Fredrik Berg, Anne-Cathrine Flyen, Åsne Lund Godbolt, Tor Boström.

User-driven energy efficiency in historic buildings: review.

Journal of Cultural Heritage. Volume 28, 2017, Pages 188-195, ISSN 1296-2074.

The article has been published in final form by Elsevier at

https://doi.org/10.1016/j.culher.2017.05.009

Title:

User-driven energy efficiency in historic buildings: review

Author names and affiliations:

Fredrik Berg

Norwegian Institute for Cultural Heritage Research (NIKU)

Pb 736 Sentrum, 0105 Oslo, Norway

email: fredrik.berg@niku.no

Anne-Cathrine Flyen

Norwegian Institute for Cultural Heritage Research (NIKU)

Pb 736 Sentrum, 0105 Oslo, Norway

email: anne.flyen@niku.no

Åsne Lund Godbolt

SINTEF Building and Infrastructure

Pb 124 Blindern, 0314 Oslo

email: asne.lund.godbolt@sintef.no

Tor Broström

Uppsala University Campus Gotland

Campus Gotland, Uppsala University, 621 67 Visby

email: tor.brostrom@konstvet.uu.se

Abstract:

The paper draws from the general literature on energy efficiency and historic buildings to explain the importance and potential of user-driven energy efficiency in historic buildings. It is the first review that places the user as a central object of study in the research field of historic buildings and energy efficiency. Relevant interdisciplinary topics and research results that make up the core of the field are presented and discussed in relation to user behaviour and its impact on energy consumption. The paper also investigates how user behaviour aspects can be integrated in a procedural approach to energy refurbishment in historic buildings.

Research and experience from the building stock in general clearly shows how a user's awareness and behaviour, such as choice of temperature, zone heating and controlled airing, can have a significant effect on energy demand yet have no physical impact on the building. However, this has not received enough attention with regards to the historic building stock, where many physical energy efficiency measures can have negative impacts on the historic qualities of the building. Modification of user behaviour can therefore be a way not only to reduce energy demand but also to minimise the physical impact of increasing energy efficiency on historic buildings.

The paper concludes that the current research agenda on historic buildings and energy efficiency has broken much ground but remains focused more on technical solutions than bottom-up user perspectives. Two main topics are identified as key barriers and future research fields: First, energy performance modelling is identified as a general barrier to developing sustainable strategies that promote user impact in historic buildings. Accurate energy modelling of historic buildings is a complex field reliant on the thermal interplay between user-building and building-district. Improved knowledge and intensified research is necessary to avoid distorted energy modelling results and unwanted rebound effects. Practical tools also require that the modelling can be used for trade-off scenarios where other sustainability aspects such as cultural heritage and economy are weighed in. Second, awareness-raising in order to foster a deeper understanding and knowledge about the construction, system and cultural heritage values of a building is proposed as a key ingredient and driver for improved and sustainable energy behaviour.

The paper argues that while user-driven energy efficiency represents an important resource for fostering less energy-demanding and less intrusive interventions in historic buildings, there are no guarantees for achieving the planned level of energy efficiency without taking into account user behaviour and the actual operation and energy performance of the historic building. To do this without risking negative consequences, improved decision-making processes are needed on policy, building and user level. An interdisciplinary bottom-up approach to energy refurbishment is presented. The essence of the model is that users and residents should always play a central role in the decision making process because the wellbeing of the historic building will always depend on its day-to-day users, and vice versa.

Highlights:

- State of the art review on user-driven energy efficiency in historic buildings.
- Non-intrusive energy efficiency measures have significant impact and potential.
- Integrated bottom-up refurbishment processes will provide for better management.

Keywords (6):

historic buildings; cultural heritage; user behaviour; energy efficiency; climate change mitigation

1 Introduction

Although energy efficiency has improved considerably over recent years, the European Union (EU) assumes that it is technically and economically feasible to make further progress by using different strategies across all active sectors. According to the EU, buildings represent the most promising target for energy efficiency improvements. Despite the fact that user behaviour is a major determinant of energy use in buildings, the energy saving potential of behaviour is often neglected or considered unimportant relative to the energy savings of technology.

Improving energy performance in historic buildings requires a deliberate balance between societal and climate goals for energy efficiency and building conservation. To reach societal climate and energy goals, different energy efficiency measures for buildings are produced and performed. These energy efficiency measures do not necessarily take building conservation or cultural heritage into consideration. In most cases they are designed to improve the energy performance of buildings without giving consideration to historic or aesthetic values. For instance, a common technical energy efficiency measure such as upgraded windows can have a negative impact on the historic fabric and overall architectural expression of historic buildings. Interventions can also interfere with inherent building physics systems and this gives rise to structural damage.

Research and experience from the building stock shows that user awareness and behaviour, such as choice of temperature, zone heating and controlled airing, can have a significant effect on energy demand without having any physical impact on the building. User behaviour can, therefore, be important not only to reduce energy demand but also to reduce or avoid the physical impact on historic buildings during the energy efficiency process.

The purpose of this paper is to elucidate the potential of user driven energy efficiency in historic buildings and to investigate how user behaviour aspects can be integrated in the energy refurbishment process. Based on a review of the existing literature, this paper aims to summarise the present knowledge of user driven energy efficiency in historic buildings by discussing the following questions:

- In what ways can user behaviour have an effect on energy demand? What is the potential?
- What aspects of user behaviour are particular to historic buildings?
- How can user behaviour aspects be integrated in the energy refurbishment process for historic buildings?

User behaviour related to energy consumption and energy efficiency has recently been given more attention, especially in the social sciences. However, research activities on the topic of user driven energy efficiency in historic buildings have been limited. This article will draw mainly on the literature of energy user behaviour and on research that deals with energy efficiency and historic buildings. The *user* is here defined as whoever is using the building more or less regularly but, given the focus of this research on domestic households, it particularly refers to residents.

2 The general research agenda: historic buildings and energy efficiency

2.1 Energy targets and historic buildings

To tackle global warming, the EU is committed to reducing its greenhouse gas (GHG) emissions by at least 20 % by 2020 (The European Commission, 2012) and 40 % by 2030 (The European Commission, 2014) compared to 1990. The long-term aim is to reduce GHG emission by 60–80 % by 2050 (The European Commission, 2009). Part of the challenge lies in refurbishing the existing residential building stock, which is normally ascribed ca. 40 % of all GHG emissions. However, there are many different theoretical, technical, and financial barriers that limit the achievement of the full energy saving potential for most buildings.

The cultural heritage of historic buildings can have a considerable effect on the outcome of the process concerns the cultural heritage significance of historic buildings. To address this problem, EU policies today allow for the exemption from certain minimum energy requirements should they unacceptably alter the “character or appearance” of protected historic buildings (The European Commission, 2010, p. 7; 2012, p. 14). However, historic buildings do not necessarily require statutory protection per se. Buildings that are not formally listed but still considered as being of heritage interest are also regarded as being worthy of protection and care. Thus, the term *historic building* also encompasses buildings that are not necessarily listed. As stated in the Burra Charter (ICOMOS, 2000, p. 1), these buildings can possess general heritage values that, with respect to past and future generations, should be maintained. Consideration for these aspects distinguishes working with historic buildings from working with the building stock in general.

Unfortunately, and contrary to general principles of preservation, conclusions about reaching efficient energy performance levels for the historic segment of the building stock are often based on the assumption that it requires dramatic physical improvements with modern standardised measures (Kohler & Hassler, 2012, p. 409). Therefore, the goal of development and reaching energy targets is often brought into a supposed conflict with the management of built heritage (Moran et al., 2014, pp. 216-217; Norrström, 2013, pp. 2638-2639). It has become evident that even small adjustments to buildings and user behaviour may have large and positive impacts on energy saving, provided that the technical condition of the historic building is adequate and that any measure takes into consideration the building’s individual characteristics (Svensson et al. 2012, p. 48). This however requires a procedural approach to the energy efficiency process.

2.2 A procedural approach to energy efficiency

A systematic approach to facilitate the best decisions when planning energy refurbishment in historic buildings has been developed and published in a European Standard (CEN, 2017). The standard provides "a normative working procedure for selecting measures to improve energy performance, based on an investigation, analysis and documentation of the building and its heritage significance". It acknowledges the importance of user aspects by stating that "significant energy savings may be achieved through the change of user behaviour without altering the building". The standard further advocates for a "multidisciplinary approach in close cooperation with the owners and users of the building" and suggests that users should be made aware of the impact of their behaviour and how it can influence conservation, energy consumption and associated cost. Thus, while the document on one hand emphasises the importance of user aspects throughout the text, it does not elaborate or specify how to achieve energy savings through user behaviour.

2.3 Behavioural aspects of energy efficiency

Yohanis (2012, p. 655) has defined energy behaviour as actions "taken by householders in their use of energy in their homes". Lopes et al. (2012, pp. 4102-4103) have in turn argued that energy behaviour represents a significant untapped potential for the increased end-use energy efficiency of buildings. Today, simple measures such as consuming less hot water, adjusting thermostats when leaving for work, lowering the temperature in different rooms, or airing and opening windows in a controlled rather than inattentive manner all represent significant and self-evident energy savings. These common-sense actions are often achieved with low or no capital investment. Although this can seem very simple, the concept of energy behaviour is more complex than that.

From a sociological point of view, it is often proposed that energy demand does not only originate in the individual but is also a social construct wherein institutional and cultural contexts influence energy behaviours and attitudes. Energy behaviour strategies (e.g. social learning, collective actions etc.) must therefore take these perspectives into consideration in order to be effective (Lopes et al., 2012, p. 4097). For further discussion about the term from a social science perspective, see for instance Owens and Driffill (2008), Godbolt (2014), Ryghaug et al. (2011) or Stephenson et al. (2010). In the following, Yohanis' (2012) definition is adopted and broadened to imply the interaction between one or more users, the building and its energy system.

As already pointed out, energy savings reached merely by behavioural change are often neglected or considered unimportant; they are often underexploited in relation to the efficiency and impact of technological solutions despite having shown reasonable results (Lopes et al., 2012, p. 4096; Lopes et al., 2015, pp. 95-96). Lopes et al. (2012) have underlined this in an extensive review where they characterised the general relation between user behaviour and energy efficiency. They presented several critical issues to get energy behaviours "properly valorised and integrated in the energy policy”. One of these was overcoming the difficulties of quantifying behaviour, which was stated to have limited the research activities and had substantial consequences for contemporary energy efficiency policies (Lopes et al., 2012, p. 4102).

2.4 Historic buildings and energy efficiency

From a historical perspective, both rural and urban built environments have been characterised by the rational and efficient use of environmental resources (The Nordic Council of Ministers, 2014, pp. 35-36). Construction materials apart, this was especially reflected in domestic energy use; for instance, the lower thresholds for adequate or comfortable indoor environment quality. It is also evident in how climate responsive cultural practices (such as the use of certain textiles and clothing) have affected traditional thresholds of comfort regimes and placed new demands on active technological solutions (Winter, 2013, pp. 528-529). It is important that we should draw on these experiences when managing the existing building stock.

To refurbish historic buildings on a sustainable basis implies that environmental, economic as well as social and cultural aspects are taken into account. The interdisciplinary knowledge needed to handle these aspects has called for increased research activity. This demand has been reflected in several calls from the Joint Programme Initiative (JPI), as well as the EU’s Seventh Framework Program and Horizon 2020. Several successful recent projects have focused on the refurbishment potential in historic buildings. Most of them have been characterised by topics regarding technical measures, careful passive solutions and the conversion to fossil-free energy sources. For example, a Norwegian study has investigated timber-frame buildings to illustrate the potential for and problems with energy efficiency measures in a life cycle perspective. This analysis was based on an evaluation of selected standard interventions applied towards different energy targets (Selvig, 2011). The European project 3ENCULT (Efficient Energy for EU Cultural Heritage) aimed to bridge the gap between conservation of historic buildings and climate change, and it aimed to demonstrate the feasibility of energy-efficiency measures in historic buildings (the results are summarised in Troi and Bastian's book “Energy Efficiency Solutions for Historic Buildings” from 2014). Another European project, Energy Efficiency for EU Historic districts’ (EFFESUS), has developed a decision-support system for historic districts; as presented by Eriksson et al. (2014), amongst others.

However, research activities invested in historic buildings, and user driven energy efficiency in particular, have been limited. Fouseki and Cassar (2014, p. 97) pointed to this gap in an editorial on future challenges and research needs stating that “how people use a building often will be more important than the type of energy-efficiency technologies selected”. The CERCMA investigation, which is a joint seminar-based Nordic effort published in 2014, acknowledged a similar outlook by concluding that “the influence of behaviour tends to be more apparent to the user” of historic buildings than buildings in general. By nudging positive user behaviour (i.e. raising awareness with monitoring and metering, cf. smart grids), non-intrusive measures were suggested to efficiently supplement or hinder large improper upgrading of historic buildings caused by inaccurate energy modelling (The Nordic Council of Ministers, 2014, pp. 19,52).

One of the few studies that acknowledge the interdisciplinary approach to the issue is Ben and Steemers's Brunswick Centre case (2014). This is a listed residential 1960s complex in London that was used to investigate what fully realised occupant behaviour in combination with cautious retrofitting could achieve in terms of energy saving. Although the findings were based on a limited dataset and generalised scenario calculations, they indicated that the impact of behavioural change can exceed the energy savings gained from technical and physical improvements. In addition to promoting efficient and intentional heating as a head strategy when refurbishing listed buildings, the authors had two main arguments. One was that "tackling behavioural change plays a pivotal role in developing integrative strategies for listed housing retrofit" (Ben & Steemers, 2014, p. 120). The other was that if behavioural aspects were to be given more consideration in building performance modelling, renewed policy and retrofit strategies could bring about energy savings that are significantly higher than that from physical improvement.

The current research agenda on historic buildings and energy efficiency indicates that there is a gap between academic and implemented research, as epitomised by its lack of bottom-up user perspectives. It is likewise clear that there are no guarantees for achieving the planned level of energy efficiency if user behaviour and the operation of the building is not taken into account, which has been stressed by both Grytli (2004, p. 24) and Xing et al. (2011, pp. 3230-3231). The gap represents an untapped potential to which there are two main possible approaches. On the one hand is unwinding the social challenge of adapting user behaviour. Changes in behavioural patterns and individual reactions to higher energy prices may directly affect awareness and the actual energy consumption of the user (Balaras, Dascalaki, Droutsa, & Kontoyiannidis, 2016, p. 124). On the other hand is the model-based approach, which is normally required to identify optimal solutions or to investigate potential energy savings in different scenarios.

3 User behaviour and energy demand - potential

3.1 A model-based approach for understanding user impact

A model-based approach can be used to compare improvement scenarios for historic buildings because the results allow for a trade-off between heritage values, on one side, and the quantified values of environmental and economic impact, on the other (Broström et al., 2014). With deeper and more specific analyses, such as life cycle assessments, it is possible to foster important planning policies and subsidy systems that are adapted to better fit the historic buildings and their users (Aksoezen, Daniel, Hassler, & Kohler, 2015, p. 85; Berg, 2016, pp. 73-74; Broström et al., 2014, pp. 163-164; Enlid, 2015). There is, however, a general problem with the model-based approach. Successful energy performance modelling requires credible data and information about factors related to the user, the building and its surrounding environment.

3.2 Gaps between expected and measured energy performance

There are significant differences between the modelled (theoretic) and actual energy performance of buildings in general (Haas, Auer, & Biermayr, 1998, p. 202). Brohus et al. (2010, pp. 2, 9) have shown that the difference between the calculated energy consumption and the actual energy consumption can exceed 100% in extreme cases. Similar to the results from Ben and Steemer's Brunswick case (2014), user behaviour is considered to be the main reason behind this significant gap between the actual and predicted energy performance of buildings.

So where is the root of the problem? Moran et al. (2014, pp. 222-223) have suggested that the difference (in gas use) can be caused by occupants not heating the whole house to the same temperature, different heating thermostat set points, the use of an intermittent heating pattern and varying occupancy regimes. In an attempt to illustrate the complexity Yu et al. (2011, p. 1409) have defined seven major factors that have an influence on the results of building modelling:

- Outdoor climate (temperature, wind velocity, sun, etc.),
- Building characteristics (size, orientation, etc.),
- Building's service systems and operation,
- Presence of users,
- Behaviour and activities of occupants (use of electronics, cooking, etc.),
- Social and economic factors (e.g. education, energy cost, etc.), and
- Desired indoor environmental quality (set-temperature, airing, ventilation etc.).

Attempting to improve user impact is therefore not an isolated task. Galvin and Terry (2016, p. 158) have claimed it is in fact extremely difficult to assess the reasons why users do or do not implement more energy efficient behaviour given the large number of possible determinants. As we have seen, users make sense of these energy efficiency issues through both social, economic and cultural factors (Godbolt, 2015, pp. 25-26).

3.3 Aspects of modelling historic buildings

Another issue with the model-based approach concerns the modelling of historic buildings in particular. In an article addressing the alternative scenarios for energy conservation in building stock, Kohler and Hassler (2012, pp. 401, 413) found that the root of the problem was that most methods that are used to model buildings are "conceptually derived from new construction". To achieve better results, Kohler and Hassler (2002), and others (Aksoezen et al., 2015, p. 85; Salat, 2009, pp. 598-600; Troglio et al., 2011, pp. 15-16) have underlined the need to broaden the scope and "understand the value, the composition and the long-term dynamic of the building stock" (Kohler & Hassler, 2002, p. 234) because it is represented by more intricate relations between aspects related to energy performance than the case of single buildings. Bourdic and Salat (2012) have discussed the subject of users on building stock level in a critical review of existing energy modelling tools. Borrowing a concept from Ratti et al. (2005, p. 763), they find that there are four critical intervention mechanisms that define urban structures and their effectiveness:

- Urban morphology,
- Building efficiency,
- System efficiency, and
- Individual behaviours.

The review concluded that there is a general need for "more systemic, multi-scale and transverse approaches to deal with the intrinsic complexity of the urban fabric" and that, instead of trying to take into account all four factors at the same time, "research efforts should focus on the interactions and relationships between existing models" (Bourdic & Salat, 2012, pp. 518, 525). The building's potential is, therefore, dependent on the district and surrounding environment, just as the user's energy saving potential is dependent on the specific building.

In conclusion, the literature shows that the user plays a significant role throughout the system and its user, building and district levels. The findings also support Lopes et al.'s (2012, p. 4101) view that it is "important to emphasise that these types of models often fail to adequately deal with socio-technical influences on energy consumption, specifically behaviour". However, to improve the accuracy of energy performance modelling, there is a need for more empirical data (Moran et al., 2014, p. 226) of the users and the uncertainty factor that they represent in the modelling of historic buildings (Huebner et al., 2015, p. 597; Silva & Ghisi, 2014, p. 390). It is important not only to improve the accuracy of modelling tools but also to gain knowledge on how user driven energy efficiency is affected by other factors (Swan & Ugursal, 2009, pp. 1832-1833).

4 User behaviour aspects and the energy refurbishment process for historic buildings

4.1 On raised awareness as a driver for energy efficiency

Leaving the modelling approach, a Danish review by Ástmarsson et al. (2013, pp. 359-360) focused on identifying practical barriers to sustainable retrofitting and renovation. It was concluded that the main problem is not a lack of technical solutions but rather informational barriers and complex or inexpedient economic incentives, such as causing the landlord-tenant (i.e. split-incentives) dilemma (Ástmarsson et al., 2013, pp. 359-360). What kind of information would then be relevant to pass on?

In a case study focusing on the Durham University estate, Adams et al. (2014) presented results indicating that more knowledge about a building's historic values can affect the user's evaluations of what was determined as appropriate levels of comfort. The authors argued that it "might be possible to engender attitudes that promote more effective use of the infrastructural legacies of the past" (Adams et al., 2014, p. 175) by raising awareness about the historic qualities of a building amongst its users. Although their study was conducted only on a few homes and inhabitants, it does indicate that attitudes towards cultural heritage (i.e. the historic qualities of buildings) can be facilitated as drivers that help improve energy behaviour.

These results are particularly interesting in light of the findings from a Norwegian study by Godbolt (2014) in which it was pointed out that the main incentive in Norway for retrofitting homes in general is improved indoor comfort and not to cut the energy bill. Is this a potential opening for alternate policy instruments for historic buildings? Li et al. (2012) conducted a large-scale occupant survey addressed to residents in a World Heritage designated settlement in south-eastern China and residents in newer reference dwellings, not only did the results show that the overall energy consumption was lower for the historic buildings due to different energy behaviour but they also showed that residents in the historic buildings responded to thermal comfort far more positively. Winter (2016, p. 383) has stated, from the perspective of reduced carbon emissions, that thermal comfort is a "significant, complex and poorly understood" aspect. Winter (2016) explicitly underlines how the field of preservation, considering its understanding about historic passive design, has a distinct contribution to better understanding this aspect. Indeed, research activities concerning energy efficiency and thermal comfort in historic buildings in general have increased during the last decade, as discussed by Martínez-Molina et al. (2016, pp. 82-83). Yet the linking of domestic indoor comfort, energy efficiency and insight regarding cultural heritage values has received little attention (Fouseki & Cassar, 2014, pp. 98-99).

4.2 On occupant feedback

Occupant feedback may help to impart awareness and support holistic building assessment. For instance, Zalejska-Jonsson (2012, pp. 142-143) has stressed how user feedback is an "important part of comprehensive building performance assessment". It was in addition seen how the green profile of the studied new low-energy buildings had a positive impact on the user's environmental awareness and behaviour. In a study about effective feedback techniques, Fischer (2008, pp. 102-103) concluded that information and awareness raising (i.e. a form of proactive engagement) provided through a combination of frequent, long-term, appliance specific feedback can contribute to electricity savings of between 5 and 20%.

Gupta and Chandiwala (2010) have investigated the correlation between user profiles and awareness by assessing existing occupant feedback techniques. Besides confirming wide gaps between modelled and measured energy consumption, their results demonstrated that initial feedback and evaluation led to the resident’s more active engagement and awareness about their energy use. Podgornik et al. (2016, pp. 32-32) presented results that confirm the importance of customised information for specific user types, and described how it has potential to increase knowledge and develop awareness with respect to established behaviour. A study by Shen and Cui (2015, p. 2117) has shown that providing customised feedback (i.e. with addressing different user types) based on different energy behaviour profiles has great potential to achieve efficient household energy consumption.

As one of few studies focusing on historic buildings, the EEC project “Low Energy Apartment Futures” (LEAF) has acknowledged that providing customised feedback is important to achieve efficient household energy consumption and stresses the importance of integrative user surveys before, during and after rehabilitation (Changeworks, 2016, pp. 3-4). The LEAF-approach suggests that surveys not only improve the decision making process for refurbishing historic apartment blocks but they also help to identify different user profiles with varying possible behavioural improvements.

4.3 On rebound effects

Pay-back calculations, in terms of both economic and energy values, do not normally take the possible rebound behavioural change following a refurbishment into account. This unintended consequence has been investigated by several authors (Greening et al., 2000; Sorrell, 2007) and is caused by how calculated and measured data “typically does not fit” (Hens et al., 2010, pp. 105, 110). Thus, it essentially implies a reduction of expected gains due to, for example, unforeseen behavioural responses. In contrast, while the rebound effect may be sufficiently large to lead to zero (or less!) energy savings, positive behavioural changes, (i.e. adjusted green behaviour) may in fact increase energy savings following retrofit (Ben & Steemers, 2014, p. 120).

One typical indicator of rebounding is how the occupant’s lack of control over heating (which can be triggered by the introduction of automatic or centralised systems) leads them to revert to window opening to control the indoor environment. On the household level, this implies that the reduced level of savings realised from energy efficiency improvement measures will eventually prolong the calculated payback time. On a larger scale, failure to take account of such rebound effects can contribute to shortfalls in the achievement of energy and climate policy goals. This is discussed in detail by Sorrell (2007). Sharpe and Shearer (2012) have also discussed this phenomena, using a listed tenement block in Edinburgh as a case study. Their research suggested that the inexperience of users regarding the inertia of a newly installed heating system in combination with a refurbished thermal envelope had led to recurring daily window opening. To overcome these tendencies, Sharpe and Shearer promoted integrated monitoring as a “useful tool in understanding building performance” (2012, p. 9).

In all, that findings from the literature indicate that there are certain interplays between user-related energy consumption, on the one hand, and the awareness of a building's cultural heritage values, on the other hand, that can trigger or facilitate a driver in energy efficiency. There are, however, a number of factors and barriers that in various ways can affect this. To avoid effects where planned energy savings are not realised, it seems that the users and residents need to be engaged and play an integrated role in the refurbishment process, including the following operational and maintenance phase.

5 Discussion

The purpose of this paper is to understand the potential of user driven energy efficiency in historic buildings and to investigate how user behaviour can be integrated in the energy refurbishment process. Before clarifying a proposed procedure, it might be worthwhile discussing user driven energy efficiency in historic buildings and its potential on a more general level.

Although this field of research is still young, user behaviour in terms of energy consumption is clearly a highly relevant topic for the sustainable management of historic buildings and there is much to learn from the literature on buildings in general. Building techniques, practices, habits and tacit knowledge of house holding and resource management that have lost their grip in tradition may be rediscovered and used to actively reduce energy needs. User driven energy efficiency in historic building includes social, economic and environmental aspects. When scaling up the otherwise modest energy savings potential of ca. 10–15 % per building, these non-intrusive measures clearly show how relevant they are as a supplement to balanced technical and physical improvement in historic buildings.

The quantification of user driven energy efficiency potential in historic buildings is indeed problematic. Research and empirical data is insufficient and the existing methodologies assessing occupant behaviour are predominantly quantitative. Although the social sciences have recently given more attention to this area, more *qualitative* approaches are required to understand energy behaviour, especially in relation to historic buildings. More focused research and case studies would help us to understand how users, buildings and groups of buildings interact. By illuminating the barriers (e.g. heritage restrictions) to building efficiency that prevent the realisation of technical energy efficiency measures, research can reveal how and if adapted behaviour can contribute towards optimising system efficiency. On quarter or district level, holistic energy performance modelling may provide useful results for designing policy instruments and foster important planning policies for the historic building stock. Subsidy systems can likewise become more flexible by redirecting certain incentives or backing to different building categories with different technical, energy and historic characteristics.

Based on the findings from the general literature on energy efficiency, it is clear that taking user behaviour into account is important not only in terms of energy modelling but also for scenarios where measures already have been implemented. For instance, rebound effects imply that the day-to-day users need to be more aware of how their behaviour affects the building's overall energy performance, and vice versa. Yet policy instruments and everyday energy saving campaigns rarely emphasise the symbiotic relationship between users, building construction and energy demand. This is part of the gap (i.e. the untapped potential) that in the case of historic buildings is often a question of implementing responsible "stewardship", as Jean Carroon chooses to call it in the book "Sustainable Preservation: Greening Existing Buildings" (2010). In other words, knowledge and awareness of the historic building requires managers, users and residents to maintain the building on its own premises as well as make a responsible effort to understand and pass on its historic qualities.

Furthermore, besides user impact, savings and benefits from energy refurbishment projects will always be dependent on the technical and physical state of the specific building. While the exact consequences for historic fabric of a changing climate are difficult to predict, many damages, deterioration processes and expensive measurements can be prevented with regular surveying and maintenance. This form of adaptation goes hand in hand with raised awareness because a deeper understanding of the technical state of the historic building supports better understanding about its history and historic significance. Efficient user behaviour in historic buildings also implies a fundamental understanding of how the historic building functions. It involves knowing when to ventilate, what areas are most heat demanding, and where the weak spots are in the thermal envelope.

On the basis of the review, it is reasonable to stress that the improvement of the energy performance of historic buildings is a balancing act between heritage significance, technical condition, energy efficiency measures and, perhaps especially, *intended use*. It is likewise evident that any plan of intervention should be ruled by a detailed understanding of the building's character and qualities, as well as a thorough investigation of targets and objectives with a potential energy refurbishment. The building should always be assessed on its own individual merits. Moreover, to avoid worsening the present degree of damage or deterioration, the building should be brought up to a satisfactory technical state before or while any measures are implemented.

A successful energy refurbishment process of a historic building follows a hierarchal procedure (as described by Grytli, 2004, p. 24; Xing et al., 2011, pp. 3230-3231), where the improvement of the thermal envelope precedes installation of energy efficient equipment and the conversion to renewable energy sources. The reviewed literature, however, shows there are no guarantees for achieving the planned energy efficiency if user behaviour and the operation of the building are not taken into account. For this reason, we acknowledge the concept of the CEN standard (CEN, 2017) but argue that users should be explicitly involved throughout the energy refurbishment process. The purpose of this is two-fold. On the one hand, it will make the users aware of the impact of their behaviour and how they can influence energy consumption without the reliance on intrusive measures. It will, on the other hand, also make users more aware of the buildings' technical state, its need for maintenance and its inherent historic qualities.

We, therefore, propose that the process following an initiated energy refurbishment project should begin with an *interdisciplinary building survey*, see Figure 1. The survey and assessment provides the necessary information about the building in order to make an informed decision on any measures, be it maintenance, repair or energy related. The analysis should cover all parts of the building (e.g. in accordance with the European standard for condition survey and report of built cultural heritage, 2012) and it should be based on its history as well as the input and experience provided by its day-to-day users. This assessment will provide the information that is necessary to make an informed decision.

- figure 1 -

The next step, when the survey is completed, is to *identify the objectives and targets* for technical, energy and indoor environment quality improvements. This also requires an interdisciplinary effort because it concerns long-term ambitions for the management, use and conservation of the building. Including users and residents in this phase is important for several reasons. The first is to raise awareness of energy and building conservation and its positive effects. The second is the social dimension of sustainability and encouraging inclusive bottom-up decision making.

The need for *physical or technical interventions* is then defined on the basis of the difference between the present energy performance of the building and the objectives that have been identified by users and involved third parties. If physical or technical measures are considered necessary to reach targets and objectives, then inappropriate measures should be excluded. If *not* considered necessary, the users and residents should all partake in understanding how the non-intrusive energy efficiency process can be implemented and secured in an operational and maintenance phase.

In the next step, *a full assessment of the net list of measures* can be conducted with respect to risks and benefits. This opens the opportunity to assess several optional packages of measures that are adjusted iteratively in relation to targets and objectives. When an optimal strategy has been identified, the *implementation* and *follow-up phase* begin. In the first stage, this requires a one-way flow of information to the users and residents. However, in order to secure a positive outcome of the energy efficiency measures that have been taken, the follow-up process must be a team effort.

6 Conclusion

The potential of user driven energy efficiency and its involvement in mitigation strategies for historic buildings has been conceptually summarised and discussed. The findings confirm the hypothesis that user behaviour has a significant effect on energy demand and that balanced approaches for historic buildings are closely linked with energy behaviour. Quantifying the potential impact of users in historic buildings is, however, a complex task. Inadequate energy performance modelling practices, and user and resident-targeted awareness-raising are identified as major challenges. A general need for further research has been identified. An increased number of case studies with measured energy performance will help to provide better empirical data on the user impact in historic buildings.

The literature review also underlined the importance of interdisciplinary studies. Further research addressing issues of historic energy behaviour, regional building traditions and indoor comfort are expected to provide new insights into the topic. Tacit knowledge about how historic buildings were designed and used originally is believed to be of particular importance when identifying energy efficiency measures in historic buildings. It can also support the use of climate friendly design solutions in new construction. Further investigations should study the interplay between policy instruments for energy saving, heritage and conservation principles, as well as the psychological drivers behind user energy behaviour.

In summary, it has been argued that user driven energy efficiency represents an important resource that can foster lower energy demand and less intrusive interventions in historic buildings. To move in this direction, this paper has argued for a more integrated, interdisciplinary bottom-up approach to the challenges posed by the energy refurbishment process in historic buildings. A procedural approach based on a CEN standard has been proposed, which highlights the need for user-based knowledge about the specific building, its technical state and maintenance needs, as well as a general understanding of its heritage related qualities and values. The essence of the model is that users and residents should always play a central role in the decision making process because the well-being of the historic building will always depend on its day-to-day users, and vice versa.

7 Acknowledgements

The authors acknowledge support from the CulClim project (Cultural valuable buildings and climate change responses in a user perspective) funded by the Research Council of Norway, project number 235617.

8 References

Adams, C., Douglas-Jones, R., Green, A., Lewis, Q., & Yarrow, T. (2014). Building with History: exploring the relationship between heritage and energy in institutionally managed buildings. *The Historic Environment: Policy & Practice*, *5*(2), 167-181.

Aksoezen, M., Daniel, M., Hassler, U., & Kohler, N. (2015). Building age as an indicator for energy consumption. *Energy and Buildings, 87,* 74-86.

Ástmarsson, B., Jensen, P. A., & Maslesa, E. (2013). Sustainable renovation of residential buildings and the landlord/tenant dilemma. *Energy Policy, 63,* 355-362. doi:http://dx.doi.org/10.1016/j.enpol.2013.08.046

Balaras, C. A., Dascalaki, E. G., Droutsa, K. G., & Kontoyiannidis, S. (2016). Empirical assessment of calculated and actual heating energy use in Hellenic residential buildings. *Applied Energy, 164*, 115-132. doi:http://dx.doi.org/10.1016/j.apenergy.2015.11.027

Ben, H., & Steemers, K. (2014). Energy retrofit and occupant behaviour in protected housing: A case study of the Brunswick Centre in London. *Energy and Buildings, 80*, 120-130.

Berg, F. (2016). *Using the life cycle analysis approach for decision and policy support concerning built cultural heritage: Norwegian case studies.* Paper presented at the Second International Conference on Energy Efficiency and Comfort of Historic Buildings (EECHB), Brussels.

Bourdic, L., & Salat, S. (2012). Building energy models and assessment systems at the district and city scales: a review. *Building Research & Information, 40*(4), 518-526.

Brohus, H., Heiselberg, P., Simonsen, A., & Sørensen, K. C. (2010). Influence of occupants' behaviour on the energy consumption of domestic buildings. *Clima 2010*, 9.

Broström, T., Eriksson, P., Liu, L., Rohdin, P., Ståhl, F., & Moshfegh, B. (2014). A method to assess the potential for and consequences of energy retrofits in Swedish historic buildings. *The Historic Environment: Policy & Practice, 5*(2), 150-166.

Carroon, J. (2010). *Sustainable preservation : greening existing buildings*. Hoboken, N.J: Wiley.

CEN. (2017). Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings *TC 346, EN 16883:2017*: Comité Européen de Normalisation.

Changeworks. (2016). *Improving the energy efficiency of apartment blocks - Low Energy Apartment Futures (LEAF) Final Report*. Retrieved from www.lowenergyapartments.eu:

Enlid, E. (2015). *Klimagassutslipp i et livsløpsperspektiv, for lafta bolighus og standard TEK17-bygg*. Retrieved from

Eriksson, P., Hermann, C., Hrabovszky-Horváth, S., & Rodwell, D. (2014). EFFESUS Methodology for Assessing the Impacts of Energy-Related Retrofit Measures on Heritage Significance. *The Historic Environment: Policy & Practice, 5*(2), 132-149.

Fischer, C. (2008). Feedback on household electricity consumption: a tool for saving energy? *Energy Efficiency, 1*(1), 79-104.

Fouseki, K., & Cassar, M. (2014). Energy Efficiency in Heritage Buildings — Future Challenges and Research Needs. *The Historic Environment: Policy & Practice, 5*(2), 95-100. doi:10.1179/1756750514z.00000000058

Galvin, R., & Terry, N. (2016). Selling energy savings in the United Kingdom: A case study of top–down pro-environmental behaviour change in commercial office buildings. *Energy Research & Social Science, 11*, 155-163. doi:http://dx.doi.org/10.1016/j.erss.2015.10.001

Godbolt, Å. L. (2014). *Market, Money and Morals: The Ambiguous Shaping of Energy Consumption in Norwegian Households.* (PhD), Norwegian University of Science and Technology. Retrieved from http://hdl.handle.net/11250/244237 (2014:313)

Godbolt, Å. L. (2015). The ethos of energy efficiency: Framing consumer considerations in Norway. *Energy Research & Social Science, 8*, 24-31.

Greening, L. A., Greene, D. L., & Difiglio, C. (2000). Energy efficiency and consumption—the rebound effect—a survey. *Energy Policy, 28*(6), 389-401.

Grytli, E. (2004). *Fiin gammel aargang - Energisparing i verneverdige hus*. Retrieved from SINTEF - Arkitektur og byggeteknikk, :

Gupta, R., & Chandiwala, S. (2010). Understanding occupants: feedback techniques for large-scale low-carbon domestic refurbishments. *Building Research & Information, 38*(5), 530-548.

Haas, R., Auer, H., & Biermayr, P. (1998). The impact of consumer behavior on residential energy demand for space heating. *Energy and Buildings, 27*(2), 195-205.

Hens, H., Parijs, W., & Deurinck, M. (2010). Energy consumption for heating and rebound effects. *Energy and Buildings, 42*(1), 105-110. doi:http://dx.doi.org/10.1016/j.enbuild.2009.07.017

Huebner, G. M., Hamilton, I., Chalabi, Z., Shipworth, D., & Oreszczyn, T. (2015). Explaining domestic energy consumption – The comparative contribution of building factors, socio-demographics, behaviours and attitudes. *Applied Energy, 159*, 589-600. doi:http://dx.doi.org/10.1016/j.apenergy.2015.09.028

The Burra Charter: The Australia ICOMOS charter for places of cultural significance 1999: with associated guidelines and code on the ethics of co-existence, (2000).

Kohler, N., & Hassler, U. (2002). The building stock as a research object. *Building Research & Information, 30*(4), 226-236.

Kohler, N., & Hassler, U. (2012). Alternative scenarios for energy conservation in the building stock. *Building Research & Information, 40*(4), 401-416.

Li, Q., Sun, X., Chen, C., & Yang, X. (2012). Characterizing the household energy consumption in heritage Nanjing Tulou buildings, China: A comparative field survey study. *Energy and Buildings, 49*, 317-326. doi:http://dx.doi.org/10.1016/j.enbuild.2012.02.023

Lopes, M., Antunes, C., & Martins, N. (2012). Energy behaviours as promoters of energy efficiency: A 21st century review. *Renewable and Sustainable Energy Reviews, 16*(6), 4095-4104.

Lopes, M. A., Antunes, C. H., & Martins, N. (2015). Towards more effective behavioural energy policy: An integrative modelling approach to residential energy consumption in Europe. *Energy Research & Social Science, 7*, 84-98.

Martínez-Molina, A., Tort-Ausina, I., Cho, S., & Vivancos, J.-L. (2016). Energy efficiency and thermal comfort in historic buildings: A review. *Renewable and Sustainable Energy Reviews, 61*, 70-85. doi:http://dx.doi.org/10.1016/j.rser.2016.03.018

Moran, F., Blight, T., Natarajan, S., & Shea, A. (2014). The use of Passive House Planning Package to reduce energy use and CO 2 emissions in historic dwellings. *Energy and Buildings, 75*, 216-227.

Norrström, H. (2013). Sustainable and Balanced Energy Efficiency and Preservation in Our Built Heritage. *Sustainability, 5*(6), 2623-2643.

Owens, S., & Driffill, L. (2008). How to change attitudes and behaviours in the context of energy. *Energy Policy, 36*(12), 4412-4418. doi:http://dx.doi.org/10.1016/j.enpol.2008.09.031

Podgornik, A., Sucic, B., & Blazic, B. (2016). Effects of customized consumption feedback on energy efficient behaviour in low-income households. *Journal of Cleaner Production, 130*, 25-34. doi:http://dx.doi.org/10.1016/j.jclepro.2016.02.009

Ratti, C., Baker, N., & Steemers, K. (2005). Energy consumption and urban texture. *Energy and Buildings, 37*(7), 762-776.

Ryghaug, M., Sørensen, K. H., & Næss, R. (2011). Making sense of global warming: Norwegians appropriating knowledge of anthropogenic climate change. *Public Understanding of Science, 20*(6), 778-795.

Salat, S. (2009). Energy loads, CO2 emissions and building stocks: morphologies, typologies, energy systems and behaviour. *Building Research & Information, 37*(5-6), 598-609.

Selvig, E. (2011). *Klimagassberegninger for vernede boligbygg vs. nye lavenergiboliger*. Retrieved from Civitas, : http://hdl.handle.net/11250/176823

Shearer, D., & Sharpe, T. (2012). *Findings from a Post Occupancy Evaluation of adaptive restoration and performance enhancement of a 19th century 'Category B'listed tenement block in Edinburgh*. Paper presented at the Retrofit 2012, Salford.

Shen, M., & Cui, Q. (2015). Behavior Driven Energy Efficiency: A Customized Feedback Approach. *Energy Procedia, 78*, 2112-2117. doi:http://dx.doi.org/10.1016/j.egypro.2015.11.259

Silva, A. S., & Ghisi, E. (2014). Uncertainty analysis of user behaviour and physical parameters in residential building performance simulation. *Energy and Buildings, 76*, 381-391. doi:http://dx.doi.org/10.1016/j.enbuild.2014.03.001

Sorrell, S. (2007). The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency: UK Energy Research Centre London.

Standards Norway. (2012). NS-EN 16096:2012, Conservation of cultural property : condition survey and report of built cultural heritage. Oslo: Standard Norge.

Stephenson, J., Barton, B., Carrington, G., Gnoth, D., Lawson, R., & Thorsnes, P. (2010). Energy cultures: A framework for understanding energy behaviours. *Energy Policy, 38*(10), 6120-6129. doi:http://dx.doi.org/10.1016/j.enpol.2010.05.069

Svensson, A., Haugen, A., Kalbakk, T. E., & Gåsbak, J. (2012). *Energieffektivisering i eksisterende bygninger. Energisparingens konsekvenser på kulturhistorisk verdifulle bygg*. Retrieved from SINTEF Byggforsk, :

Swan, L. G., & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and Sustainable Energy Reviews, 13*(8), 1819-1835.

Decision No 406/2009/EC of the European Parliament and of the Council, 5 C.F.R. (2009).

Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, 18 C.F.R. (2010).

Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, 315 C.F.R. (2012).

Communication from the Commission to the Parliament, the Council, the European Economic and Social committee and the committee of the Regions: A policy framework for climate and energy in the period from 2020 to 2030, (2014).

The Nordic Council of Ministers. (2014). *CERCMA : Cultural Environment as Resource in Climate Change Mitigation and Adaptation*. Retrieved from Copenhagen:

Troglio, E., Doni, M., & Haas, T. (2011). *Urban typologies and heat energy demand. A case-study in the Italian context.* Paper presented at the Proceedings of the 51st Congress of the European Regional Science Association, Barcelona.

Troi, A., & Bastian, Z. (2014). *Energy Efficiency Solutions for Historic Buildings*: EURAC research/Passive House Institute.

Winter, T. (2013). An uncomfortable truth: air-conditioning and sustainability in Asia. *Environment and Planning A, 45*(3), 517-531.

Winter, T. (2016). Climate change and our heritage of low carbon comfort. *International Journal of Heritage Studies*, 382-394.

Xing, Y., Hewitt, N., & Griffiths, P. (2011). Zero carbon buildings refurbishment—A Hierarchical pathway. *Renewable and Sustainable Energy Reviews, 15*(6), 3229-3236.

Yohanis, Y. G. (2012). Domestic energy use and householders' energy behaviour. *Energy Policy, 41*, 654-665.

Yu, Z., Fung, B. C., Haghighat, F., Yoshino, H., & Morofsky, E. (2011). A systematic procedure to study the influence of occupant behavior on building energy consumption. *Energy and Buildings, 43*(6), 1409-1417.

Zalejska-Jonsson, A. (2012). Evaluation of low-energy and conventional residential buildings from occupants' perspective. *Building and Environment*, *58*, 135-144. doi:http://dx.doi.org/10.1016/j.buildenv.2012.07.002

List of figures

Figure 1: The chart illustrates a procedural approach to energy efficiency in historic buildings where the users are integrated into the process. With the users of the building taking part in outlining the general objectives and needs they bring about the grounds for future decision making while the values of the building is given ample room to be passed on to its users. Figure: F. Berg