INTEGRATED APPROACH TO ENERGY EFFICIENCY IN CULTURAL HERITAGE BUILDINGS

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ABSTRACT

According to Croatian legislation cultural heritage buildings are not obliged to provide an energy certificate and to improve energy efficiency. The experience has shown that approximately 25% of public buildings are in the category of cultural heritage facing complex set of problems in energy efficiency and protection perspective. This paper shows, through some examples the importance for integrated approach and balancing of energy and protection requirements, towards reduction of maintenance costs and the carbon footprint in the heritage buildings. The survey of energy efficiency improvement in cultural heritage buildings is based on energy audit methodology and use of infrared thermography measurement. Suggestion of appropriate energy efficiency measures according to construction period and appreciation of possible energy savings is given.

Keywords: energy efficiency in buildings, renewable energy sources in buildings, energy certification of buildings, energy concept, environment impact on heritage buildings

ENERGY CERTIFICATION PROCEDURE IN CROATIA

The implementation of EU Directive 2002/91/EC on the energy performance of buildings (EPBD) in the Croatian legislation has introduced the mandatory energy certification both for the new buildings and the existing ones. The following regulations have been adopted so far: Technical Regulation on Energy Economy and Heat Retention in Buildings; Technical Regulation on Heating and Cooling Systems in Buildings; Ordinance on Energy Certification of Buildings; and Ordinance on Requirements and Criteria to be met by Energy Auditors and Energy Certifiers of Buildings. In June 2009 the National methodology for energy audits of buildings was adopted, creating conditions for the energy certification of buildings. In energy certification of buildings, i.e., evaluation and classification of building based on energy demand, an energy audit is a basic tool for assessment of energy efficiency level. Energy certification provides transparent data on energy demand of a building to the owners, users and the market. First step in energy certification is calculation of specific annual heating energy demand

$Q_{H,nd,ref.}$ The building is graded in energy consumption classes, starting from A^+ or the lowest heat energy demand ($Q_{H,nd,ref} \leq 15$ kWh/(m^{2}a)), and further on to level G or the highest heating energy demand ($Q_{H,nd,ref} > 250$ kWh/(m^{2}a)). The calculation is conducted for one of the two reference climates, the inland (Karlovac) and coastal (Šibenik), with 2200 heating degree days as division point. Buildings designed in accordance with the current regulation requirements are graded mostly in the C energy class while significant energy performance improvement must be provided to be graded in the B, A or A^+ energy class. When conducting an energy audit for energy certification purpose, annual heating demand $Q_{H,nd}$ is calculated [1], for actual and reference climate conditions. This information must be entered in the energy certificate, while the entries of other energy demand are optional for the moment. Finally, energy certificate should contain information on total primary energy demand E_{prim} (kWh/a), i.e., data of pre-calculated quantity of total annual energy demand [2]: total primary energy for heating, domestic hot water preparation, cooling and lighting, as well as energy for ancillary devices and regulation. In addition, the CO_2 emission generated by each energy source should be stated.

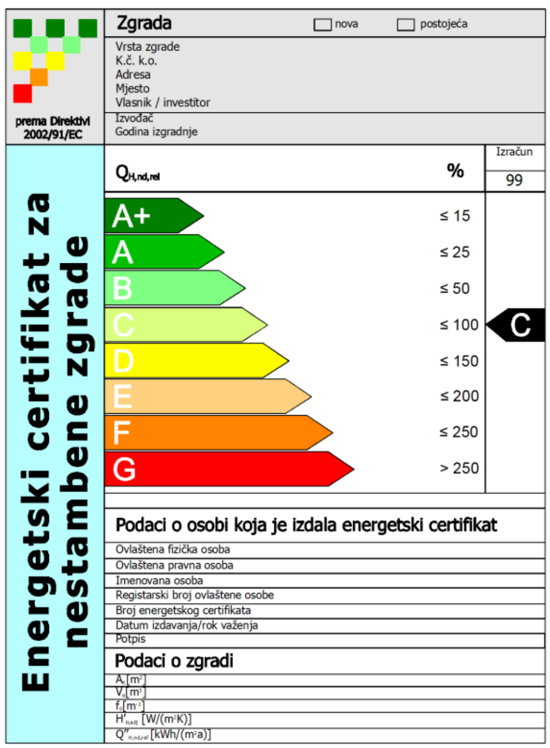

Figure 1. Front page of an energy certificate

After calculation of annual energy demand, the energy performance analysis is directed at suggestion of feasible energy efficiency measures and must include:

- Improvement of thermal performance of the building's envelope,
- Improvement of energy performance of the space heating system,
- Improvement of energy performance of the space cooling system,
- Improvement of energy performance of the ventilation and air conditioning system,

- Improvement of energy performance of the domestic hot water preparation system,
- Improvement of energy performance of the electricity consumption systems – lighting, appliances and other consumption,
- Improvement of energy performance of other specific sub systems.
- Possibility of fuel change or use of renewable energy sources for generating thermal energy and electricity,
- Improvement of the regulation and control systems,
- Improvement of the water supply and consumption system (optional),
- Necessary evaluations and calculations of savings for the selected measures.

Economy feasible measures are entered in an energy certificate, indicating possibility to improve energy efficiency of a building. An energy audit also provides an energy concept to be used in refurbishment program. Energy concept of a building is an integrated and optimal combination of energy efficiency measures in the sense of quality of construction, energy supply, efficient energy use, lifecycle assessment and minimizing environmental footprint. National energy conservation goal introduces obligatory energy consumption reduction in the buildings sector [3]. This will implicate significant changes in buildings sector and construction industry aimed at systematic energy refurbishment of the existing buildings and construction of efficient and autonomous new buildings. In that regard, energy certificate as a document indicating energy performance of a building will be important marketing instrument promoting energy efficient design principles and improved dwelling comfort.

ENVIRONMENT IMPACT ON CULTURAL HERITAGE BUILDINGS

Omitting cultural heritage buildings from energy certification will have negative impact on their construction and energy performance in the long term. Former energy surveys in cultural heritage buildings have shown incoherent planning and maintenance practices throughout long life span, high energy consumption [4] and use of low efficiency technical systems resulting in poor energy rating in E, F or G classes. Climate change is not only affecting the natural environment but also the built environment and numerous heritage buildings are affected by these changes. The example is material corrosion due to both climatic and pollution influence. Even though observations for a large number of materials were studied, a relationship dose–response was established only for O_3 effect on copper, cast bronze and limestone [5]. Research by Screpanti and De Marco shows Italian heritage buildings are at risk of corrosion caused by synergistic effects of O_3 and other pollutants. Similar conditions could be taken for the whole Mediterranean basin. Therefore activities should be taken to reduce pollution from all energy consumption sectors even in cultural heritage buildings to reduce the negative effect on own preservation.

INTEGRATED APPROACH AND BALANCING ENERGY EFFICIENCY AND PRESERVATION PRINCIPLES

Integration of energy efficiency and preservation practices is contemporary approach contributing to energy and economy savings for the single building but also in broader perspective to mitigating carbon footprint and environment impact. Two major groups of buildings can be described taking different construction principles: pre 1900 including historic styles and post 1900 including early modernity period. The construction practices of these periods did not incorporate durability, maintenance or energy efficiency aspects extending use and economy lifecycle. Pre 1900 buildings are built in natural materials, brick, mortar, wood, rarely using concrete and steel, maintaining durability without using innovative solutions in construction, energy or maintenance practice. The post 1900 buildings use generic materials as concrete, aluminum, steel, plastic, incorporating innovative principles but achieving higher durability, maintenance or energy standards.

Common use of cultural heritage buildings is for public services, as in the example of hospital in Duga Resa. There are four buildings in the complex of total 3500 m^2, two of them heritage buildings of 933 m^2. The buildings are in 24 hours use accommodating hospital. Energy audit assessment shows highest heat loses are present on ceilings toward unheated attic and basement, while windows and façade surface were refurbished in 2006 and have better thermal performance. For heating and domestic hot water preparation two 470 kW boilers fueled by light fuel oil are used and the heating system is only partially automated. On heritage buildings alone there are 20 split heating/cooling units. Lighting system is consisted mainly of older type fluorescent lighting, in the kitchen LNG and electricity are used, high electricity consumption is determined in washing room and for the medical equipment. According to heat energy demand the building would be graded in G energy class. Here the following energy efficiency measures were suggested: since change of envelope material and appearance is not allowed, significant energy savings can still be achieved by insulating ceiling toward unheated attic with 20 cm of rock wool. Total costs are 190.000 kn (26.000 eur) and payback period is 2,2 years. Change of boiler with more efficient one, including automation and installation of thermostatic radiator sets are recommended for the heating system efficiency improvement. Total investment is 140.000 kn (19.200 eur) and payback period is 1,2 years. Solar thermal system for domestic hot water preparation can cover up to 70 percent of total hot water demand. The system can be installed on the new building roof. Total investment is 400.000 kn (54.800 eur) and payback period is 6,3 years. Recommendations in electricity consumption systems include reactive power compensation, change of lighting fixtures or elements, all resulting in payback period of less than 5 years. Total annual CO_2 saving by implementation of all measures is 110 t or 30 percent.

Office building in Split is interpolated in the city block with south oriented street front. Total surface of 1410 m^2 is divided on 6 floors. Besides offices it accommodates conference room on the first floor and kitchen with dining area on the ground floor.

The 1930 building was constructed in cast concrete with 60 cm thick walls. In 1997 reconstruction no thermal insulation was used while new windows do not meet current heat retention requirements. The front façade is in stone mortar finish and courtyard facades in cement mortar finish. Heating and cooling energy is distributed to offices by fan coils and energy is generated by heat pump air-water located on the building′s roof. Additional heating/cooling systems are installed powered by 2 heat pumps air to air, with air inlet and outlet channels. There is a separate air conditioning systems water-air with fresh air inlet. Conference room is air conditioned by split unit heat pump and by fan coils. Sanitary rooms have radiator heating and exhaust ventilation. Kitchen, foyer, meeting room and conference room have exhaust ventilation. Highest electricity consumption is for lighting, electronic equipment, heat pumps and split units, kitchen appliances, elevator and electric domestic hot water boiler. According to heat energy demand the building would be graded in D energy class. Eligible energy efficiency measures include thermal insulation of flat roof in minimum of 18 cm of xps with and courtyard walls in minimum of 14 cm of stone wool with plaster finishing. Total investment in insulation is 354.250 kn (48.500 eur) and payback period is 20,48 years. Heating and cooling system should be balanced (flow and pressure level) in order to improve indoor comfort and provide temperature regulation on opposite orientation. Total investment is 63.816 kn (8.740 eur) and payback period is 9,5 years. Solar thermal collectors would cover 80 percent of total domestic hot water annual demand. Thermal modules can be placed on a flat roof with no disturbance of the façade front. Total investment in completely functional system adapted to present components is 28.100 kn (3.850 eur) and payback period is 5 years. Efficiency of lighting system can be improved by installing new efficient bulbs. Due to high installed power capacity additional costs can be avoided by implementation of this measure. Total investment is 23.000 kn (3.150 eur) and payback period of 4,6 years. All measures contribute not only to energy savings but also to maintenance costs reduction, longer life span of equipment or systems i.e. total life cycle cost is improved. Total annual CO_2 saving by implementation of all measures is 16,04 t or 20 percent.

IR THERMOGRAPHY MEASUREMENTS

Infrared thermography is based on heat energy measurement in the infrared spectrum and is presented on a thermogram. On both presented buildings infrared thermography measurement was used to assess heat losses and gains through the external envelope and location of thermal bridges in order to select eligible energy efficiency measures. Qualitative measurement method was used.

In Duga Resa building typical thermal bridges are detected (Figure 2) on the connection of external and internal walls (represented by higher heat losses), on the external wall corners (colder area), on the connection of roof and external wall (higher heat losses) and on the niche below the window (higher heat losses). Highest heat losses are through windows, especially glazing.

Figure 2. Photography and thermogram of a building in Duga Resa

These measurements show the actual need of thermal insulation of the external envelope which in this case can only be partially met. Walls can be thermally insulated

from inside but usually this is applied only on window niches. Change of sealing can improve thermal performance of windows.
Infrared thermography measurement on office building in Split (Figure 3) was performed during summer period and shows influence of Sun shading on heat gains. Façade area shaded by balcony has up to 5˚C lower surface temperature and absorbs and emits less heat energy to the inside providing better indoor comfort. The 60 cm thick concrete walls have high thermal capacity to absorb and release heat. Heat losses of the envelope shown by calculation are even higher than in the example of historic building.

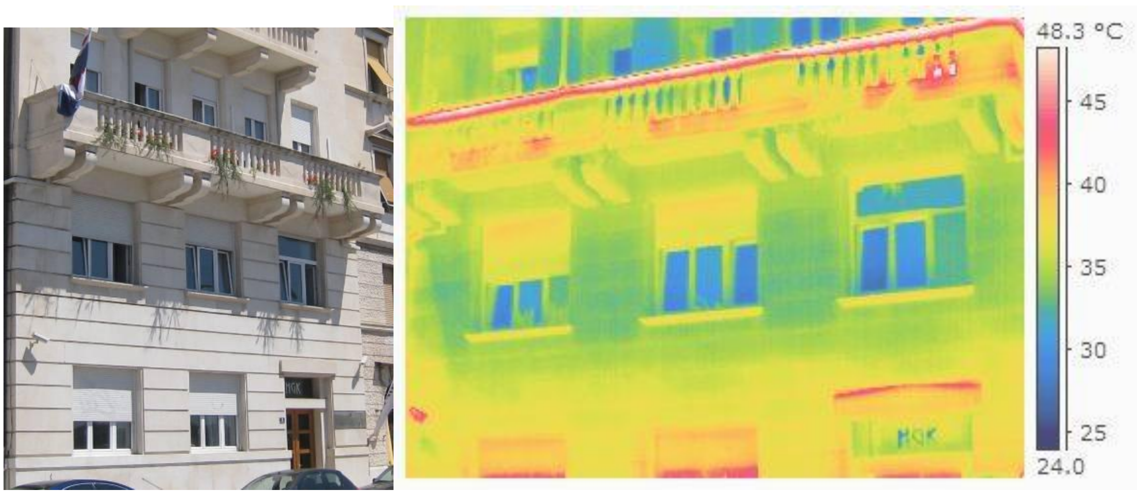

Figure 3. Photography and thermogram of a building in Split

RESULTS OF AN ENERGY AND CONSERVATION EFFICIENT REFURBISHMENT

Conservation principles are aimed at maintaining the elements of style, materials and construction techniques of the construction period. For two categories of buildings presented here, pre-1900 and post-1900, typical measures and savings can be determined. In pre-1900 buildings low cost energy efficiency measures can be performed namely thermal insulation of the window niches, ceiling toward unheated attic and improvement of thermal performance of windows, design of warm buffer entrance zone, etc. Most common measure in energy system improvement is change of boiler and fuel and use of thermostatic radiator or fan coils sets improving total system efficiency at least by 20 percent. Solar thermal collectors often can be integrated without influencing appearance. Post 1900 buildings can improve heat retention of the external envelope often more than 50 percent. Improvement of thermal performance of windows and large glass surfaces must by followed by use of shading devices or other techniques to improve indoor comfort. In both groups of buildings savings can be achieved in electricity consumption systems and very often this system is not in compliance with current technical standards. Highest savings in all types of buildings can be achieved by integrating energy efficiency measures in a harmonious energy system. Heat retention is always the first step in energy efficiency improvement. Reducing energy demand enables use of efficient and innovative systems with

renewable energy sources, reducing energy and management costs, improving indoor comfort and minimizing environment impact.
Total energy savings can be even higher when using Passive house standard principles. Example of industrial building from 1900, refurbished to accommodate office building in Wels, Austria (Figure 4) shows renovation of “10+ factor”, achieving energy autonomous building, reducing energy consumption by 90 percent and mitigating CO_2 emission by 95 percent [6]. Here high efficient vacuum insulation is used on part of façade for rehabilitation of thermal bridges while the rest of the envelope is thermally insulated on the inside of the wall preserving existing envelope appearance. Heat energy and electricity are generated from renewable energy sources. Heat energy is generated using flat ground source heat pump and additionally passive cooling technique is applied. Electricity is generated by photovoltaic modules. Day lighting technique reduces the use of artificial lighting.

Figure 4. Industrial architecture style and combined with innovative opening detail

CONCLUSION

Cultural heritage buildings would benefit from energy certification primarily from energy consumption assessment and insight in eligible energy efficiency measures. Potential conflicts between conservation and development can be avoided by increasing the functional integration of urban space through better and more comprehensive planning and research. Heritage buildings usually accommodate important civil or public services with high functionality, safety and comfort requirements. Conservation strategies must integrate natural potentials, innovative principles and efficient energy systems to preserve environment, appearance and heritage values, combining science and art, ambiance and development.

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