Energy behaviour in historical buildings: limits and potentials for the project evaluation

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ABSTRACT: The presented research (split in two papers) deals with the energy efficiency of historical buildings, both the monuments and the widespread historical fabric of the cities. At present the idea of a more sustainable approach has been shown mandatory also in the field of restoration. Sustainability seems to stress the limit of compatibility between the need to enhance the energetic performance of building's elements and their conservation. Changing the approach could resolve the problem: to think in terms of improvement instead of trying to meet necessarily the rigid requirements of the regulations. That would require, in any case, a in depth knowledge of the building, although the software currently in use does not properly allow to take advantage of this knowledge, because of the poor libraries and steady approach. Nevertheless there are some dynamic modelling software that can partially simulate the thermal behaviour also for a historical building and the paper's conclusion shows the requirements for the needed development.

Keywords: energy efficiency, restoration, conservation historical buildings, software

1. INTRODUCTION

The present research deals with an important issue quite overlooked till now in restoration studies: matching of traditional goals of conservation with the need of improving energy efficiency of historical buildings. Traditionally, protected buildings are preserved for their cultural values, which are defended mainly through limitations of the changes required by new uses. The problem of the relationship between use, fruition and adaptation in historical buildings has been thus transformed into a clash of values.

The most relevant problem to be pointed out in restoration projects, but more generally in architectural projects, is seen as sum of actions focused on single technological node as if they had no links with others. Taking into account the whole building under the perspective of its energy efficiency suggests to investigate historical building techniques, because only in-depth knowledge of historical materials and building techniques allows to calculate the energy performance according to most useful indicators to evaluate their efficiency. The efficiency evaluation also implies the measurement of some relevant parameters on different typologies of ancient buildings through experimental tests in stead of the average data provided by available literature.

Moreover, the specific knowledge of the historical built heritage is very useful to inspire new solutions based on empirical knowledge of the typical pre-industrial world.

As a matter of fact, the knowledge on energetic behaviour of old buildings have not yet been studied in a adequate way with respect to their complexity, nor there is an agreement about the ways of upgrading general performances taking care of cultural values. At present, common practices are set without following any guideline and shared priority. At last, the most common calculation tools used for the evaluation of the building energy consumption are those used for contemporary buildings, therefore, do not contain the sufficient information regarding the technical terms and properties of historical elements and their interaction. As a result, these calculation tools have a poor flexibility to the application on historical buildings, and their modelling is not reliable apart from adjusting the inputs appropriately to obtain results close to the experimental data, and this requires the tight collaboration between the experts of restoration and building physics. The experience presented in this paper derived from the need to meet the expertises of both the disciplines, and to identify the implementation and conflict solutions which is very hard to resolve by the application of commercial software.

2. ENERGY SAVING AND CONSERVATION

European Commission has decided that by 2020 there is to be a drastic cut in polluting emissions in the atmosphere (at least 20% less than 1990) and that the quota energy from renewable sources will increase at least to 20% of total energy consumption. In fact, in the near future this process will involve major acceleration of energy performance improvement in building sector, also for the existing buildings, including those of a historical character, independently of their protection regime. In the global environmental approach, as proposed in the LEED NC plan (USA) [1], the need for sustainability in the conservation of the historical built heritage has a wider perspective rather than just meeting the goal of energy consumption reduction. In this paper the authors discuss only about the energy efficiency issue because of the urgent need to achieve a multi-disciplinary perspective for both the goals, to improve the energy performances of historical buildings and to protect them, before that a poorly common reasonable practice of envelope component substitution makes massively disappearing the parts and elements of historical buildings. In fact, although the European directive admits some exceptions for heritage buildings, it is clear that problems related to environmental sustainability and energy saving heavily interfere with the management of historical urban settlements and sensitive landscapes that represent the cultural framework of territories. The target of energy consumption reduction has been issued in the European Directive 2002/91/EC, however, it is interesting to analyse its implementation in the Member States and different regions, mainly referring to the requirements for the adaptation of historical buildings, with the aim to avoid negative effects as already happened in other situations (for example when the European Directive 93/76EEC Energy Efficiency, SAVE, allocated funds for the substitution of windows) (Fig. 1).

Figure 1: Old removed windows. (image by Roger Curtis)

Just for these reasons the need for a new approach at the issue involves the restoration area, and particularly the integrated conservation area, in which needs of use do not conflict with the protection ones, and in which the management of change is vital for the building and is respectful for its history (all changes and adaptations that let the building come through ages). Adaptations of existing buildings, in fact, emphasize a recurring theme, connected to the risks of a transformation that could provoke a decrease in the building value. That is even more evident on listed Built Cultural Heritage. The situation is made worse by the fact that the performances evaluation (indicated as references by laws) is made through streamlined models and parameters coming out from averages, and it is not possible to consider the infinite variety of real cases. It often happens that the uncritical application of abstract models disadvantages the existing buildings, or its components, promoting substitutions without any proof of a real advantage within the global energy balance. Indeed some recent studies deny the existence itself of such advantages. During the last years, these problems have been translated into requirements and exhaustive detailed legally binding regulations, often expressed only in sector-based terms. As in many other cases, the specificity of the approach has been till now scarcely mediated in the application on historic built environment. The architectural restoration project has to deal with problems connected to the use of the building, its durability in time, safety, accessibility as well as energy efficiency. At present the laws are tending to answer to the supposed conflict between conservation and transformation through the tool of derogation. The derogation (as it already happens in other sectors, such as accessibility, fire prevention, seismic design etc.) should represent an opportunity for an aware modulation of the project, but it was considered as a way to remove problems, rather than to adopt gradual interventions. The crucial point (that would discredit the idea of incompatibility between these two subjects) is to define the level of the requirement for a historical building and should avoid to necessarily meet rigid prescriptive requirements: the intervention should not distort the character of the ancient building, but should complement its potentials. The energy behaviour of historical buildings should be evaluated in a different way. The idea is to borrow the same approach already used, in Italy, for earthquake proof regulations (Fig. 2) and for the removal of architectural barriers (Fig. 3). At present, it is not required to obtain the same level of safety for an ancient and new, but we have to demonstrate that the intervention would improve the structural behaviour of the ancient building.

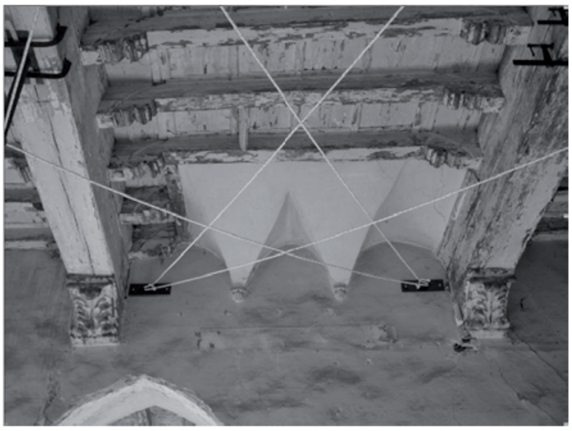

Figure 2: Cremona, Pallavicino Palace. Wooden floor straightened by means of stainless steel cables and telescopic shores.

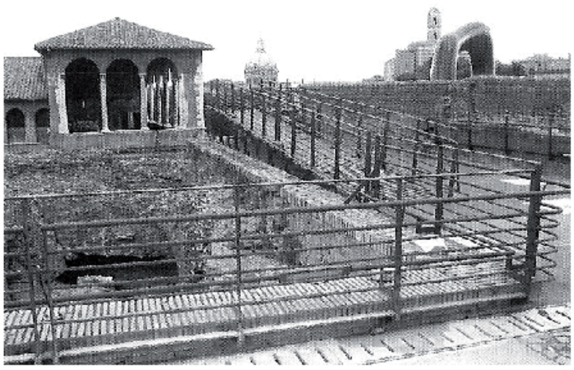

Figure 3: Rome, Markets of Traiano, arranged on 5 levels, linked by steep stairs. In the upper side of the complex two accessible paths had been realized.

Accordingly, when alterations of the building are undertaken in order to increase its energy performance, it should not be mandatory that each component of the structure meets the strict requirements of regulations. Instead, the designer should demonstrate that the thermal efficiency of the elements would be upgraded to a reasonable extent that is compatible with conservation needs. The wrong application of previous earthquake proof regulations has already caused heavy interventions on traditional masonries; they have worsened the global behaviour of structures with disastrous consequences. We must learn from these mistakes, they taught us that traditional buildings have a behaviour which is different from new ones, and the solutions created by that logic are often harmful. A qualitative test on energy efficiency, which the designer guarantees, could be effective. But which are the possible improvements? These should be decided from the original features of the building. First of all, one should distinguish between a historical building within the urban fabric and an isolated one. Then the typology of the building would show the different features that can be taken into advantage or should be corrected, and then, depending on the destination of use, specific comfort conditions are required. The extension and grade of intervention would be influenced by the conservation state of the existing building and the kind of ownership (undivided or split among different owners like it happens in the urban context).

In any case one has to consider that energy refurbishment are accompanied by other advantages (besides the environmental one). Indeed the improved insulation of walls, roofs and floors, improvement of windows transmittance and removal of air leakages together with modern HVAC system, offer comfortable spaces better responding to the growing users needs not only for residential buildings but also to the historical one.

If we want to keep in use these buildings, we have to raise their performances to a level that can be not identical to the new ones but at least comparable to them. Moreover by resolving possible energy problems, such as thermal bridge, cold areas, etc. also allows to eliminate possible causes of degradation.

The interventions for improving the performance of historical buildings requires a deep of knowledge of its constructive elements including the thermal behaviour. But it is hard to realize because of the use of different materials, the wide range of the traditional techniques; and the use of old techniques, which have been lost with time. While the foundation of the majority of modern buildings is based on the functioning of HVAC systems, insulated and water-tight (using vapour barriers, sheaths, membranes…) envelope, ancient buildings takes the advantage of the thermal inertia of masonry. They were built from materials that contain a higher amount of moisture and designed to be permeable to the vapour. Also, they use natural ventilation for air change, to remove the moisture and to cool the rooms (fig. 4).

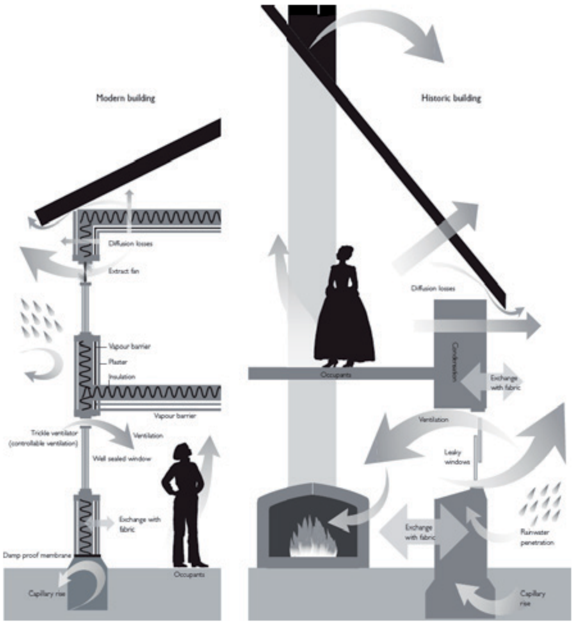

Figure 4: Diagram showing the typical differences in movement of moisture between a historic (right) and a modern building. (Image by Robyn Pender)

Another aspect that should not underestimated is the importance of building management system. This point is still considered rarely, but it has already been adopted in the regulations concerning with fire safety. The security management (talking about risk calculation and finding equivalent solutions) is the result of the complexity of this subject. In the field of energy conservation, the management of heating and cooling systems, the correct execution of a good natural ventilation (when mechanical systems are not present), lighting control, etc. can heavily affect the global performance of the building. Building automation brings forward a new centralized computer system to control various aspect of the building, and their use in monumental historical buildings is growing rapidly.

3. EVALUATION OF THERMAL PERFORMANCES IN HISTORICAL BUILDINGS'

3.1 THERMAL PROPERTIES OF THE BUILDING COMPONENTS

Heavy transformation with a significant impact on the historical buildings are normally related to incorrect assumptions. With reference to the current energy regulations to establish the final performance of a building the former performances should be taken into account. To highlight the main energy inefficiencies a detailed analysis of the building should be performed. The thermal behaviour of historical buildings is somehow still unresolved because of the attempt to use the same evaluation methods/criteria used for modern constructions and the limited knowledge of the building construction techniques that are far different from the modern ones. This critical point is valid both for monumental and widespread historical fabric because of the lack of systemic approach and information and do not depend on the dimensions, complexity, number of the technological elements and historical /artistic importance of the building. Main problem is to find out the thermal characteristics of materials and architectural components in a historical building. For a new building the technical data related to conductivity, vapour pressure resistance, and other physical properties have to be certified by the producers, while for existing, historical buildings, these data are missing. Such information could be roughly evaluated using nomograms, tabulated data or through calculations and also sometimes through destructive tests but with much higher costs that are not economically acceptable. An extremely thick wall of unknown structure is not unusual, some information can be collected by historical documents related to the building constructions, while other requires core sampling or boroscopy; Infrared thermography allows to locate masonry texture which is not visible because of the finishing. Sometimes the only possibility is to make hypothesis based on some pieces of information available : for example, for a wall of a given thickness made of bricks, considering the bricks size, it is possible to evaluate the quantity of mortar in the wall, that means to estimate the global U-value. Nevertheless these are theoretical average values because the real values depends also on thermal properties of the mortar humidity level in the wall due to infiltration or rising damp. In any case, this approach is still the most commonly used and the values are the one obtained by table sand nomograms. The use of more sophisticated instruments like thermo-flux meter, can produce more reliable data for the part of the wall in which the measurement has been performed, but this value could be significantly different from other part of the same wall, due to the building techniques, material used, humidity, etc. In spite of using correct U values, another problem is related to the simulation of the energy performance of a historical building and the possibility to evaluate properly the effect of the proposed interventions. Some of the traditional bioclimatic solutions, generally adopted in historical buildings, whose benefits are known but difficult to evaluate through simple simulation software used by architects (i.e. wind extractor or other natural ventilation systems).

3.2 SOFTWARE FOR ENERGY SIMULATION

Several energy simulation software are available and it is possible to find products with different accuracy level used for different analysis and are normally utilized by different users. Each software uses specific algorithm for the calculations, have different input mode and can produce output of different typology. In general the more powerful and complete is the software, the more detailed and precise input it requires. In any case, even detailed software simulates traditional building techniques with difficulties. The simplified evaluation software that uses average monthly data and steady state calculations (the one largely diffused for the energy certification in Italy) is simple to use but the results are not reliable because the evaluation of the variation of both the air temperature and solar radiation are considered elements of less importance. On the other hand, dynamic simulation software are typically used by engineers to perform detailed calculations. These software make detailed analysis that take into account the thermal mass of the building, the effect of natural ventilation and all the variables can be scheduled (solar gains, internal gains, etc.). Detailed data have to be used both to describe climatic conditions and the building properties; both input and output require deep knowledge in building physics and the software can not be easily used by "conventional" architects. The so-called ***sketch design*** software is in between simplified and detailed simulation software. These pieces of software use a dynamic simulation to take into account the thermal inertia, but require a simplified input in term of climatic data and building description. The user interface is normally based on graphical icons to which numerical values are related.

Table 1: Data required for building energy performance calculation.

INPUT
Typological features of the building
– Net volume of the heated space – Surface areas of all the envelope elements – Typology and importance of thermal bridges – orientation of all the envelope elements – shading coefficients of all the transparent elements of the envelope
Constructive features of the building
– Thermal transmittance of all the opaque and transparent elements of envelope – Thermal capacity of all the envelope elements – Reduction coefficient referred to the frame – of windows – Linear transmission coefficient of all the thermal bridges
Climatic data
– Monthly average outside temperatures – Monthly global solar radiation on horizontal and vertical (for each orientation) surface
How the building is used an occupied
– Inside air temperature – Ventilation rates (air changes per hour) – Length of heating time – functioning mode of heating system (continuous/ intermittent) – Shading system management – Average heat gains

This simplified approach reduces the accuracy, but allows a wider diffusion of the software that could be easily used by architects and planners. A similar approach with a software designed for traditional, historical architecture would be very useful and appropriate for large diffusion. If we consider that the Italian heritage is significant not only for the monuments but also for the diffused quality of historical buildings, the use of a powerful and simple tool to address the rehabilitation could be very important. The possibility to evaluate different options for historical building, not considered as monuments to be integrally preserved, is another important goal as the low cost compared to the detailed analysis required for protected buildings.

3.3 SOFTWARE FOR SKETCH DESIGN ANALYSIS

Considering the previous framework our research was focused on the evaluation of powerful and simple to use sketch design software to test their ability to simulate properly historical buildings. The results are discussed in the second paper [2] of the same authors in the present conference. The use of dynamic simulation was considered essential because of the necessity to have detailed information on the performance parameters (e.g. inside air temperature) in free- float mode both for summer and winter season. Objective of the research was to verify possibilities and limits of these software (that are normally used for the early stage of the design process of contemporary buildings) for the application in historical buildings. The software have been tested with three small churches that have been chosen for their simple shape but with a wide range of building technologies in order to verify the sensitivity of the software. The three churches have no heating system and it was positive because the objective was to compare data collected in a free running condition with the simulations and not the energy consumption. Due to the existing monitored data (air temperature and humidity collected hourly for more than one year), it was possible compare the software output with the real collected data and verify the differences.

4. LIMITS OF THE EXISTING SOFTWARE

Different software is used by researchers and professionals to make simulations of the thermal conditions in a building. The outside climatic conditions are generally described using statistical data or hourly collected data, while the inside conditions are described through the data on the building use (internal heat gains etc.). In the literature, a large number of studies on the simulation of building energy performance have been conducted : the results are quite similar and the advantage of thermal mass is clearly identified especially for the summer use and the best results are related to the use of free night ventilation [3].

The sketch design software confirms their limits in the evaluations of historical buildings. The first problem is related to the input of building data (thermo-physical properties) and are strongly related to the considered building technologies. In these software, the definition of the thermal mass of the envelope is limited to the choices among five level of heaviness (from very light to very heavy). The highest surface mass considered is about 800 kg/m^2 that is considered a heavy envelope for modern architecture (about 45 cm thickness of heavy bricks), but it is not representative of a wall with a thickness more than double with a front mass of 2000-2500 kg/m^2. Another issue is related to the evaluation of natural ventilation. In general, if there is any possibility to input specific data for natural ventilation (it is not always possible), the input data required is the ventilation interchange coefficient. This information is defined in the UNI-ISO regulations for natural ventilation in new buildings or can be estimated for mechanical ventilation, but the real value can be much different and hard to evaluate in case of the historical buildings where the openings are permanently opened small windows, or window with low air-tightness [4].

Generally software for sketch design analysis have limited range for data input and are not flexible enough to evaluate windows or doors of different typologies (comprehensible for new buildings, much less in case of buildings those have gone through several rehabilitations and modifications during the centuries). Most of the software is designed for residential buildings or offices (that usually means 3 meters height) [5], while historical buildings can have significant differences in the interior heights, not only for castles and churches, but also for residential building in the city centres. Other problems are related to the moisture level into walls that modify the theoretical U value together with thermal mass and ventilation rate, these parameters are not requested (or not properly defined) while they represents some of the main characteristics of historical buildings.

We must remember the final objective of the simulations that is to help the designer to choose between different design options and the modifications of the interior thermal conditions with reference to the former one (i.e. improving insulations, changing windows etc.). Architects and researchers working with historical buildings have neither appropriate software nor adequate tools for the energy performance analysis.

5. REQUIREMENTS FOR THE SOFTWARE FOR THERMAL SIMULATION OF HISTORICAL BUILDINGS

The software for sketch design analysis uses a dynamic simulation approach, nevertheless the historical buildings are not properly modelled because the thermal behaviour is strongly dependent on the thermal inertia, a parameter that is not properly considered in the calculations and generally underestimates the results. In the simulations the inside air temperature profiles are too much related to the outside climatic conditions, while in the measured data the thermal inertia causes a reduced temperature fluctuations. The development of the software specifically oriented to historical buildings should be considered, both in terms of user interface (the way to ask questions to the user) and in terms of database (limits and values related to experimental data for specific building techniques, moisture conditions, etc.). Even in this case, the simulated results will be still approximated but more representative and much closer to real conditions.

Table 2: Requirements for the software for thermal simulation of historical buildings.

KNOWLEDGE OF THE BUILDING
– Evaluation of the THERMAL TRANSMITTANCE OF MASONRY built from traditional methods (stones, bricks): usually it is not possible making measurements with a heat flow meter (because of the high costs and time consuming) It would be useful to have abacus (classified for geographical areas) showing typical values for the most used solutions (so-called "a sacco" masonries, composed by two bricks or stones walls, one external and the other one internal, where the gap is filled with stones and mortar, are still the hardest to generalize) – Evaluation of THERMAL TRANSMITTANCE OF ROOFS AND BASEMENTS – Evaluation of AIR LEAKEGES and of NATURAL VENTILATION – Evaluation of masonry TRANSMITTANCE INCREASING caused by HUMIDITY RATING
MODELLING SOFTWARE
– WIDER range for thermal transmittance values of the building elements – Necessity of a VOCABULARY suitable for historical buildings, to avoid misunderstandings – Possibility to insert INPUT REFERRED TO VENTILATION not (or not only) in terms of number of air changes per hour, but accordingly to historic buildings requirements (for instance the quantity of air leakages, in percentage or according to a scale of values more intuitive); how to obtain these values is still a question – Advantages obtained by THERMAL INERTIA of the thick masonry does not appear enough quantify appropriately into the modelling process (within the input data and, probably, in the calculation algorithms) – Possibility to insert MORE DATA TO DESCRIBE WINDOWS AND DOORS (to consider various types of windows or doors, with different values for glazing and frame, also for each wall), since in historical building each element is different from another – More control about the data related to possible SURROUNDINGS WITH OTHER BUILDINGS (situation quite common in historical centre of cities) – Useful to have the possibility to operate directly on the GRAPHICALLY CONSTRUCTION of the building (instead to be limited to manually insert data, as already present in more sophisticated software)

The description of the abilities requested to such software and the user necessities should be clearly focused first and the information flows should be analyzed considering the importance of the communication process. The necessity of a new "description language" of the building closer to the architect approach and more related to his/her grammar is considered necessary.

Table 2 shows the proposal for the requirements for the software for thermal simulation of historical buildings

6. CONCLUSIONS

The present work addresses the problems related to the evaluation of energy performance of historical buildings and also describes the limitations of the currently used energy simulation software to model these building. This necessitates the development of new energy simulation software dedicated for historical buildings, the essential requirements in this respect are proposed. Many experiences and research have already been completed in this field, others are under conclusions and it seems to be possible to organize the results as the guidelines for architects that have to consider about the possibilities of increasing energy efficiency in rehabilitation and renovation projects. No desire to have a pre defined catalogue of technical solutions to be used passively, but a set of examples, methodologies and procedures to help the architect to arrive at the specific solution for a given project. We should recognize and re-discover traditional methods (and perhaps replicate them in a technological update): they would be employed especially in protected historical building although not monumental. At the same time, when we have to work on a monumental one, we should investigate if some peculiar solutions are already present and are possible to implement or complement them with other solutions.

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