Europe schools seldom if ever, have cooling systems in classrooms. This was not an issue some years ago but, progressively, school operational months like May, June, September and October have very hot days and therefore the lack of cooling is becoming a serious problem. The indicators employed to define the threshold of a nZEB, are based on primary energy consumption divided by the useful building area. The way it is calculated, as the norm [16] itself points out, does not guarantee that an acceptable comfort is achieved. The example school shows, perhaps, an extreme but real case. The example school chosen, based exclusively on these indicators, would already be a nZEB. Thus its energy consumption is low and the school will hardly find any economically profitable measure based on energy savings. Hence the economic benefit seems not to be a good target, at least, for schools. If, according to the new CTE-DB-HE ~~2018~~2019, the school wants to get the nZEB label, some renovations are needed to reduce solar heat gains and thermal conductivities of the envelope, as if the school was new. Precisely this last constraint, according to our results, would be a big obstacle for school renovations. For existing schools achieving the thermal upgrade of the envelope, as a whole, might not be economically feasible. Moreover, as in the example case, if the school has already a low energy consumption then the renovation driving force becomes weaker.

Let us assume, for the moment, that this upgrade is really accomplished, regardless of economical considerations. The school would finally receive the nZEB label and the occupants would perceive a better performance due to an improved thermal comfort. However there are two drawbacks. In the first place, the singularities of being an old building were overlooked or not taken into account. It is very common that existing schools have partial renovations of building sections or even more recent constructions attached to the old building. In the second place, the national code does not force to provide cooling or heating service to all zones, although the consumption indicator is referred to the overall useful area. Therefore, during summer, the comfort might be even worse than in the original state due to overheating problems. Besides, during the other periods, the reduction in thermal dissatisfaction was not optimized, since the driving force was to comply with the national normative. It could be said that the goal of the investment was not, in our view, correctly oriented. Finally, this could affect, in the long term, to the perceived quality of nZEB labels.

In the previous section §5.3 another strategy was suggested. Instead of upgrading the old building as if it were new, the idea was to look for the big *thermal weaknesses or loopholes* of the old building and to try to optimize the decisions from economic, feasibility and comfort points of view. This was our case (B). The current annual comfort ($\overline{PPD}$) is quite bad. The example school in case (A), belongs to comfort Category-III but close to an unacceptable comfort level. Cases (C) and (B) are still in Category-III but they move away from Category-IV and improve the comfort. Nevertheless, case (B) performs better than (C) in both, energy and comfort. Paradoxically, case (B) would not be a nZEB according to the CTE-DB-HE ~~2018~~ 2019 , because although the energy indicators comply (see Table (12)), the thermal parameters of the envelope still fail (see Table (11)) to be those of a new building. Therefore, despite all the three cases have in common that their energy indicators are below the nZEB threshold, only case (C) is actually a nZEB.

It is worthwhile to make a final remark. In all cases, the dry-bulb temperature set-point schedule was the same. Therefore the comfort changes were due to envelope improvements and additionally, in case (B), also to the fact that all occupied zones had heating and cooling services.

7. Conclusions

The outcomes of this work are the following:

- The combination of audit and energy simulation, creates a powerful checking or diagnosis tool. If while trying to tune the model parameters, inside their sensible uncertainty range, the relative error, with the audit measurements, cannot fitted between ±10% and ±30%, then this might be an indicator that something relevant is going on. In our case, there is a mismatch in the cooling needs (energy consumption and installed capacity). The particular conclusion, here, is that the *official* weather files, used for the energy labeling of buildings, do not contain the effects of the climate change. Therefore governments should upgrade the weather files. An alternative solution, could be to make, the energy performance certification of buildings, completely self-referencing.

- Many studies agree that school rehabilitation is not cost-effective (unless photo-voltaic energy is produced in-site). Therefore seeking for nZEB energy efficiency is not attractive from an economical point of view. However, there are other benefits: the ultimate one is to improve the comfort and getting ready for the climate change. Therefore, for a building owner, spending the same money on energy resources, but achieving a better overall comfort can be an incentive. It can be stated as an *energy poverty issue*:

keeping acceptable comfort conditions in schools is not an economic objective, as it is in other tertiary buildings like hotels or hospitals. Schools, frequently lack of cooling services and some times even of heating ones.

- The way the primary energy indicator is currently calculated (based on norm [16]), treats comfort as a by-product. It may happen that comfort levels could be unacceptable and the indicator may overestimate tertiary buildings performance.
- The previous item would downgrade the energy label quality and the confidence on an nZEB label as a valuable asset. Declaring a school as nZEB but at the expense of low comfort rates could be hazardous for the schools rehabilitation.
- The concept of nZEB should be defined without ambiguities otherwise it may create incoherences and flaws. For instance, the Spanish nZEB requirement of upgrading the envelope with the same constraints imposed to new buildings seems not to be reasonable. As the paper shows, the money could be spent in a more profitable way by fixing the weakest elements of the school. Moreover, sometimes acting on some elements of an existing building is just not feasible or too expensive.
- Practically, any school renovation measure focused on energy saving is likely not to be economically profitable.
- The comfort is not exclusively determined by the thermostat set-point. The current indicators and norms may allow the labeling of a school as a nZEB but displaying a low comfort level. Therefore, the policies should be reoriented to include some kind of comfort optimization.

According to our results, our recommendations to policy makers would be the following:

- The nZEB definition must distinguish between new and existing schools.

- It would be advisable to attach summer and winter comfort indicators into the nZEB label.
- A comfort level equal to Category-II, with low variability within the building zones, should be a requirement of a nZEB school.
- Financial instruments based exclusively on economical savings would be inefficient for school renovations or rehabilitations. On the contrary, investments oriented to improve comfort (even during extreme weather conditions due to climate change) while keeping, perhaps, the same consumption level, could be appealing for private and public sector schools.

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(Overall budget €3.591.689, 35).(http://sherpa.interreg-med.eu) We would like to thank also the reviewers for their effort. Their suggestions about new recent references, of which we were not aware of at the time of writing, have enriched the paper.

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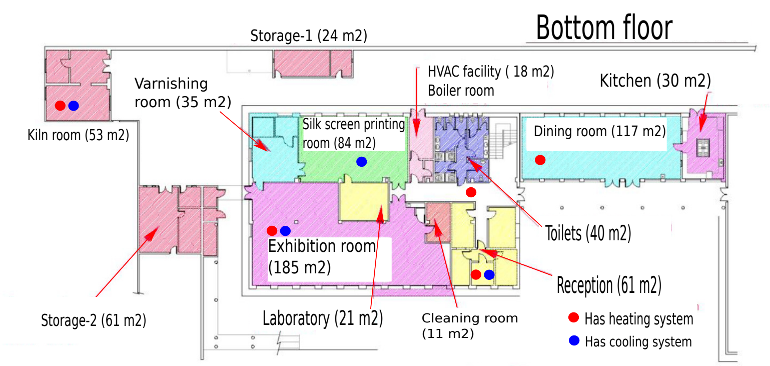
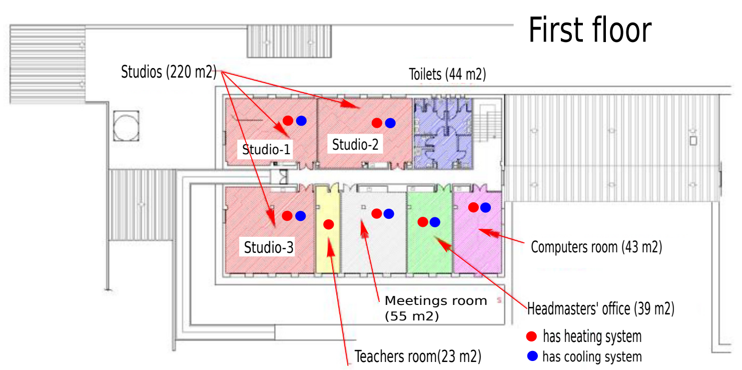
Built area of the complex [m^2]	21361
Built area of the school [m^2]	1328
Year of construction	1948
Occupation	50-60 students and 15 teachers
Timetable	9:15-16:45, July administrative tasks only, August closed
Periods (W)	Winter: Jan,Feb,Mar,Nov,Dec
(S)	Summer:Apr,May,Jun,Jul,Aug,Sep,Oct
Pictures of the site	
Heating & DHW systems	
Cooling system	

Table 4: Case example: Data-block 1 from audit. General data and visual inspection.

Kiln room
Varnishing room
Silk screen printing room
Exhibition room
Laboratory
Dining room
Reception
Kitchen



Studio-1
Studio-2
Studio-3
Teacher's room
Meetings room
Computers room
Headmaster's office



Useful area (A)	$1243[m^2]$ (without storage(1&2) spaces)
Compactness: V/A	$2.12[m]$

Table 5: Example school: Plans. Zone area. Heating and cooling services

Component	Layers	$U[Wm^{-2}K^{-1}]$
Floor (soil)	reinforced concrete $3[cm]$	$U = 3.71$
	concrete mortar $4[cm]$	$U_{max} = 1.00$
	paving stone $3[cm]$	
External walls	brick $11.5[cm]$	$U = 1.70$
	air gap (ventilated) $2[cm]$	$U_{max} = 1.00$
	brick $5[cm]$	
	gypsum plaster $2[cm]$	
Roof	floor tile $2[cm]$	$U = 1.60$
	concrete mortar $1[cm]$	$U_{max} = 0.65$
	roofing felt $0.5[cm]$	
	slab $37[cm]$	
Dining-room Roof	sandwich panel	$U = 1.00$
		$U_{max} = 0.65$
Fenestration	Simple glass $[5mm]$	$U = 5.70$
	metallic frame	$U_{max} = 3.20$
	interior curtains	
Door	metallic sheet $8[mm]$	$U = 6.70$
	simple glass $5[mm]$	$U_{max} = 3.20$
$U_g < U_{g,max}$	$G_{July} < G_{July,max}$	Complies CTE-DB-HE ~~2018~~2019
$2.7 < 0.8$?	$6.1 < 4.0$?	No

Table 6: Example school: estimated envelope thermal properties and limiting values according to the new Spanish code CTE-DB-HE ~~2018.~~ 2019. *(Remark: the U values include the convective film coefficients).*

Type of producer	Nominal efficiency	Seasonal efficiency	Rated thermal Power $[kW]$
Conventional boiler	0.92	0.80	99.4
Cooling equipment	N/A	$SCOP = 2.16$	59.1
Electric heater-DHW ($50[l]$)	1.00	N/A	2.0
No mechanical ventilation	N/A	N/A	N/A

Table 7: Example case: estimated seasonal efficiency of the producers and rated thermal power.(*Note: N/A non-applicable*)

	Electricity consumption $[kWh]$						
	Actual			Simulation			
Month	2016	2017	Mean	Lights	Appl.	Cooling	Subtotal*
January	2337	2596	2467	944	491	0	2144
February	2208	2483	2346	1048	546	0	2304
1 March	1713	2277	1995	1154	601	0	2464
April	2103	1802	1953	772	574	5	2059
May	2100	2093	2097	603	628	280	2220
June	1647	1937	1792	436	453	606	2203
July	*590	909	750	71	71	210	1061
August	1004	*828	916	0	0	0	709
September	1915	1914	1915	387	402	690	2188
October	2023	1906	1965	845	624	0.00	2178
November	2817	2549	2683	1138	597	0.00	2444
December	1935	1935	1935	776	407	0.00	1892
		Total=	22811			Total=	23865

Table 8: Case (A). Left: Values obtained from the bills of two years. Right: Values from the simulation. (∗) *Note: an "unknown" constant consumption equal to* $(590 + 828)/2 = 709$ *is added in each subtotal row.*

	Natural gas consumption $[kWh]$				
	Actual			Simulation	Kitchen
Month	2016	2017	Mean	Heating	Estimated value*
January	5500	5000	5250	6935	-
February	7700	11000	9350	5876	-
March	8500	7700	8100	3979	-
April	5800	3000	4400	0	-
May	3400	3200	3300	0	-
June	500	500	500	0	-
July	0	0	0	0	-
August	0	0	0	0	-
September	0	0	0	0	-
October	500	500	500	287	-
November	1800	1800	1800	3655	-
December	8000	8000	8000	5612	-
		Total=	41200	Total=26344	Total=14856

Table 9: Case (A). Left: Values obtained from the bills of two years. Right: Values from the simulation. (∗) *Note: the gas consumption of the kitchen is estimated for a year round*

Measure		NPV	$IRR([\%])$	$DPP([yrs])$
Optimizing electric tariff		(+)	49.2	0.02
Window renovation		(−)	0.00008	22.6
Thermal wall insulation		(+)	0.096	7.0
Upgrade HVAC system		(−)	0.001	29.3
Solar window protection		(+)	0.11	8.7
	Led	(+)	0.144	7.0
Lighting	Occupancy detectors	(+)	0.061	12.6
	Daylighting	(+)	0.356	3.0
Consumption controls		(+)	0.139	7.34

Table 10: Example school. Economical evaluation of the energy saving measures proposed by the auditing company

Main thermal properties of the school buildings

#	VENT.	Blinds† control	Walls $U(e)$	Roof $U(e)$	Floor $U(e)$	Windows U $SHGC$	Doors U
(B)	SHR	Yes	0.461 (6)	0.419 (6)	0.575 (5)	5.69 0.830	6.67
	ECO						
(C)	DIR	Yes	0.726 (3)	0.366 (8)	0.756 (4)	1.00 0.431	1.00

Summary of main traits of the school buildings

	AH	AC	U_g	G_{july}	$U_{g,max}$	$G_{July,max}$	nZEB
(B)	Yes	Yes	**1.00**	**5.1**	$<$ **0.8**	$<$ **4.0**	No
(C)	No	No	0.65	2.7	< 0.8	< 4.0	Yes

Legend

VENT.	*Ventilation*
$SHGC$	*Solar Heat Gain Coefficient*
SHR	*Centralized air handling unit with Sensible Heat Recovery*
ECO	*Centralized air handling unit with economizer or free-cooling*
DIR	*Ventilation direct into the rooms*
AH	*All spaces have heating*
AC	*All spaces have cooling*
U	*U-factor, overall heat transfer coefficient* $[Wm^{-2}K^{-1}]$
(e)	*Thermal insulation thickness* $[cm]$
U_g	*U-factor, Global Building heat transfer coefficient*
G_{July}	*Building solar heat gains during the month of July* $[kWh \cdot m^{-2}]$
max	*Subscript for maximum allowed value according to CTE-DB-HE 2019*

Table 11: Upgrade changes performed in the example school. # (B) tailored rehabilitation (C) full rehabilitation nZEB according to CTE-DB-HE 2019. †*(Note: Blinds are active for a solar radiation setpoint of* $300[Wm^{-2}]$*.)*

CASE	$\overline{PPD}$ [%]	(σ)	Heating Cooling energy demand [kWh]	Lighting [kWh]	Total primary energy $C_{ep,tot}$ [kWh/m^2]	Non-renewable primary energy $C_{ep,nren}$ [kWh/m^2]
(A)	(W)12.20	(0.62)	(W)23630	(Y)8172	(Y)44.3	(Y)40.9
	(S)18.20	(1.08)	(S) 3867			
	(Y)14.80	(0.71)				
(B)	(W) 7.52	(0.36)	(W) 6563	(Y)8172	(Y)26.1	(Y)22.8
	(S)19.15	(0.87)	(S) 3997			
	(Y)11.49	(0.49)				
(C)	(W) 8.52	(0.41)	(W)16775	(Y)8172	(Y)37.2	(Y)33.7
	(S)24.63	(1.91)	(S) 4122			
	(Y)13.85	(0.85)				
(see §2), $CFI = 2.85[W/m^2] \rightarrow$ nZEB limits:					$C_{ep,tot,max}$	$C_{ep,nren,max}$
					185	80

Table 12: Comparison of the school actual state (A) with the upgrades (B) and (C). At the bottom, it shows the maximum values for a nZEB for Valencia (CTE-DB-HE 2019, HE0 section, see §2). The conversion factors f from final to primary energy consumption were: natural gas ($f_{ep,tot} = 1.195$, $f_{ep,nren} = 1.19$) and electricity ($f_{ep,tot} = 2.368$, $f_{ep,nren} = 1.954$). *Remark: the seasonal efficiency of the heating and cooling systems is assumed to be the same as the current values.*

BOTTOM FLOOR COMFORT

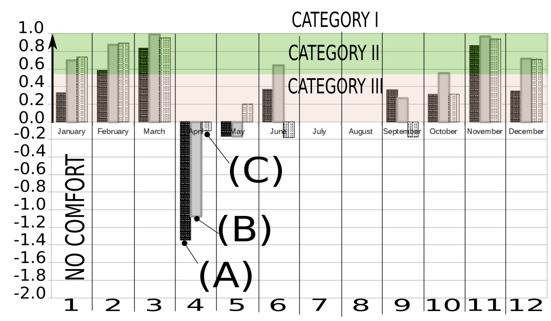
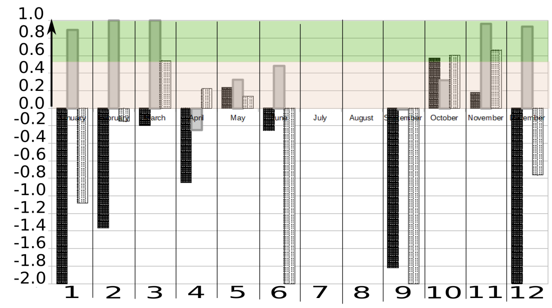
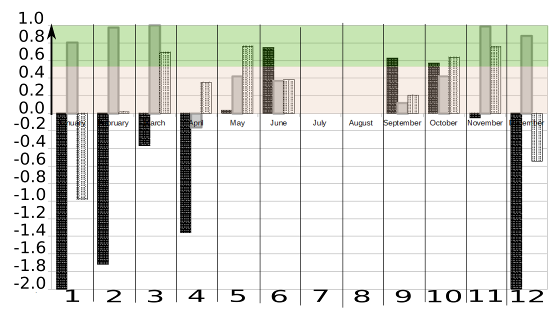
$\overline{PPD}_i$[%]	Monthly *mapped*-$\overline{PPD}_i$
Kiln room (Y)(A12.86)(B11.09)(C10.92) (S)(A19.80)(B18.25)(C18.61) (W)(A 9.68)(B 7.34)(C 7.38)	
Varnishing room (Y)(A21.10)(B 9.79)(C18.75) (S)(A18.80)(B16.80)(C31.11) (W)(A25.60)(B 6.22)(C16.42)	
Silk-screen printing room (Y)(A21.00)(B 9.61)(C12.44) (S)(A13.90)(B16.10)(C13.48) (W)(A28.80)(B 6.51)(C15.09)	

Table 13: (A)-Current state,(B)-Tailored rehabilitation,(C)-nZEB according to CTE-DB-HE ~~2018~~2019, (Y)-Annual (S)-Summer (W)-Winter. x-axis= ordinal number of the month, January≡ 1. *Remark:* 1 ≡*Category I* , *Upper band*≡*Category II* , *Lower band*≡*Category III. Negative values indicate not enough comfort.*

BOTTOM FLOOR COMFORT (cont.)

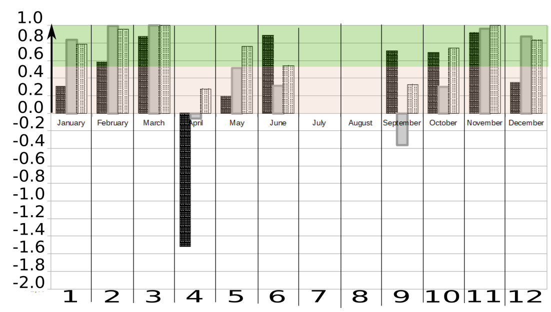
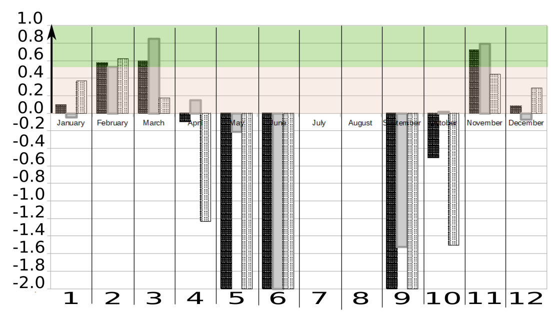
$\overline{PPD}_i[\%]$	Monthly *mapped*-$\overline{PPD}_i$
Exhibition room (Y)(A11.60)(B 9.87)(C 8.25) (S)(A13.30)(B17.14)(C12.80) (W)(A 9.60)(B 6.45)(C6.58)	
Dining room (Y)(A23.70)(B15.57)(C32.38) (S)(A39.80)(B27.10)(C71.29) (W)(A11.30)(B11.31)(C11.59)	

Table 14: (A)-Current state,(B)-Tailored rehabilitation,(C)-nZEB according to CTE-DB-HE ~~2018~~2019, (Y)-Annual (S)-Summer (W)-Winter. x-axis= ordinal number of the month, January≡ 1. *Remark:* 1 ≡*Category I* , *Upper band*≡*Category II* , *Lower band*≡*Category III. Negative values indicate not enough comfort.*

FIRST FLOOR COMFORT

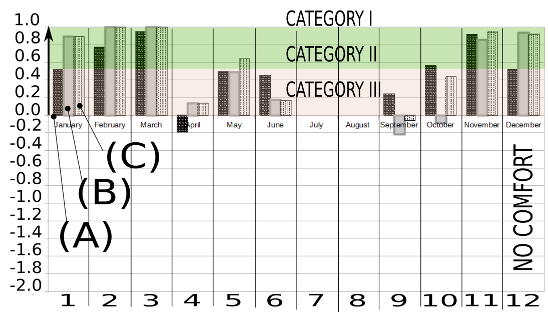
$\overline{PPD}_i\%$	Monthly *mapped*-$\overline{PPD}_i$

Studio-1

(Y)(A10.14)(B10.17)(C 9.25)

(S)(A12.20)(B17.64)(C15.77)

(W)(A 8.40)(B6.45)(C6.29)

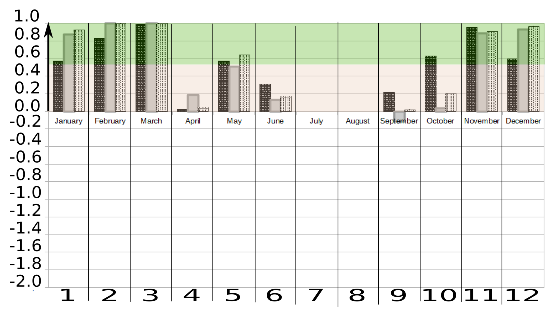


Studio-2

(Y)(A 9.70)(B 9.92)(C 9.53)

(S)(A11.90)(B17.07)(C16.36)

(W)(A 7.90)(B 6.44)(C 6.22)



Studio-3

(Y)(A 9.64)(B10.22)(C 8.98)

(S)(A12.10)(B17.99)(C15.38)

(W)(A 7.70)(B 6.40)(C 6.06)

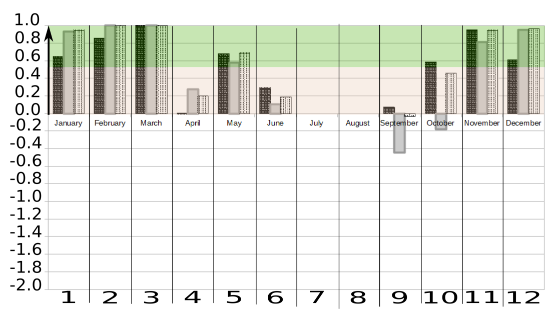


Table 15: (A)-Current state,(B)-Tailored rehabilitation,(C)-nZEB according to CTE-DB-HE ~~2018~~2019, (Y)-Annual (S)-Summer (W)-Winter. x-axis= ordinal number of the month, January≡ 1. *Remark:* 1 ≡*Category I* , *Upper band*≡*Category II* , *Lower band*≡*Category III. Negative values indicate not enough comfort.*

FIRST FLOOR COMFORT (cont.)

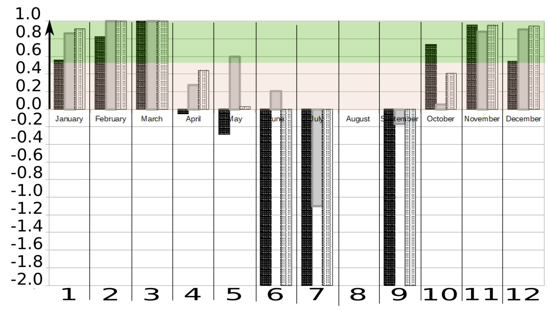
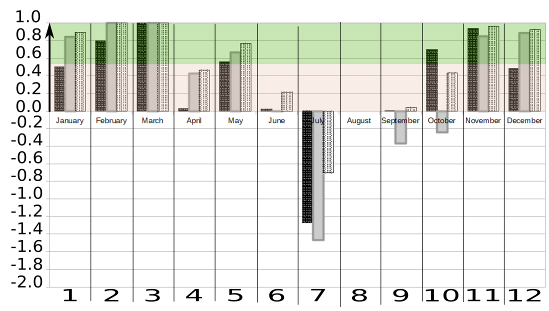
$\overline{PPD}_i$%	Monthly *mapped*-$\overline{PPD}_i$
Teachers room (Y)(A21.75)(B11.00)(C20.42) (S)(A36.20)(B18.24)(C42.05) (W)(A 8.00)(B6.49)(C6.16)	
Headmaster's office (Y)(A11.49)(B11.71)(C 9.77) (S)(A15.00)(B19.77)(C15.80) (W)(A 8.30)(B6.64)(C 6.22)	

Table 16: (A)-Current state,(B)-Tailored rehabilitation,(C)-nZEB according to CTE-DB-HE ~~2018~~2019, (Y)-Annual (S)-Summer (W)-Winter. x-axis= ordinal number of the month, January≡ 1. *Remark:* 1 ≡*Category I* , *Upper band*≡*Category II* , *Lower band*≡*Category III*. *Negative values indicate not enough comfort.*