The Effects of Energy-efficient Buildings on Facilities Management and Usability with a Focus on Passive House Schools in Norway

Antje Junghans, Dr.-Ing.
[Norwegian University of Science and Technology]
antje.junghans@ntnu.no

ABSTRACT

The objective of this paper is to improve the understanding of energy-efficient buildngs' management and usability. The intention is to contribute to overall improvements in the energy efficiency of built environments through an integrated approach to considerations of building design, facilities management, and user perspectives. An overview of the development of highly energy-efficient buildings with a focus on passive house school buildings is presented. The passive house standard is defined considering a newly developed and recently implemented passive house standard for non-residential buildings in Norway. The effects of energy-efficient buildings on facilities management and usability are comparatively studied with a focus on Norway's first and one of the newest passive house schools. Finally, the benefits and risks, the need to develop highly energy-efficient buildings, and the management and user interaction are discussed and summarized.

1 INTRODUCTION

Energy-efficiency of the built environment is of high importance all over Europe and on international level. Since it has become common knowledge that buildings contribute to 40% of the total energy consumption in European countries much effort has been input into improving existing building stocks and further improvements are still needed (EU, 2012). While the energy-efficiency improvement of the built environment lasts for some time, the development of management concepts and a better understanding of the buildings users' behavior merits more attention. Such integrative understanding would help to achieve buildings' projected performance and close the research gap recently highlighted by Bordass and Leaman (2013, p. 1): "Research into building performance continues to reveal that even the best buildings often fail to perform as anticipated." Consideration of the effects of interaction between building design, management, and use would also contribute to a better understanding of the processes or mechanisms that occur within building stocks. Buildings themselves do not consume energy, but rather the users or mechanisms within them create the demand for energy (Sartori, Wachenfeldt, & Hestnes, 2009). The development of innovative technology and its implementation in highly energy-efficient buildings such as passive houses and nearly zero-energy buildings is driven by policy and legislation, including for example Directive 2012/27/EU on energy efficiency. This energy efficiency directive states requirements regarding the improvement of energy efficiency in the public building sector: "Member States shall encourage public bodies, including at regional and local levels, with due regard to their respective competences and administrative set-up, to follow the exemplary role of their central governments to purchase only products, services and buildings with high energy-efficiency performance" (EU, 2012, p. 15). If the implementation of Directive 2012/27/EU is accepted as performance-based norm, it might also increase the demand for facilities management competence with reference Joanna Eley's vision—published before the implementation process of the EU's Energy Performance of Buildings Directive (EPBD) had begun—–that "In the fullness of time, if performance-based building and regulations are accepted as the norm, facility managers will become key players in assessment" (Eley, 2001, p. 5).

The decission to study passive house schools is based on the fact that school buildings form the largest group of public buildings and belong to one of the three largest groups of non-residential buildings in Europe. Non-residential buildings are more complex and less studied than residential buildings. The European non-residential building stock includes mainly wholesale and retail buildings (28%) a large amount of office buildings (23%), and as third largest group the educational buildings with a 17% share in terms of total floor area. The remainder of the non-residential building stock comprises the following categories: hotels and restaurants (11%), hospitals (7%), sport facilities (4%), and other buildings (11%) (Laustsen et al., 2011, p. 8). The overall building stock of all EU27 countries, Norway, and Switzerland has been assessed as having c.25 billion m^2 of useful floor area, of which 25% are non-residential buildings and 75% residential buildings, used by more than 500 million people (Laustsen et al., 2011). Norway, the northernmost country in Europe, currently has a population of 5 million people. The country's existing building stock is estimated as having a gross floor area of 325 million m^2 divided between residential buildings (210 million m^2; 64%) and non-residential buildings (115 million m^2; 36%) (Haugen, 2008). Sartori et al. (2009, p. 1614) state: "Energy demand in the building stock in Norway represents about 40% of the final energy consumption, of which 22% goes to the residential sector and 18% to the non-residential sector." Norway has traditionally used a high amount of electrical energy for heating buildings. Due to the country's dependence on hydroelectricity, buildings in Norway have some of the lowest CO2 performances found in Europe (Laustsen et al., 2011). However, due to limited supplies of hydropower, the increasing demand for electricity causes problems, as stated by Halse (2005, p. 1) almost ten years ago: "consumption of electricity is reaching a level where additional growth will have to be covered by traditional non-renewable resources."

2 METHODOLOGY

The research is mainly based on the conduction of case studies. Case studies are considered as a most suitable approach to develop insights in a high level of complexity in its real-life context. The passive house school examples have been selected based on a thourogly conducted state of the art literature review. The development and implementation of passive house school design has been studied on international level (PHI., n.d., NS3710, 2012) and the management and usability with a special focus on Norway (THOMSEN, J., BERKER, T., HAUGE, Å. L., DENIZOU, K., WÅGØ, S., & JERKØ, S., 2013). The information utilized for the first case study, Åsveien School, is based on a project which has been conducted in cooperation with a public Real Estate and Facilities Management department. In autumn 2013 a group of master studends were involved in workshops, and the conduction of experts' interviews and site visits. The information about the second passive house school case study is based on published scientific conference papers (DOKKA, T. H., & ANDERSEN, G. (2012), JERKØ, S., MYSEN, M., HOMB, A., NERSVEEN, J., NILSEN, S., BLOM, P., & CHRISTOPHERSEN, J. (2006), research reports (THUNSHELLE, K., & LAPPEGARD HAUGE, Å. (2012) and interviews and site visits conducted by the author in 2014.

3 THE STATE OF THE ART

The passive house concept has been described earlier as "buildings, for which thermal comfort (ISO7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions –without the need for additional recirculation of air" (PHI, n.d.). The basic principles of passive houses were summarized in five categories: (1) thermal insulation, (2) passive house windows, (3) ventilation with heat recovery, (4) airtightness, and (5) thermal bridge free design (Feist, 2013). This concept was mainly applied on passive houses, which were built as private homes, with the main objective of reducing the amount of energy used for heating. This was achieved through the construction of highly insulated, compact and airtight buildings with ventilation systems with heat recovery and special passive house windows.

In Norway, the passive house concept was further developed into a passive house standard for non-residential buildings (NS3701, 2012). Lexow and Dokka (2012, p. 5) state: "Standards Norway is the first member of the European Committee for Standardization (CEN) to have a national standard with criteria for Passive Houses covering all building categories defined in the national building code." The standard specifies requirements for different non-residential building types, according to the Norwegian climate, building construction method, and architectural context. All buildings in Norway certified as energy-efficient conforming to either passive house or low-energy standards. The certification includes the minimum requirements for heat losses, cooling demand, heating demand, energy supply, and technical infrastructure as elements of a building's design, components, and systems, as well as air tightness of the building envelope.

A conceptual structure for the description of passive houses can be summarized as follows: (1) General information providing some general information about the building (building type, gross floor area, location, and year of construction); (2) Winter heat insulation described by the compactness of the building form and quality of the thermal insulation of the building envelope (ground floor, outer walls, and roof), regarding the passive house requirement of reduced heat losses for transmission and infiltration; (3) Summer heat protection described by the quality of summer heat protection and how zero energy supply for cooling is achieved considering the orientation of rooms, heat storage, solar shading; (4) Energy supply considering the main energy sources and the technical systems of heating, domestic hot water, ventilation, lighting, technical equipment, and cooling; and (5) Windows described as such and as building parts, and with consideration of entrance doors.

4 PASSIVE HOUSE SCHOOLS IN NORWAY AND SELECTION OF CASE STUDIES

The passive house concept has been studied in Norway since the year 2000. In 2005, Norwegian researchers recognized a growing interest in the passive house concept in relation to low-energy housing. At that time mainly residential passive house buildings such as single-family houses were constructed. However, a growing interest in the passive house concept was identified. Halse (2005, p. 4) stated: "Passive houses and low-energy housing is on the verge of market breakthrough." Five years later, in 2010, the first Norwegian passive house school building, Marienlyst School in Drammen, was taken into use (Dokka & Andersen, 2012; Thomsen et al., 2013; Thunshelle & Lappegard Hauge, 2012).

The number of high-energy efficient non-residential buildings is expected to increase continuously up to 2020 in Norway. (Enova, 2012, p. 15). The Norwegian Government is supporting municipalities in the development and construction of climate and environmentally friendly pilot projects under the programs "Framtidens by" (Cities of the Future) and "FutureBuilt." As part of the program "Framtidens by", city municipalities are encouraged to share ideas on climate-friendly city development in cooperation with the business sector, the regions, and the Government. "Framtidens by" is scheduled to run for six years (2008–2014) and the 13 largest cities in Norway involved in the program are: Bergen, Bærum, Drammen, Fredrikstad, Kristiansand, Oslo, Porsgrunn, Sandnes, Sarpsborg, Skien, Stavanger, Tromsø, and Trondheim (Government.no, 2011).

The "FutureBuilt" program is scheduled to run for ten years (2010–2020) and will support the realization of 50 projects contributing to the reduction of greenhouse gas emissions and a good city environment. Projects may also include urban areas or individual buildings. The cooperating partners in "FutureBuilt" are four municipal authorities (Oslo, Bærum, Asker, and Drammen), the Ministry of Local Government and Modernisation, the Norwegian State Housing Bank (Husbank), the Norwegian energy national fund (Enova), the national fund to reduce greenhouse gas (GHG) emissions from transport (Transnova), the National Office of Building Technology and Administration, the Green Building Alliance, and the National Association of Norwegian Architects (NAL). In 2014, the project documentation included six school projects (Table 1) within a total of 30 pilot projects: urban areas, schools, kindergartens, office buildings, cultural centers, and housing projects (futurebuilt.no, 2014).

Table 1. The development of passive house schools in Norway sorted by the year of construction (Newest, Oldest), (Source: futurebuilt.no, 2014, “Framtidens by”* and/or “FutureBuilt)

School building	School name (Norwegian name), location, year of construction	Energy-efficiency and FM relevant key figures	School type of use and user relevant key figures
	Åsveien skole,* Trondheim, 2013–2015	Gross floor area (GFA): 8836 m^2 Energy demand: 61 kWh/m^2/year	Primary school with 630 students, and autism center for 20 students
	Veitvet skole, Oslo, 2011–2015	GFA: 8789 m^2 Energy demand: 62 kWh/m^2/year	Primary and lower secondary school for Class 1 to 10, class with multiple-use hall, 840 students (school and multipurpose hall)
	Nye Gran skole, Oslo, 2010–2015	GFA: 6079 m^2 Energy demand: 61 kWh/m^2/year	Lower secondary school, 540 students, 65 man-labor years, 80 users
	Frydenhaug skole, Drammen, 2011–2014	GFA: 5795 m^{2,} Energy demand data unavailable	Intermunicipal primary school and resource center for students with disabilities 100 students, 110 man-labor years
	Bjørnsletta skole, Oslo, 2010–2014	GFA: 9677 m^2 Energy demand: 64 kWh/m^2/year	Primary and lower secondary school, 790 students, special department for 12 students with autism
	Stasjonsfjellet skole, Oslo, 2010–2014	GFA: 3663 m^2 Energy demand: 74 kWh/m^2/year	Lower secondary school 390 students, 35 full-time equivalent (FTE) man-labor years
	Søreide primary school, Bergen,* 2011–2013	GFA: 7910 m^2 Energy demand: 43 kWh m^2/year	Primary school
	Heistad skole, Porsgrunn, 2008–2012	Energy demand (NS-3031): 37 kWh/m^2/year	Primary school, special department for 14 severely disabled students

	Marienlyst skole, Drammen, 2008–2010	6454 m^2 GFA Energy demand: 70 kWh/m^2/year	510 students, 95man-labor years c.12 m^2/student

5 SIMILARITIES AND CONTRASTS BETWEEN THE OLDEST AND NEWEST PASSIVE HOUSE SCHOOLS

Åsveien School in Trondheim is the newest passive house school in Norway. The building has been under construction since July 2013 and will be finished and taken into use in 2015, five years after the completion and start of operation of Norway's first passive house school Marienlyst School in Drammen in 2010.

5.1 Comparison of the school buildings' energy performance

In Trondheim, Åsveien School, which will be a passive house primary school has been under construction since 2013 and will be finished and taken into management and use in 2015. The project, including the main building of the primary school for 630 students and a department for 20 students with autism, has a total gross floor area of 8836 m^2. In addition, a multipurpose hall with a gross floor area of 2336 m^2 is under construction on the same site (Hasenmüller, 2013).

Marienlyst School, a lower secondary school is located in the centre of Drammen, a city c.40 km west of Oslo. The school is adjacent to a sports arena (Marienlyst idrettspark) and a public swimming pool (Drammensbad). The school has a heated floor area of c.6450 m^2. The school has a compact building form comprising three stories. Due to natural changes in the ground level on site, the first floor is partially buried and includes a large auditorium for the whole school, as well as locker rooms, rooms for special functions, and a library. The second floor has a community area with a café, workplaces for teachers, administration offices, and rooms for special functions. The third floor consists mainly of compact student areas and group rooms. The architectural design is characterized by a clear and simple building shape with much variation in architectural expression, form, and use of materials (Dokka & Andersen, 2012, Hahn, 2013).

Table 1 shows a comparison of the simulated energy demand of both Åsveien School and Marienlyst School, built according to Norwegian standards (NS3700, NS3701, and NS3031). The measured energy consumption of Marienlyst School for the academic year 2011–2012 is also shown.

Table 2. Building Energy Performance (kWh/m^2/year) of Two Passive House Schools in Norway (Dokka and Andersen, 2012, Hasenmüller, 2013)

Energy use categories	Åsveien School simulated energy budget	Marienlyst School simulated energy budget	Marienlyst School measured energy consumption
Room heating	9	12.8	13.7
Ventilation heating	4.4	0.6	4.1
Domestic hot water	10	10.1	3.1
Fans and pumps	12.7	10.8	12.8
Lighting	8.3	15.5	13.3
Technical equip.	8.8	13.3	13.9
Cooling	0.7	0	0
Total net energy demand	53.9	62.9	60.9

5.2 Effects on facilities management

The general understanding of facilities management in Norway is that it refers to the European standard, and it includes all traditional roles and methods related to the administration, operation, maintenance, and development of buildings, and service provision for building users. A triangular symbol is often used to visualize the interaction between the three key players, namely the building owner, building user, and building manager. However, in everyday practice many actors interact and thus there are also strategic, tactical, and operational levels in the functioning of buildings. For example, the school janitor may be described as an actor at an operational level (Haugen, 2003, p. 14). Some Norwegian public authorities are continuing with the traditional administration, operation, and maintenance (*forvaltning, drift, vedlikehold* (FDV)) focus, whereas others have adopted the FM approach in full. A variety of organizational models and service provision concepts exist, including the client-supplier-model, and different approaches to in-house service provision, outsourcing, or out-tasking (Haugen, 2003, 2008; Junghans & Olsson, 2014; Novakovic et al., 2012).

Marienlyst School is one of 21 school buildings that together account for 300,000 m^2 of public buildings owned by Drammen Municipality. Drammen Eiendom KF, the real estate and FM department of Drammen Municipality, represents the owner of the school building and is responsible for the buildings' management and operation as well as the management of facilities service provision. The general field of responsibility of the real estate and FM department includes operation, maintenance, modernization, new building development and realization, purchasing, selling, leasing, and renting.

Energy management is a subdomain of FM, and integrates all relevant facilities services to ensure that "Client demand for utilities (technical infrastructure) is satisfied by services resulting in a comfortable climate, lighting/shading, electrical power, water and gas" (EN 15221-1, 2007). The main area of responsibility is visible in the operational and utilization phase of a building. Regular monitoring of the power consumption, benchmark analyses, and identification of savings potentials and their implementation are essential working areas in energy management (Junghans, 2012).

The users of Marienlyst School experienced some problems with their school building that could be associated with the commissioning of the building and fine-tuning of automatic systems in the first year of occupation. The researchers highlighted the following issues (Thunshelle & Lappegard Hauge 2012):
(1) Temperature: Cold temperatures during the first winter, in 2010, especially in the mornings, were reported in interviews. A lack of supply from the district heating network was indicated as the main reason together with the fact that the winter of 2010 was particularly cold. One year later, the problems were not mentioned, but many of the interviewed students responded that some rooms could be cold or have varying temperatures. It was also pointed out in the interviews that some rooms could be hot and airless in summer months. The latter problem was connected with the use of sunscreens (see "Solar shading" below).
(2) Ventilation and air flow: The interviewees indicated that there were problems with air pressure conditions in the building. Doors were either slamming or were too heavy to open easily, or they remained open and emitted a peeping sound, probably due to the ventilation system. [Comment from the author: Probably the maintenance staff would have known why the doors made a peeping sound? Perhaps the doors were also fire doors that needed to be kept closed when not in use, and therefore emitted a warning sound if they were accidentally left open.] There were some complaints about the heavy and bad quality air in the small auditorium and small group rooms in core areas on the third floor, and thus the ventilation in these areas needed to be investigated further. The described problems indicated a need to examine the balancing and sizing of the ventilation units in the school.
(3) Solar shading: The interviews and responses to the researchers' questionnaire documented that the automatic shading and lighting did not work properly. Heat from the sun was also sometimes problematic. Teachers often wanted opportunities to override the solar shading systems in order to have more control over room temperatures. In addition, it appeared that the electric lighting that turned off automatically (controlled by light motion sensors) should have been fine-tuned so that it was more sensitive to movement than it was when the evaluation was conducted.

5.3 Effects on usability

Norwegian researchers have developed a systematic approach for the assessment of school learning environments. The main criteria evaluated are structured in the following three categories, with increasing degrees of complexity:

1. Evaluation of the Indoor climate with focus on five subcategories: thermal- (temperature quality), atmospheric- (air quality), acoustic- (sound quality), actinic- (light and radiation), and mechanical environment (vibrations)
2. Evaluation of the indoor environment, which includes: indoor climate, together with two subcategories, namely the aesthetic environment (visual impact) and the psychosocial environment (interpersonal relationships)
3. Evaluation of the physical environment, which includes the evaluation of the indoor environment (mentioned in point 2 above), together with four subcategories: the building's suitability for the use (operations and functionality), its suitability for the users (universal design), the user density (area efficiency, m^2/student, and volume/student), and usage time (duration of room usage, over time) (Jerkø et al., 2006).

Teachers, other employees, and students at Marienlyst School needed more information about how the building automation system worked and could be adjusted. Especially the solar shading, lighting, and temperature regulation needed to be better understood. Thus, there is a need for cooperation between the users and management staff of new schools when the final adjustments to all technical systems are being made according to user demand. The passive house building at Marienlyst School has improved awareness of the environmentally friendly profile of the school. Moreover, the teachers indicated that they would have liked more information about the passive house concept to communicate to their students (Thunshelle & Lappegard Hauge 2012).

6 CONCLUSION

In this paper, the complexity of energy-efficiency improvements in built environments has been studied with focus on passive house schools in Norway. The intention has been to improve the understanding of passive houses and how they are managed and used. A structure for the description of passive house examples has been developed based on the definition of the passive house concept and the Norwegian passive house standard (NS3701). Nine Norwegian passive house school projects have been identified through publically accessible sources. Marienlyst School in Drammen and Åsveien School in Trondheim, respectively the first and most recent passive house schools, were selected as study cases. The building energy performance of both schools has been compared on the basis of the simulated energy budgets, and the measured energy consumption of Marienlyst School has been reported. The definition of facilities management in Norway and an approach for usability evaluation have been shown to structure the effects of facilities management and usability. In the studied cases, the effects of FM referred to energy management and the janitor as a key actor at an operational level were indentified. The paper reveals that the main aspects of usability are related to the provision of a good indoor climate quality and communication with and feedback from the building user.

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