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An Integrated Approach for an Historical Buildings Energy Analysis in a Smart Cities Perspective

Roberto De Lieto Vollaro[a], Luca Evangelisti[a], Emiliano Carnielo[a], Gabriele Battista[a], Paola Gori[a], Claudia Guattari[a], Aldo Fanchiotti[a]

[a)] *University of Roma TRE, Department of Engineering, Via Vito Volterra 62, 00146, Rome, Italy*

Abstract

Currently, the study of the energy performance of buildings is based on a simplified calculation that estimates the thermal loads using monthly or seasonal average outdoor temperatures. In addition, the employed software require technical data such as the specific heat capacity of materials, but at the same time they are not able to properly consider the thermal inertia of buildings. The more precise evaluation allows to assess the correct interventions for energy requalification under a smart cities perspective. This study was performed considering a stationary software (Aermec MC11300) and a dynamic software (TRNSYS). Three simulations considering transparent elements characterized by progressively improved properties of thermal transmittance and solar gain factor have been performed. It has been performed a comparison between the outputs of the two software in order to highlight the different ways of evaluating the energy contributions on thermal loads. Finally, the models were validated by means of an in-situ measurement campaign using a heat flow meter - in order to measure the thermal transmittance of the opaque walls - and a thermographic camera. This modus operandi allowed to appreciate how the use of a dynamic software is more appropriate to deal with the inertial properties of the structure to calculate in a more detailed way the annual thermal loads and to obtain more information on individual heating zones.

Keywords: building energy analysis; integrated methodology; thermal loads; smart cities.

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1. Introduction

Recently buildings energy performance and energy savings issues are of great interest for the scientific community and the importance of these topics comes from the need to reduce fossil fuels consumption and pollutants emissions. In fact, trough the Directive 2002/91/CE the European Community highlighted how the increase of energy efficiency is a point of strength within the set of measures and actions necessary to comply with the Kyoto Protocol.

Cities are the center of economic activities, development and research, therefore, they are the key for the 'smart' growth of the European Community. In Europe the 80% of carbon emissions comes from urban areas: buildings, industries and transports are a mix of elements that greatly contribute to increase pollution in the old continent. For this reason, Europe needs to promote urban sustainability, in order to achieve the goals expected for 2020.

Resources' efficiency and sustainability are based on the concept that urban environment has to be effective and characterized by a low natural resources consumption. Consequently, European Countries need to achieve an high life quality in order to be sustainable also in the future. The Energy Efficiency Plan 2011, adopted by the European Commission last March, is an example of European policies in this field. Generally, solving efficiency problems in urban areas is based essentially on energy efficiency policies.

Measures able to further improve building's energy performance should take into account climatic and local conditions as well as indoor climate environment and cost effectiveness [1].

In last years, energy diagnosis was a very important issue treated by several international studies [2,3,4,5]. In particular, in Italy the European Directive has been applied through the Decree n.192. It issues criteria and conditions to improve building's energy performance in order to promote development, enhancement and integration of renewable energy sources and to contribute to achieve national aims for limiting greenhouse gases emissions imposed by the Kyoto Protocol [6].

In Italy energy requirement for civil structures is more than 40% of the national energy consumption: an efficient design of buildings and plants can be the key strength in order to deal with the cited issues [7].

The building-plant system design starts from the assessment of buildings heat loss and, consequently, from the annual thermal loads. In Italy these analyses are based on the UNI TS 11300 requirements [8]. These standards require an energy analysis under steady-state condition, or a simplified procedure that is not able to accurately analyze real conditions.

Currently, energy audits are conducted through specific software analysis and, because of this, they are based on the Italian regulations. For that reason, this kind of investigations show the characteristics connected to the stationary features of climatic phenomena [9,10,11].

Consequently, in order to provide a more detailed analysis, it is possible to define an integrated design methodology able to assess the buildings energy performance. A methodology based on a dynamic analysis, which allows to study climatic variations over time, can lead to a more precise thermal loads estimation. This new approach takes into account the dynamic properties of the structures and allows an accurate modeling process that reflects the actual building geometry [12].

Several studies apply both the dynamic approach and steady-state analysis. It was shown how the highest-energy-performance wall system has a proper combination of dynamic thermal transmittance and thermal admittance [13]. The final goal of the study was to analyze the effects of external walls thermal inertia on the energy performance of buildings. Starting from dynamic simulations the effects of the walls thermal inertia effectiveness on climatization demand of the test cell was assessed for different sets of design and operational parameters. Other studies have also shown that the thermal behavior of buildings is a key point in order to obtain an effective use of energy which allows both energy saving and pollution reduction. The energy used by buildings is mainly determined by thermo-physical properties of building envelope. In particular, in [14] the authors aimed to assess thermal behavior of opaque wall materials under the influence of solar energy.

The proposed methodology is based on an analysis conducted under dynamic conditions, with the consequent possibility of appreciating the climatic oscillations along time, can lead to a precise estimation of thermal loads.

The presented approach can be applied not only to conventional buildings (i.e. complying with current construction's standards) but also to ancient structures whose artistic and architectural constraints can limit the possibility to improve passive efficiency. This approach will lead to a new method of integrated design, which is combined with the use of dynamic software. This methodology is more complete and complex compared to the steady-state approach that is commercially available and widely used for the energy analysis and it could be considered as a valid means for smart cities' design.

2. Methodology

Using a specific software is a fast and easy method to evaluate the annual energy consumption of a generic building. But, as it was shown in the introduction, the obtained result is not always strongly representative of the actual structure behavior. In this work two different approaches have been implemented: steady-state and dynamic conditions. The first one is represented by the application of Aermec MC11300 which is a steady-state software; the second one is performed through TRNSYS which is a dynamic software.

In particular, AERMEC MC 11300 is a thermal loads calculation program based on Italian building energy performance requirements and the applied procedure relies on some approximations [15]. The limitations that the users have to take into account concern the external temperature which is considered equal to the average monthly temperature. Using simplified thermal balance equations, characterized by the lack of details of the generated models, makes hard to design a roof with a particular geometrical characteristics and to define all the details of the ground on which the structure will be built.

On the contrary, the dynamic software TRNSYS is based on an advanced calculation code which applies the transfer function relationships of Mitalas and Areseneault and it is able to provide the thermal loads for each hour during the day [16]. Through the application of TRNSYS it is possible to overcome the limitations previously mentioned, exploiting different characteristics. First of all the software allows to appreciate the variation of the external temperature calculated through a suitable time step, consequently the annual thermal loads will be calculated as a sum of hourly load values. In this calculation program more complex balance equations are used – Transfer Function Method - [16]. Moreover, materials thermal resistivity and heat capacity data, both of which affect thermal inertia, are employed. Finally, more detailed building structural models can be used as input, which can provide more insightful information.

3. The Case Study: An Historical Building

The building takes into account for this study is an historical one placed in the center of Italy. The research aims to highlight the differences of monthly thermal load values, for this reason a steady-state analysis as well as a dynamic one has been conducted. The analyzed building is composed by five floors (three over ground and two in the basement), presenting a rather complex geometry (Fig. 1).

Fig. 1 – The analysed building

By analyzing building's planimetric characteristics it is possible to assess the walls thickness. These values are very different between each other and they range from 10 cm up to 173 cm. The whole structure is composed by blocks of tuff tied together with lime. The two basement floors were obtained by digging directly the tuff. Because of this, the building's south side is in direct contact to the ground. The building's west side is connected to the ground for a small part. The east side of the structure is close to another building. Due to the high number of walls that have different thicknesses, different thermal transmittance values have to be considered. The materials mainly used to build the structure have been reported in Table 1.

Table 1 – Construction's materials characteristics.

Material	Conductivity *[W/mK]*	Heat Capacity *[kJ/kg K]*	Density *[kg/m^3]*
Tuff	0.630	1.300	1500
Concrete	1.263	1.000	2000
Brick	0.500	0.840	840
Roof's spruce beam	0.120	1.600	450
Plaster	0.900	0.910	1800
Perforated brick	0.325	0.840	1070
Insulating material	0.170	0.920	1200
Shingle	1.000	0.840	2000
Tile	0.840	0.840	1700

3.1 Validation of the simulation model

Software modelling and simulations of this building require a validation by using proper methods. Because of this it was necessary to verify the effectiveness and the reliability of the simulated model through a set of in-situ measurements. With reference to thermal analysis, the software TRNSYS and MC 11300 assigned to the structure's walls thermal transmittance values consistent with the materials of the software libraries.

In order to make the modelling and simulation able to represent the actual building's behavior, these transmittance values require a further analysis. This analysis was performed by using an heat flow meter, which makes a direct measurement of the thermal transmittance, and a thermo tracer which makes a thermographic inspection of structural abnormalities (Fig. 2).

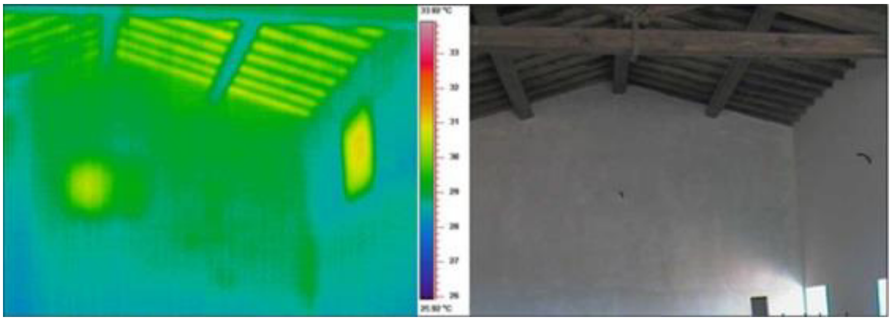

Fig. 2 – Cold bridge on the east wall of the second floor

4. Results and Discussion

Starting from these data, simulations under steady-state and dynamic conditions were performed with the MC11300 software and with TRNSYS respectively and it is possible to distinguish between heating load (winter period) and cooling load (summer period). This allowed us to highlight the numerical differences between the loads themselves (in percentage points). This comparison has been made by considering three different simulations characterized by different kinds of glasses adopted in the model. The first simulation was performed using a single glass with a 4mm width, the second one was performed considering a double glazing with 4/16/4 mm width, containing air. Finally, the last simulation was carried out applying a double glazing with 4/16/4 mm width, containing argon. Table 2 provides information regarding the frame and transparent elements.

Table 2 – Glazes' technical characteristics

ELEMENT	CHARACTERISTICS	TRANSMITTANCE[W/m2K]	G-value
Frame	-	2.27	-
Single glass	Single glass sheet 4 mm width	5.68	0.855
Double insulated glass	Double glazing 4/16/4 with air	2.83	0.755
Double highly-insulated glass	Double glazing 4/16/4 with argon	1.40	0.622

Tables 3-4-5 report thermal loads highlighting the percentage difference obtained through the application of TRNSYS and MC 11300.

Table 3 – Percentage differences between calculation codes – Single Glaze

SINGLE GLAZE WINDOWS	TRNSYS	MC 11300	Percentage Difference [%]
Heating [kWh/year]	43604.0	38179.0	14.2
Cooling [kWh/year]	9943.0	11239.0	-13

Table 4 - Percentage differences between calculation codes – Double Glazing (Air)

DOUBLE GLAZING - AIR	TRNSYS	MC 11300	Percentage Difference [%]
Heating [kWh/year]	34522.6	29445.0	17.2
Cooling [kWh/year]	9290.0	11674.0	-25.6

Table 5 - Percentage differences between calculation codes – Double Glazing (Argon)

DOUBLE GLAZING - ARGON	TRNSYS	MC 11300	Percentage Difference [%]
Heating [kWh/year]	31930.6	27914.8	14.4
Cooling [kWh/year]	8245.0	9696.9	-17.6

Analyzing the results obtained through the software MC11300 and considering the heat balance equations used by the program (equations adopted by the UNI TS 11300) it can be seen that when the quality of the windows used in the model increases, at the beginning there is an increase of the cooling load and then a decrease of it. These results are justified by the variation of the terms appearing in the following equations:

$$Q_{heat} = (Qt + Qv) - \eta_{util}(Qi + Qs) \quad (1)$$

$$Q_{cool} = (Qi + Qs) - \eta_{util}(Qt + Qv) \quad (2)$$

Using insulated windows, that are characterized by a reduction of U-value and G-value, a decrease in terms of solar gain (Q_s) and transmission losses (Q_t) has been observed. However, a comparison between the two contributions shows a larger reduction of the transmission losses (Q_t) which leads to an increase of the Q_{cool} value.

Considering double glazing windows with argon a further decrease of both transmittance value and G-value has been obtained. In this case the result is a higher reduction in terms of solar gain (Q_s) which leads to a decrease of Q_{cool}.

Regarding the heating loads obtained through the application of the MC 11300 software, a progressive reduction of the energy demand, useful to increase insulation properties of windows, has been observed. Progressively, employing windows characterized by a lower transmittance allows to obtain a more thermally isolated building's shell. Therefore, by considering the Q_{heat} equation a decrease of transmission losses (Q_t) has been obtained.

Taking into account a software based on steady-state conditions, the variation of all the parameters previously mentioned depends on the external temperature which is set to a constant value for each month.

Similarly, regarding the heating loads calculated using TRNSYS, a reduction of the energy demand due to the improvement of the buildings shell insulation was obtained.

Cooling loads values obtained with TRNSYS are lower compared with the loads values calculated under steady-state conditions (Tables 3-4-5). Also by considering cooling loads values, obtained under dynamic conditions, a progressive decrease of their values can be assessed. This decrease is related to the structure characteristic which releases during the night the heat stored during the day. The heat stored by the walls is released to the surroundings and the building's internal temperature can go below 26°C. Air conditioning system does not work below this temperature because it is programmed to prevent the building's internal temperature from exceeding the threshold value of 26°C.

5. Conclusions

Finally, taking into account a detailed calculation of heat flows - hour by hour - and building's inertial capacity, using more complete and complex heat balance equations, it is possible to assess large variations of seasonal thermal loads. These variations call for the need to overcome the limitations of the steady-state analysis through a more sophisticated approach, such as the integrated methodology propose. This procedure is able to assess more correct interventions for energy requalification in a smart cities perspective.

In order to fill the gaps of a simplified procedure to define buildings' energy behavior, it was modeled an historical building placed in the center of Italy and it was analyzed its behavior both under steady-state and dynamic conditions. For the first step it was used the software MC11300 - able to consider the steady-state part of climatic phenomena - and for the second one it was applied the program TRNSYS - able to appreciate the climate changes over time -. Through these software the building's geometry has been reproduced and three different simulations have been implemented. Progressively transparent elements with more suitable characteristics in terms of thermal transmittance and g-value were simulated. Finally, the obtained numerical results were compared. In order to validate the model a set of in-situ measurements has been performed.

As long as extremely simplified models of the physical phenomena will be considered in the definition of the structure's energy needs, it will be possible to define buildings' behavior only with a simplified approach, with a consequent effect on the coupling building-plant.

References

[1] European Directive 2002/91/CE 16 December 2002 Regarding Buildings Energy Performance.

[2] Dounis A.I., Caraiscos C.. Advanced control systems engineering for energy and comfort management in a building environment—A review, Renewable and Sustainable Energy Reviews 13 2009; 1246–1261.

[3] Na Zhu, Zhenjun Ma, Shengwei Wang, Dynamic characteristics and energy performance of buildings using phase change materials: A review, Energy Conversion and Management 50 2009; 3169–3181.

[4] Garcıa Casals X.. Analysis of building energy regulation and certification in Europe: Their role, limitations and differences, Energy and Buildings 38 (2006) 381–392.

[5] Perez-Lombard L., Ortiz, Rocıo Gonzalez J., Maestre I.R.. A review of benchmarking, rating and labelling concepts within the framework of building energy certification schemes, Energy and Buildings 41 2009; 272–278.

[6] LEGISLATIVE DECREE 19 August 2005, n. 192.

[7] 11300.cti2000.it, Certificazione energetica degli edifici – EPBD.

[8] UNI/TS 11300-1, Determinazione del fabbisogno di energia termica dell'edificio per la climatizzazione estiva ed invernale.

[9] Henninger R.H., Witte M.J.. Energy Plus Testing with Building Thermal Envelope and Fabric Load Tests from ANSI/ASHRAE Standard, 140-2004, prepared for: U.S. Department of Energy Efficiency and Renewable Energy Office of Building Technologies Washington, D.C., 2007; www.energyplus.gov.

[10] Ferrari S.. Building envelope and heat capacity: re-discovering the thermal mass for winter energy saving, Proc. 2nd PALENC & 28th AIVC Conferences, 2007; Crete Island, Greece.

[11]Ferrari S., Baldinazzo M.. Valutazione delle prestazioni energetiche degli edifici: dalle norme semplificate all'analisi dinamica, Proc AICARR, Certificazione energetica: normative e modelli di calcolo per il sistema edificio-impianto posti a confronto, 2008-2009; Bologna, Torino, Napoli (IT).

[12]Citi L., Gori V.. Software for transient thermal performance analysis of buildings, 2011; [Software]. Available from: http://users.neurostat.mit.edu/lciti/software.
[13]Aste N., Angelotti A., Buzzetti M.. The influence of the external walls thermal inertia on the energy performance of well insulated buildings, Energy and Buildings, 2009; pp 1181-1187.
[14] Vijayalakshmi M.M., Natarajan E., Shanmugasundaram V.. Thermal behaviour of building wall elements, Journal of Applied Sciences, 6(15) , 2006; pp 3128-3133.
[15] http://www.masterclima.info/category/MC-11300.aspx, Aermec MC11300.
[16] http://sel.me.wisc.edu/trnsys, TRNSYS.
[17] www.comuniitaliani.it/056/042/clima.html, climate and geographic data.
[18] http://www.mae-srl.it/allegati/3_18_596.pdf, MAE: Heat flow meter - the reference standard.