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# Computational Model For The Estimation Of Thermo-Energetic Properties In Dynamic Regime Of Existing Building Components

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**Abstract**. The guidelines of the European community towards a low-carbon economic society identify one of the most important scenarios in the energy efficiency of existing buildings. The discrepancy between the requirement and availability of free heat (endogenous heat, solar radiation) in certain hours of the day and operating conditions, makes the steady-state hypothesis generally inappropriate. In particular, the oscillating component of the transmitted flow, compared to the average temperature difference, is regressive in winter and dominant in summer. From this it follows the reliability of the stationary forecast models in winter and the need for dynamic forecast models in summer. The dominance of the continental climate in the EU, compared to the Mediterranean one, led to the actual delay in the development of dynamic models, especially at a regulatory level. In this paper, a methodology for assessing the dynamic properties of a building component is evaluated. The methodology, based on heat transmission equations implements a numerical model for existing building components whose input data can be obtained from experimental measurements. The developed model has been used to estimate the energetic and thermal behaviour of a building envelope subjected to energy efficiency measures.

## 1. Introduction

In the world the design of buildings is increasingly addressed to the use of digital procedures. The European Community has recently published directives 2014/24/EU [1] that provide for the digitization of processes. Italy accepted these directives has made Obligatory the use of the BIM (Building Information Modeling) for public works by providing for different time deadlines starting from 2019 up to 2025 where all public works concerning buildings must be managed digitally [2–7]. The flowchart of the procedures used in this work comprising: initial performance measurement, simulation of intervention solutions based on the use of the BIM model are described in Figure 1. The characterization from the thermal point of view of the components of the building envelope, of which there is often no information, and subsequently developing intervention solutions can be considered a reverse engineering problem as shown for numerous themes [8–11] . Energy design is among the digital procedures and the verification of dynamic energy parameters, it is fundamental to the realization of nZEB buildings. The Energy Performance of Buildings Is one of the Main Focuses of the European Union. In the year 2010, the Europe Council issued the Energy Performance of Buildings Directive [12] subsequently updated in 2018 [13], setting the minimum energy performance requirements for new buildings and major renovation projects [2]. In Italy the Directive was implemented with the national laws n. 90/13 and successive Technical Standard, such as the UNI/TS 11300 series (Italian National Unification/Technical Specification) [14] and ISO 52016 [15], were enacted. These technical specifications/standards are based on dynamic mathematical models that are closer to the measured thermal behavior of the building.

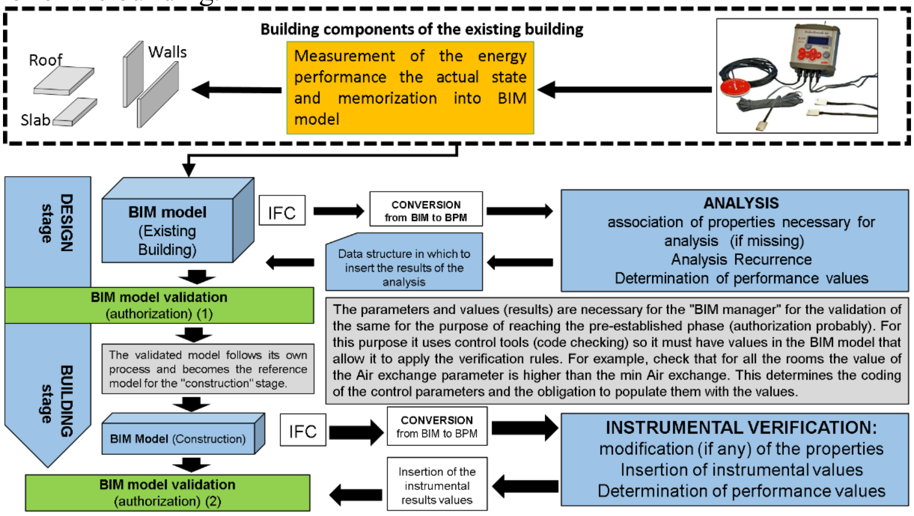



*Figure 1 - Flowchart - Data measurement and BIM model*

For the buildings components, these technical standards were developed the last ten years [15–17] and are more useful for temperate and sunny climates. The most important component of the building, which characterizes its dynamic behavior, is the building envelope. this It can be either be massive or lightweight with Solar shields or not, but should serve to guarantee the thermos-hygrometric comfort of its internal spaces [18]. This model utilizes the three mechanisms of heat transfer: radiative, conductive and convective. For most stratigraphy layers of the building components, for example the exterior walls of buildings, the heat transfer it happens through the conductive mechanism. The current use profiles of the private dwellings, public and services buildings by the people, highlight a dynamic variation of loads associated with the prevalence of the solar radiation in the Mediterranean climate, that also dependent on the variation of the different seasons. All of the abovementioned effects lead to a preference for dynamic physical models for energy analysis and simulation of energy behavior of the buildings in the Mediterranean area and to the realization of stratigraphies with different types of insulating materials [10]. One of the methods for dynamic analysis of the casing based on transfer matrices is explained in the ISO 13786 [17,19–21]. With the method described in ISO 13786 it is possible to use the transfer matrices method to evaluate the dynamic thermal heat transmittance, the phase shift that between the temperature peak and the incoming heat flow peak and the decrement factor (which indicates the ratio by the module of thermal transmittance and periodic thermal transmittance). In some works [22] is shown the wall placed in the climate chamber with the open shells and the sinusoidal. In Italy the SEN (National Energy Strategy) highlighted how the energy efficiency of existing buildings is one of the primary objectives as these buildings are the most energy-sized ones. Most of the existing buildings have no historical or technical documentation. UNI 10351 [23] and UNI 10355 [24] report thermal characteristics of the different component for old typical building walls or typical masonry stratigraphy.

However, in general, it is impossible to establish exactly the correspondence between the existing walls and the recommended in UNI 10351 and 10355, unless it is through the trials of coring[25]. This test is highly invasive, and it is considered dangerous to the preservation of old buildings. In this work, the authors propose one reverse engineering methodology to model the existing state and find project solutions for energy efficiency of building components an inverse/indirect method to derive the thermal properties of building walls starting from thermal measurements. The inverse method is based on the direct method proposed in ISO 13786, which utilizes the harmonic analysis of integration of the Fourier heat equation probably published for the first time in the 1906 edition [18]. The results, carried out through a rebuilding of the reverse harmonic method of the Fourier heat equation, allow to rebuilt the thermal properties of the wall by simple measurement of the temperature and thermal flux both on the outside wall and the inside wall. Hence, in this work, two main sections are presented: the direct harmonic method and the in- verse harmonic method whit the use the BIM platform. In this case, to understand more clearly the second section, the first section is detailed with some flowcharts steps showed in figure 1 and figure 2. At the end of the work, a practical application of the proposed method can calculate the transfer matrix of the thermal property of a “dummy” wall because the homogeneous and isotropic material has the same thermal characteristics of a “real” wall with all of its layers when the magnitude of phase shift and the decrement factor are known. This “dummy” wall has the same properties of a wall with several layers. In the application of nondestructive methods, Brian H. and Mohamed T. K., or Malhotra V.M. and Carino N. J. and Pia G. et al. [26–28], agree with the statement that is possible to measure the average density $\rho$ of the component “in situ”. In the procedure used by some autors [17,22], it is possible to have the specific heat c (J/kgK) of the wall in study-case. In this case, it will be possible to adopt the method for energy-retrofitting in a dynamic application. The model described by ISO 13786 [17] was implemented in the GEAR BIM Tools software, able to interact with the BIM models the interoperable data standard called IFC[29,30].

## 2. Energy benefit evaluation procedures through BIM Tools

The energy retrofit of existing buildings is a fundamental aspect to reason the objectives set by the European Board Has Recently Issued The EU Directive "Roadmap for Moving to Competitive -Low Carbon Economy in 2050" [31,32] Which Lays Down Recommendations to Achieve The Reduction of Greenhouse Gas Emissions Under 80 For Cent of the 1990 Level by Such a Date. Often for existing buildings the stratigraphies of building components and a way to ascertain the starting performance and to perform measures are often known. The procedure implemented, developed for the physical-mathematical part by Ricciu and others, allows through the use of the BIM model of the existing state and the data measured on the construction components the execution of intervention simulations to improve energy performance. This process is schematized in Figure 2

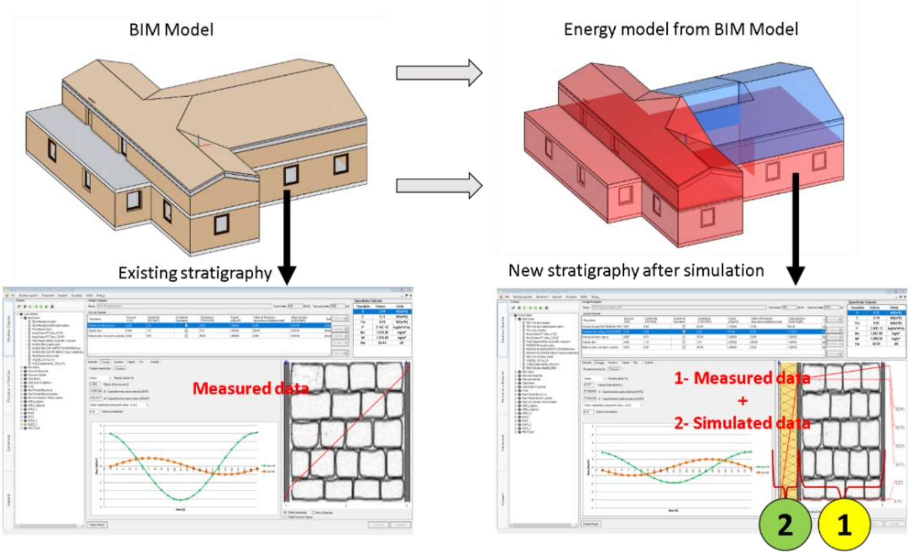



*Figure 2- Generation of alternative solutions for stratigraphy based on the BIM energy model*

The unified handling of a set of physical problems can be seen as an innovative aspect of the developed model presented here that integrates effectively with the three dimensional architectural CAD. The model does not need any ad hoc three dimensional geometric modelling, but can make use of the same model developed for the architectural project.
The physical, geometrical, environmental, characteristics, that are necessary for the simulation of the performance of a building, through the use of BIM are many. The tools that let use the geometrical data or more generally the data of the building from a three-dimensional model, modify and complete the information on the building, on climate, or on different environmental aspects with the need for energy simulations are numerous [33–35]. Several of them allow to import gbXML and IFC formats automatically or in a semi-automatic way to simplify the input of geometrical data and sometimes of those related to the physical properties of building components. A very important aspect when working with different data formats, is the congruence of geometric information data, which is not always guaranteed, taking into account the input mode required by the software or by the calculation model used for energy simulation [3]. This fundamental aspect, if not considered, can spearhead to results affected by errors [3]. The procedure tested in this work encountered a considerable advantage in using the data on the energetic performance of the measured construction components and entered within the BIM base data. The advantage of this approach consists in the fact that for the energy designer [4] it is faster to perform simulations and obtain scenarios of aid to decision-making. This aspect is reflected on the quality of the design result as it is possible to perform many more simulations and optimize the result compared, for example, to the beneficial cost ratio.

## 3. Case study

The methodology described was applied to a case study consisting of a building from the University of Cagliari shown in Figure 3 realized at the beginning of 1900.

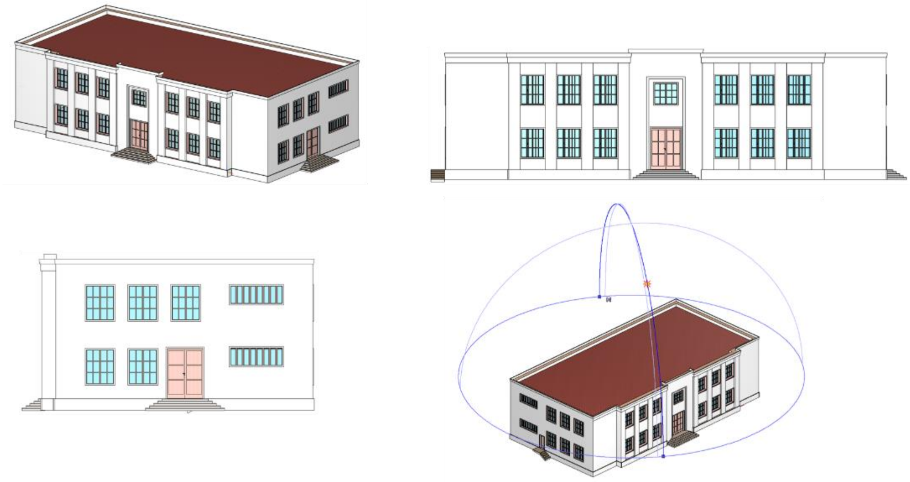
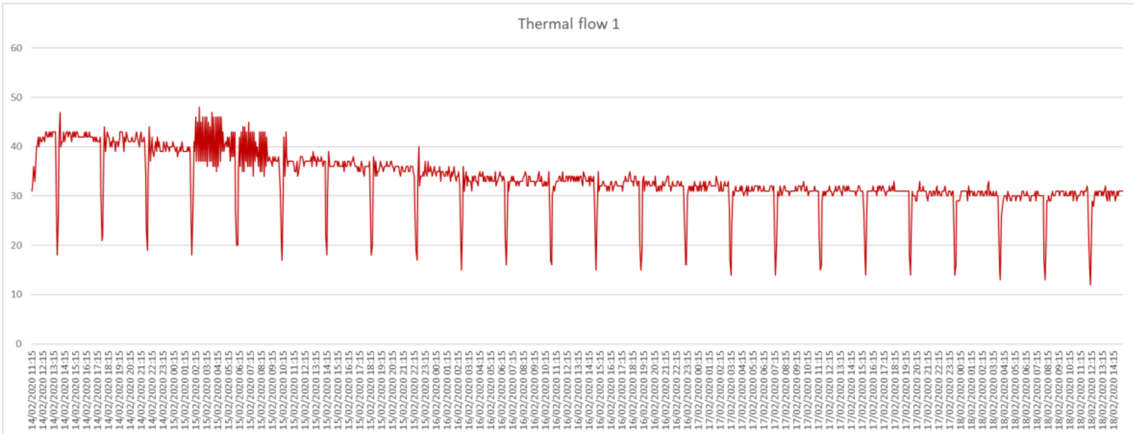
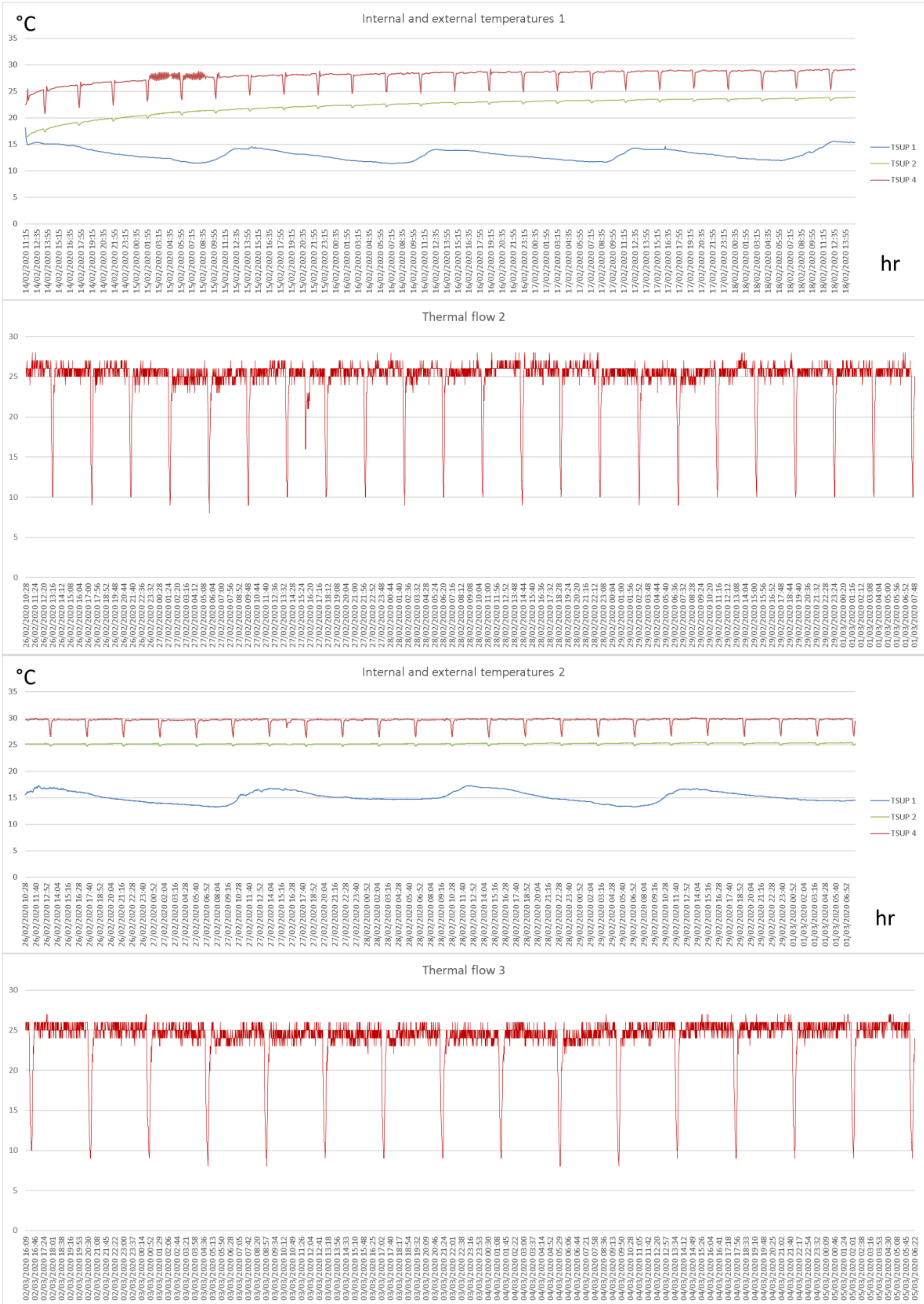


*Figure 3- BIM model case study*

On the study case various measures have been carried out to caress the walls of the building envelope from the thermo-energy point of view. The result of these measurements is shown in Figure 4. The graphs of the measurements show how the internal and external temperatures varies and how the relative thermal flow is varied to difference between internal and external temperature. The data have been reported raw as well as downloaded from the data logger and loaded into the GEAR model [33]. Performing the measures to characterize the external masonry of the building has been tested according to the method adopted by some autors to determine the oscocient thermal flow, surface temperatures completely referred to a period of 24 hours. After this it has been determined the transfer matrix to assign to the wall so as to be able to simulate the behavior of this with the new layers of insulating material. The new layers of insulating material are to be considered as an energy-efficient intervention on the existing building. In particular on existing walls.

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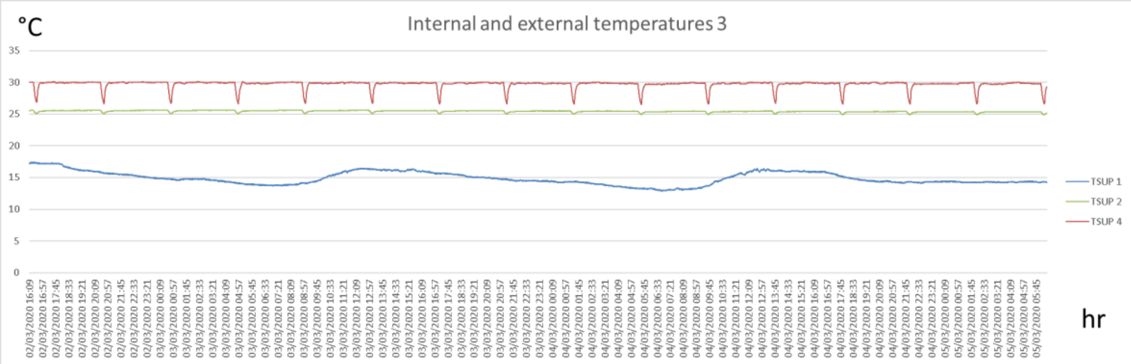


*Figure 4- Thermal flow and temperatures measurements on the study case*

In the BIM model created for the case the energy zoning has been defined. The zoning conscribed in creating groups of rooms with the themes of the energy point of view. In the Language BIM of the IFC standard, the Rooms are called spaces. The new layer of thermal insulator designed for the type of walls on which the measurement campaign was performed at all the walls that delimit the spaces. Figure 5 shows the graphic result of this zoning performed within the BIM platform.

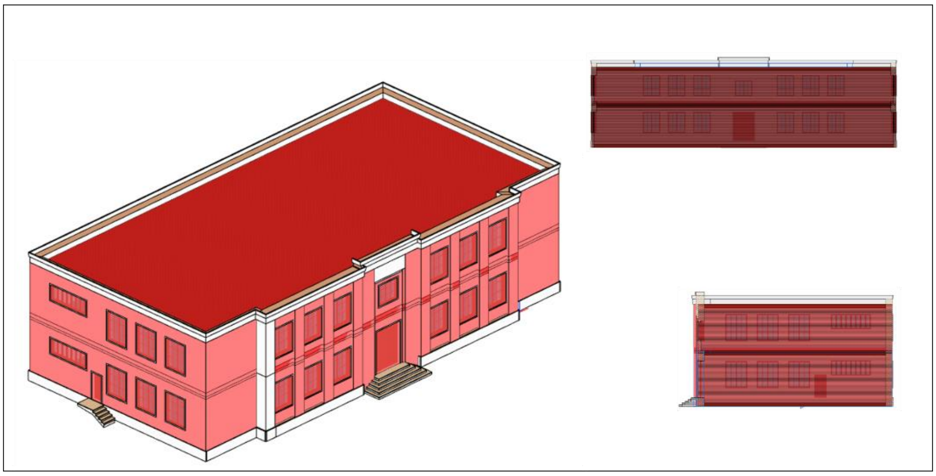

*Figure 5- Energetic zones representation with BIM platform*

According to ISO 13786 [17] and Carslaw H.S., and Jaeger J. Cresults, it is possible to use the direct matrix method to evaluate the periodic thermal heat transmittance; the phase shift be- tween the external temperature peak and the incoming heat flow peak; and the decrement factor. The method works with a single (or multi) layer wall, crossed by a sinusoidal heat flow generated by the sinusoidal variation of the temperature on the two sides of the wall, assuming known the thermal conductivity (W/mK), the specific heat (J/kgK) and the density (kg/m³) of the entire wall. That is a typical thermal forcing on the building envelopes during the daily climatic conditions at middle latitudes. In this paper the authors propose the application of an inverse approach developed over ISO 13786 to obtain the thermal properties of the building components by measuring the sinusoidal periodic steady state (temperature and thermal flux) on the two faces of the wall. In this method the decrement factor and the phase shift between the input and output heat wave are measured and used to build the transfer matrix, from which the thermal conductivity (W/mK) and the specific heat (J/kgK) of the entire wall are carried out. Technically, the proposed method could be applied whenever there is a transfer of energy varying over time according to the sinusoidal law. If the variation was not sinusoidal, the Fourier harmonic analysis method could be applied. In this paper the works of some authors [17,22] method is mathematically solved and tested on a sample building component.

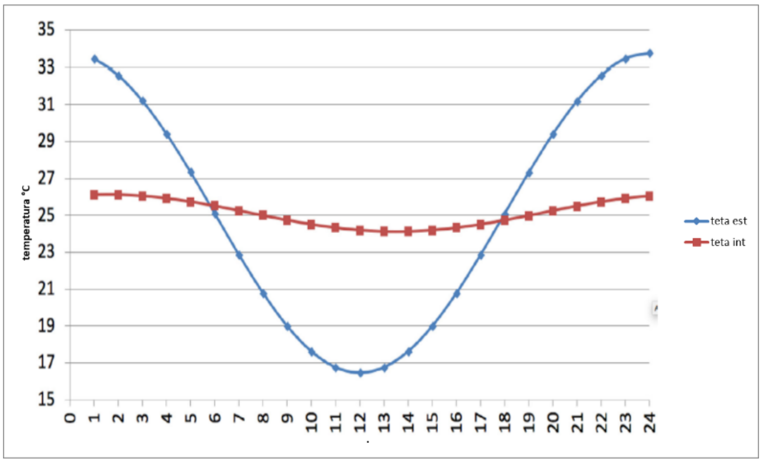


*Figure 6- Energetic zones representation with BIM platform*

Figure 6 shows the oscillations of external and internal temperatures in the period of 24hr considered. As can be observed the oscillation of the external temperature is much more accentuated than the internal one.

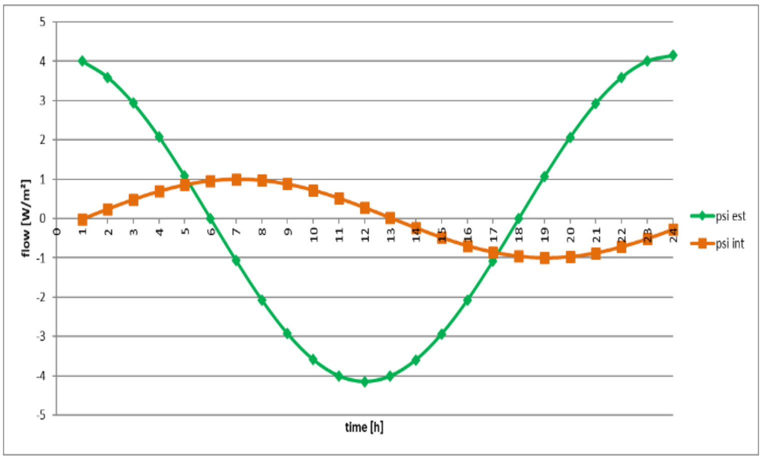


*Figure 7- Energetic zones representation with BIM platform*

In the same way in figure 7, the trend of the hypothesized thermal flow is shown on the internal and external surface of the building component. Finally, in figure 8 the workflow followed in the BIM Tool application in which it is one inverse methodology of method ISO 13786 explained by some authors [17,22], to apply it to the case study considered.

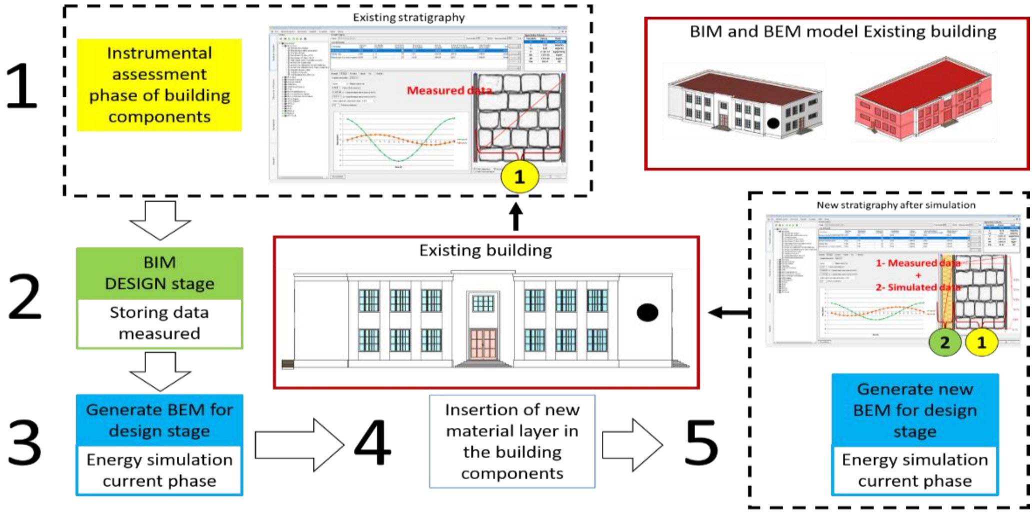


*Figure 8- Energetic zones representation with BIM platform*

The workflow described in Figure 8 In particular, steps 4 and 5 can be repeated several times to generate different intervention solutions. Everything can be used as an aid to the decision-making process to consider the different performance and economic aspects of the different proposed solutions.

## 4. Conclusions

In this work the calculation model provided by ISO 13786 was analyzed with the methodology proposed some autors. The inverse method based over ISO 13786 allows you to relate the data measured with data on the design phase.The model so described, useful in the planning phase of interventions on existing buildings makes it possible to operate project choices on the thermo-energy performance of the casing based on the measure of the provision of the individual building components. The model has been implemented within the Gear BIM Oriented software. The elaborations allowed to evaluate the utility of the model starting from the measurement of the ante-opera performance stored in the BIM model of the study case. On the BIM model the energy simulations that allowed the energy needs of the envelope according to the standards provided by the EPBD Two, following the designed thermal insulation intevents.

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