Improving the energy efficiency of built heritage in cold regions

Issues and opportunities

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Abstract – The paper presents results from the research project "Smart energieffektivisering av kulturhistoriska byggnader i kallt klimat". The research is expected to develop, test and assess methods and solutions to increase the energy efficiency of heritage timber buildings in the northernmost part of Sweden.

The sub-arctic climate, with long, cold winters and mild summers, requires a significant use of energy, especially in historic buildings. This means that the difference in thermal performance and energy use with newly built buildings is greater and, at the same time, that even non-invasive interventions can be enough to save a considerable amount of energy with a limited impact on heritage values.

Valuable timber buildings from the late 19th and early 20th century are analysed in the cities of Piteå, Malmberget and Kiruna. Results are based on data collected on their energy and thermal performances, on the analysis of their constructional features and on the assessment of their heritage value.

Keywords – built heritage; energy efficiency; timber buildings; cultural values; cold climate

1. INTRODUCTION

The research project "Smart energieffektivisering av kulturhistoriska byggnader i kallt klimat" ("Smart energy-efficiency solutions for heritage buildings in cold climates") aims to investigate how heritage valuable buildings in cold climate regions can be made more energy efficient in a smart way, without affecting their heritage and architectural values. Buildings located in cold regions are using more energy for heating, meaning that more savings are possible. Unfortunately, there are many examples from the past of irresponsible energy saving efforts applied to heritage buildings, such as the application of extra insulation and the change of valuable historic windows with new ones. The project is part of the Swedish Energy Agency's research and development programme Spara och Bevara (Save and Preserve).

In this project, energy measurements and simulations, as well as heritage values, are under investigation in typical timber buildings built between the 19th and early 20th century in Northern Sweden. Different retrofit measures and strategies will be developed and simulated in the studied houses. The goal is to develop and disseminate scientifically based and practically applicable methods and techniques for improving the energy efficiency of heritage valuable timber houses in cold climates.

Besides describing the methods adopted to collect qualitative information and quantitative data on case studies, this paper aims at presenting some preliminary results of the project. Controversial issues that have emerged so far will be discussed, especially in relation to heritage values. For this reason, the discussion mainly focuses on interventions to increase the energy performance of the building envelope, which are among the most impactful on the cultural values of heritage buildings but, at the same time, have a high potential for energy saving in cold climates.

2. DESCRIPTION OF THE ANALYSED BUILDINGS

The case studies selected for this study are timber buildings with a recognised cultural value built between the late 19th and early 20th century in the northernmost part of Sweden (Kiruna and Gällivare municipalities are above the Arctic Circle). They all lie within a subarctic climate zone according to Koppen classification, with long, cold winters and mild summers.

The Rådhus in Piteå, in the northern Bothnian coast, is today used as a public museum for the City of Piteå. It was built between 1829 och 1837 as a courthouse, but today it houses exhibit halls, offices and a small shop and reception.

Figure 1. Analysed buildings. Clockwise: the Rådhus in Piteå, Bläckhorn B53 in Kiruna, house 158 in Malmberget and house 420 already moved to Koskullskulle. Photos: Tomas Örn and Andrea Luciani.

It is situated in the main square of the City of Piteå. It has a recognised heritage significance and since 1994 it is a listed building. [1] The building is also part of an area of national importance from a cultural point of view. [2] The central heritage significance is the architecture and design of the building as well as its function as a character building for the adjacent square and the overall cityscape.

The “Bläckhorn” houses are located in Kiruna, founded in 1900 as the company town of Luossavaara-Kirunavaara AB (LKAB) in order to mine the rich iron ore deposits in the area. The houses, designed by the architect Gustaf Wickman as multifamily residential units for LKAB workers, embody many of the typical construction features of the “Kiruna style”. [3] The project has studied the houses identified as B52 and B53, which were among the first timber variants to be built (1901-04). They were also among the first ones to be moved to their new location in the summer 2017, after the 2004 announcement of the need to move a significant part of the town to continue mining. The B52 and B53 houses are part of a designated area of national interest [4] and they are protected in the local development plan due to their heritage significance.

As in Kiruna, the case studies analysed in Gällivare municipality are residential buildings owned by the company LKAB and affected by the impacts of mining activities. Part of a cultural environment of national importance [2], they are among the 30 heritage buildings that will be preserved by moving them from the company area of Malmberget to the nearby locality of Koskullskulle. House 420 (former address Långa Raden 7, Johannes neighbourhood) was built in 1911 in Jugend style for LKAB managers and has already been moved in autumn 2016. House 158 (current address Puoitakvägen 5, Hermellin neighbourhood) was built in 1897 for the workers of the mine. The moving, initially planned for the spring or summer 2018, has been delayed.

3. METHODS AND DATA COLLECTION

Quantitative information (measured and calculated energy and temperature data) and qualitative information (cultural value assessment) were discussed and analysed in a multidisciplinary framework in order to find appropriate measures for the energy retrofit of the studied buildings. The method used, as well as the multidisciplinary composition of the research group (architecture, civil engineering, building conservation), follows the recently approved European guidelines [5] which recommend a broad range of expertise and qualifications to address the complex task of improving the energy performance of historic buildings.

Cultural value assessments on the case studies are based on the understanding of heritage as socially constructed. The values produced over time by the interactions of the analysed heritage buildings with the surrounding society and environment, are personally interpreted by the authors, on the basis of their direct experience and perception of the buildings, of the official declarations of cultural interest and of the documentation collected on the buildings. In the case of the Rådhus in Piteå, the evaluations of three different building conservators, collected by Cruz [6], are also used as a basis for discussing different energy retrofit strategies.

In Piteå and Kiruna, the collection of quantitative data went on from December 2014 to September 2016. The energy supplied for space heating and domestic hot water was measured using a Saber energy meter (KYAB, Sweden) connected to the district-heating sub-station. Indoor and outdoor temperatures were measured using factory-calibrated sensors (range –40 °C to +80 °C, accuracy ±0.1 °C). All these measurements were complemented by thermographic surveys of the buildings performed using a FLIR T620bx thermal imaging camera (thermal sensitivity: <0.04 °C, resolution: 640 x 480 pixels).

In Gällivare, energy use measurements are still ongoing while the thermal transmittance of walls and roofs (U-value) was measured by heat flux meters (expected accuracy on walls for 12h: ±5 %) and calculated according to the standard ISO 9869 [7]. In Kiruna the thermal transmittance of the different building components were calculated following the indications contained in the ISO 6946, ISO 13370, ISO 13789 standards..[8] [9] [10]

In Piteå, the airtightness of the building envelope of Gamla Rådhuset was measured using the European standardized fan pressurization method. [11] The air leakages were then localised with an infrared camera. Dynamic building energy simulations of Gamla Rådhuset were performed in IDA ICE advanced version 4.7 (Equa, Sweden). The simulations were carried out with ASHRAE weather data for Luleå, located 35 km away. The energy use for the existing building was calculated and validated with the measured energy use. The air permeability of the building envelope, the indoor temperatures, the heat exchanger efficiency and the ventilation air flows were set to measured values in the model. The input U-values, thermal bridges and geometries of the building envelope were estimated through drawings and onsite inspections. Internal heat gains from occupants and electrical appliances and lighting were based on drawings, schedules for occupant presence and onsite inspections.

4. FINDINGS AND DISCUSSION

4.1 HOW DOES THE PERCEPTION OF HERITAGE VALUES AFFECT ENERGY RETROFIT CHOICES?

Recent research has extensively explored the issue of integrating cultural value assessment into the process of improving the energy efficiency of heritage. [12] [13] [14] The EN16883:2017 [5] standard also deals with the problem of assessing the impacts of energy retrofit measures on heritage significance. Nevertheless, a recent work by Örn [15] has shown that research in this field often lacks a thorough discussion of the conservation theories which are at the basis of decisions and assessments. Örn suggests a decision support system for energy efficiency measures in heritage buildings integrating different conservation approaches: an *Objectivistic approach*, based on the ontological view of values being embodied within the material of an object, and a *Relative approach,* which understands values as being socially constructed when objects are perceived as socially or culturally meaningful.

As a matter of fact, the intrinsic subjectivity and relativity of this kind of assessments is a relevant issue. Even in the presence of a formal value evaluation or a declaration by an authority, the perception of how the heritage values or significance are affected will change not only depending on the professional background or role of the actors involved, but even among actors with a similar background. Just considering the category of conservators, different understandings of conservation theories can result in very different evaluations of what is acceptable or not in relation to a change in the material authenticity or in the aesthetical appearance of the object.

This was the case of the panel of experts consulted about the most appropriate retrofitting strategy for the Rådhus in Piteå. A list of possible measures for improving the thermal performance of the building envelope was given to three building conservators: one from the Swedish association of professional building conservators (SPBA), one from the local planning authority, and one from the County Administrative Board of Norrbotten. They provided statements of what they thought of each proposed measure from a building conservation perspective. The measures (or combination of measures) that each expert considered to be appropriate were simulated as three different retrofitting scenarios, in order to quantify their potential energy savings. As showed in Table 1, the experts' answers on which of the measures they considered to be acceptable, lead to very different outcomes in the potential reduction of heating energy use. A fourth scenario is added as a reference to show the total reduction of heating energy use in case all the measures accepted by at least one of the experts were implemented.

Moreover, a comparison between the two buildings studied in Malmberget shows that also in the past value assessment could lead to different outcomes regarding preservation and energy performance. House 158 was heavily retrofitted in the 1960s, including the addition of insulating layers to improve its energy performances: an extra insulation of 50 mm of mineral wool was added to the exteriors

Table 1. Proposed energy retrofitting strategies for the Rådhus in Piteå

Scenario 1	Adding 250 mm mineral wool insulation to the attic				
Scenario 2	Adding 250 mm mineral wool insulation to the attic + addition of 70 mm insulation to the external walls + Changing the inner pane with "energiglas" with U value 1,8 W/(m².K) + improving the existing infiltration rate from 1,6 l/(s.m²) to 1.2 l/(s.m²)				
Scenario 3	Adding 250 mm mineral wool insulation to attic + replacing the existing door with improved door with U value 1,4 W/m².K + addition of 70 mm insulation to the basement walls + addition of 45 mm extruded polystyrene on the basement floor + changing the inner pane with "energiglas" with U value 1,8 W/(m².K) + existing infiltration rate 1.6 l/(s.m²)				
Scenario 4	Adding 250 mm mineral wool insulation to attic + addition of 70 mm insulation to the external wall + Addition of 70 mm insulation to the basement walls + addition of 45 mm extruded polystyrene insulation on the basement floor + Changing the inner pane with "energiglas" with U value 1,8 W/(m².K) + improved door with U value 1,4 W/m².K + Improving the existing infiltration rate to 1.2 l/(s.m²)				
	Base Case	Scenario1	Scenario 2	Scenario 3	Scenario 4
Heating energy use (kWh/m²/year)	77,5	75,6	62,5	68	58
Total energy use (kWh/m²/year)	132,7	130,7	117,6	123	113
Reduction in heating energy use (%)		2,4	19,3	12,2	25

and the external panelling was remade; 70 mm were added to the roof. On the contrary, in the house 420 the appreciation for its refined finishing and details, both in the interiors and in the exteriors, likely resulted in an opposite strategy: it is very well preserved and no measures for energy efficiency have been implemented.

The current energy performance of the houses, given by their energy declarations, and the measurements on field of the U-value confirm the difference. House 158 uses 195 kWh/m^2/year and a typical thermal transmittance of the outer walls of 0.32 W/m^{2}K was measured; in house 420 the corresponding values are 300 kWh/m^2/year and 0.47 W/m^{2}K. Both houses rise questions and doubts about the impact on cultural values of future proposals of energy retrofit. In one case, despite the very poor performance of the building in such a cold climate, the room for action will probably be very limited and every proposal will have to be considered very carefully. In the other case, the evaluation will focus on the cultural value of energy retrofit interventions from the past, and on whether to keep and upgrade them or to attempt a “de-restoration”, which could significantly affect the energy efficiency of the building.

4.2 DOING LESS, DOING MORE OR DOING NOTHING?

Both European directives and Swedish legislation allow exemptions from energy requirements when the cultural, architectural or aesthetical values are affected. [16] [17] [18] Both in Kiruna and Malmberget, this cautious approach was reinforced by the exemptions introduced in 2007 by the Government to avoid the risk of what was referred to as “cultural destruction” [19]. This could occur when large numbers of historical buildings are to be moved and rebuilt in a new place and, according to the previous law, they would have to meet present-day building requirements. The fear was also that this would have caused a rent increase for the tenants. In both cities, these were among the main reasons why energy retrofit measures are not included within the moving process, and will not be implemented.

In the case of Kiruna, the need for a deeper energy renovation of its existing building stock was shown by Johansson and others [20]. They calculated that the ongoing transformation could allow the town to meet the Swedish national energy reduction target for 2050, but only by replacing all the buildings affected by the mining activities with new ones that achieve the passive-house standard. Of course, meeting such a high performance level would be impossible for a heritage building. Nevertheless, giving up on improving the energy performance of Kiruna’s Bläckhorn houses exemplifies a typical situation where doing nothing is maybe the safest option, but not the absolute best when considering other societal needs.

In an earlier paper [21], the authors have proposed an energy retrofitting strategy for the building envelope of the Bläckhorn house B52, starting from a cultural value assessment to identify the character-defining elements of the building. The measures proposed in Table 2 are meant to: a) minimize the impact on the character defining elements, i.e. the shape, materials and finishing of the

Table 2. Proposed interventions for house B52 in Kiruna (adapted from Luciani et al. 2017)

Building elements	Thermal transmit-tance (W/m²K		Description of the proposed refurbishment measures	Contribution to reducing total thermal transmittance	Estimated savings of heating energy use
	Before	After			
Attic (timber frame structure)	0.39	0.17	Removal of sawdust fill and addition of 300 mm cellulose loose-fill insulation	5 %	4 %
Outer wall (paneled timber log structure)	0.48	0.30	Addition of 50–80 mm wood fibre insulation board to the inner side	9 %	7 %
Basement (1960s concrete structure)	0.93	0.27	Change to ventilated crawl-space basement with 100 mm foam insulation	39 %	31 %
Windows (triple pane, wood frame)	2.1	1.2	Addition of secondary glazing	6 %	4 %
Doors	1.4	1.4	No changes applied	0 %	0 %
Linear thermal bridges	0.062	0.044	Estimated improvements due the proposed measures	2 %	1 %
	Average: 0.77	Average: 0.30	All changes of individual elements implemented	60 %	48 %

exteriors and the timber structure; b) add new elements that reflect contemporary needs in the most compatible and reversible way (e.g. the addition of insulation and secondary glazing to the inner side of the walls); and c) optimize the life cycle of the existing building components, even when not original (e.g. the windows). Furthermore, they are based on rather inexpensive and accessible technologies and they can be easily added to the usual renovation works required by the moving of the house in its new location.

It must be underlined that a large part of the energy savings come from the substitution of the existing basement floor with an insulated and ventilated crawlspace, which is a consequence of the movement of the building. All other measures proposed for the building envelope are nevertheless estimated to lower the heating energy use of around 15–20 percent. This example shows that a sound retrofit strategy can enlarge the room for action for the energy retrofit of traditional timber buildings, and overcome a precautionary over-use of exemptions.

4.3 UNDERSTANDING THE OPPORTUNITY AND ECONOMIC VIABILITY OF ENERGY RETROFITS IN COLD CLIMATES

In a demanding cold subarctic climate, improving the energy performances of historic buildings can be a key-factor to ensure their preservation, and particular attention should be payed to limit the heat losses through the building envelope. This context thus offers interesting opportunities because even an intervention not so invasive on heritage values can help to save a comparatively higher amount of energy. Most of the cases discussed in this paper are facing the extraordinary situation of being moved due to the ground deformations caused by mining activities. It is worth mentioning that, in an early stage of the process, the poor energy performances of these buildings (and the operational costs implied) were quoted among the reasons for which their demolition and substitution with new buildings could be considered a preferable and less expensive option, compared to their moving and preservation [22].

As already mentioned, at present no particular energy saving measures are planned for the buildings that have been (or are going to be) moved, because of the exemptions they can have and, supposedly, for budget restrictions and other economic reasons. In the authors' opinion, nevertheless, implementing energy retrofit measures in this phase, especially on the building envelope, could be a winning option to increase the economic, environmental and social sustainability of the whole operation. Of course, the implementation of the measures would come at an additional cost, but the increase should not be so high in perspective, considering all the other operations and interventions of renovation that are already implied in the movement of the buildings. Hopefully, the results from this research will give the real-estate company that owns the buildings a good incentive to make energy efficiency measures.

In a cold climate, better energy performances should have a higher impact in lowering operational costs [23], thus reducing their payback time, but this hypothesis needs to be verified with a more accurate assessment of the life-cycle costs of the operations described [24]. In the long term, however, lower operational costs could contribute to pay back to the owner part of the whole investment for moving the building or to lower the rent of the apartment for the tenants. A further consideration is valid also for heritage buildings in more common situations: saving in heating energy use means that in the long term more budget can be allocated into building maintenance and preservation actions.

5. CONCLUSIONS

Sound strategies for the retrofit of the envelope of heritage buildings, such as those proposed in the paper, could save a consistent amount of energy in the timber buildings analysed in the project, but a key issue is still how to integrate in the process the complex operation of assessing the impacts of energy saving measures on cultural values.

This paper has shown that cold climates offer interesting opportunities for improving the energy efficiency of valuable historic buildings. Unfortunately, this potential is often left unexplored because other factors come into play, such as exemptions, budget restrictions or an unclear understanding of which measures are acceptable or not from a heritage perspective. The next steps of the project will thus focus primarily in implementing and disseminating tools that can help stakeholders, particularly owners and authorities, in understanding these opportunities.

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