Investigation of work-practices, skills and everyday challenges of building operators with respect to indoor climate and energy

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ABSTRACT

Focus on sustainable construction brings many requirements and standards to ensure energy efficiency and high indoor environmental quality (IEQ). However, these are mainly used in design phase. Commissioning becomes increasingly common to ensure functionality when building is taken into use. However, buildings are expected to stay in use for many years. It is a building operator, who ensures that building delivers healthy and comfortable environment. It is beyond discussion that his/her skills and professional level affect building's actual performance. The present study had an objective to investigate work skills, experiences and professional challenges of building operators in Danish office buildings with particular focus on IEQ and energy efficiency. Thirty building operation professionals working in 23 companies were interviewed. The results showed that occupant complaints were a driving factor with respect to IEQ related measures. Knowledge of standards and requirements regarding IEQ turned up to be rather superficial. In most cases, there was a lack of a well-defined operational strategy regarding IEQ. The results show that there is a need to provide a missing link between technological part of building operation and a strategic part defining clear goals and practices.

INTRODUCTION

Current focus on sustainable and energy-efficient construction comes with many requirements and standards to ensure low energy use and comfortable indoor climate (European Commission, 2018; European Standard, 2019). However, most requirements are only used in the design phase. Buildings are designed using advanced drawing tools, and their performance is assessed with dynamic simulations. Calculations are carried out to ensure that the building meets the energy frame. When the building is taken into use, commissioning and performance testing are prescribed in many countries (Danish Standardisation Authority, 2014). However, we expect the building to be in operation for fifty or more years. There are mostly no requirements for how the building should perform for the rest of its lifetime. It is just expected that a healthy and comfortable environment is guaranteed every day.

Building operation and maintenance (OM) falling under Facility management (FM) is a very complex and interdisciplinary area. The personnel dealing with building operation must possess many different skills. The immediate profession one would think of in this context is "a caretaker" or "a superintendent". Someone who comes and changes a bulb or a door handle when it breaks down. The caretaker removes snow in winter and mows grass in the summer. He or she can also repair leaky pipes or change a thermostat on a radiator. Nevertheless, in the case of an office building, the task list for such a person is usually much longer, and does not include only manual work. Caretakers, now called building operators must also be familiar with different systems for ventilation, heating, air-conditioning or lighting as well as their control.

Nowadays buildings are often equipped with many advanced technologies. It is somewhat expected that their use will lead to high quality indoor climate and low energy use. However, all complex control systems and advanced technical installations are in the end operated by humans. Therefore, it is crucial that the technical staff has right skills and competences. Knowledge regarding competencies and skills of building operators in Danish office buildings is very limited. Moreover, there are no official and systematic studies focusing on relation between building operators' work-competencies and building performance - energy use and indoor environmental quality (IEQ).

Objective of the present study was to investigate competencies, experiences and challenges of building operators in at least 10 companies or public institutions operating one or more office/non-industrial buildings. A special attention was paid to IEQ and energy-efficient operation.

METHODS

Data collection

Semi-structured interviews were used to collect the data. The method enables collecting of both qualitative and quantitative type of information (Göçer et al., 2015). Quantitative data represented technical information about investigated buildings (construction year, heated area, installed heating, cooling and ventilation systems - HVAC). Qualitative data included building operators' experiences, practices and opinions. The installed HVAC systems form a framework for building operators' everyday tasks. Systems also directly affect the required level of competence that the operators must have in order to solve their tasks. On the other hand, the technical data regarding HVAC systems cannot reflect operators' experiences, frustrations and opinions. A template containing basic structure of the interview was prepared and implemented to an online tool. Table 1 gives an overview of the structure. The strategy regarding OM/FM, IEQ or energy efficiency, mentioned in Table 1 referred to a written document summarizing the plan/policy the organization has with respect to given topic. Strategy is approved by the management and it is known to all relevant employees. During each interview, the interviewer noted relevant information either directly in an electronic form on a PC/tablet or with handwriting. If possible, the interview was audio recoded. The recordings were always conducted with a consent from the respondents. Transcripts of the recordings were used for detailed analysis. All data were anonymized so it was not possible to identify companies, individuals or particular buildings.

Table 1. Interview topics.

Section of the questionnaire	**Included topics**
A company and buildings the respondent is responsible for	General data about the company, buildings (construction year, area) and technical facilities (heating, cooling, ventilation)
Operation and maintenance (OM)/ Facility Management (FM)	Organisation, responsibility and strategy for OM/FM
Indoor Environmental Quality (IEQ)	Responsibility and strategy regarding IEQ, requirements, operation-related parameters (set-points, night setback), education and competencies with respect to IEQ and building automation
Energy use	Responsibility and strategy regarding energy use, energy management, energy saving goals
Personal data (focused on a specific respondent)	Job title, length of employment, background, education, skills/competencies needed, gender, age

During the interviews, the respondents were asked to assess their skills regarding their current profession. The assessment was done on a scale from 1 (not enough skills) to 5 (very appropriate skills). The respondents were also asked to evaluate education/training they received regarding IEQ and building automation. To do that, they had to express to which extend they agreed or disagreed with three statements: a) "I think that I have learned a lot.", b) "I can directly use the obtained knowledge to solve every day's problems." c) "I think that the educational materials were good." They indicated their agreement with the statements using a scale from 1 (totally disagree) to 5 (totally agree).

Studied cases

A case was characterized as company (or a public institution) that operated one or more office buildings. Additionally, the case should have an organized OM/FM department. Identification of cases and consequent data collection was divided into two tracks. The first track focused on companies having a long-term collaboration with The Copenhagen School of Marine Engineering and Technology Management (MSK). This resulted in 12 interviews conducted in 11 cases. These interviews were not audio-recorded, so qualitative analyses were not possible. The second track included cases from the Frederiksberg municipality along with other cases located on the island of Zealand (11 cases) and in Jutland (1 case). All cases were situated in Denmark.

The survey was not focused on a particular category of professions. The idea was to cover as many as possible levels in the FM structure of the individual companies. The study worked with the following professions: *service technician, supervisor technician, function or project leader, facility manager, top manager.*

Data analysis

Quantitative data formed a basic structure for the analysis (see Table 1). The analysis combined quantitative data for each the topics in the structure with qualitative input collected during the interviews – respondents' insights, comments, observations and reflections. Qualitative data were analysed using the MaxQDA software (VERBI Software, 2018), which enabled coding the interview transcripts to identify trends, similarities and contradictions among the studied cases. During presentation of results, the quantitative data were supplemented with qualitative details.

RESULTS

Survey respondents

There were altogether 30 respondents (27 men, 3 women). Ten interviews were recorded, resulting in more than ten hours of audio material. The three mostly represented professions were supervisor technician, function/project leader and facility manager. Supervisor technicians and project leaders accounted for 53% of the conversations. Facility managers accounted for 37% of all interviews.

On average, the respondents have worked in their current position for 10 years (minimum 3 months and maximum 36 years); 61% of respondents have worked in their current position for more than 3 years. Most respondents were educated electricians or engineers

(Fig. 1). Despite various anecdotal narratives, the study indicated a consistency among positions in building operation and education of the employees.

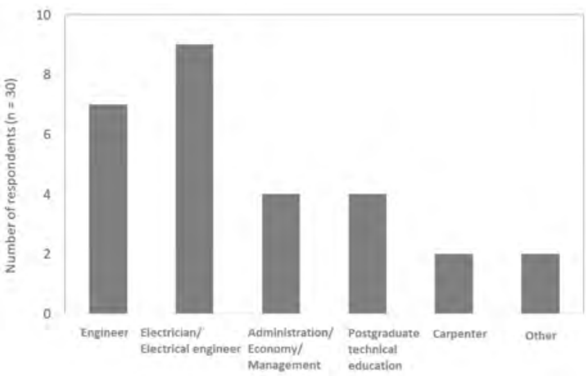

Fig. 1. Educational background of respondents in the survey.

Most respondents evaluated their skills at level 4 or 5, thus as appropriate for their current profession. Among the skills, the respondents lacked most, knowledge about IEQ and Building Management Systems (BMS) were frequently mentioned. Regarding approaches to obtain a new knowledge, several respondents mentioned that the best would be if they could learn on "their own" buildings. It made sense for them to be able to relate the theory to their daily work.

Studied cases

The survey included a total of 23 cases, 35% of cases were public institutions like municipalities or educational institutions, 30% of cases were private companies focused on administration and service (IT, consulting, etc.) and 26% were private companies engaged in production or development (operation of production lines or workshops were not included in the survey). In all cases, building operators worked with both medium (600–10 000 m^2) and large (> 10 000 m^2) office buildings mostly built after 1985. The survey showed that most building operators had experience with district heating, mechanical ventilation and mechanical cooling. There were nine cases where the respondents mentioned ventilation with variable airflow (VAV). In these cases, the airflow was modulated according to CO_2 concentration or room temperature.

Operational strategies

For each case in the survey, it was analysed whether building operators were aware of the strategies that their organization had adopted regarding OM, IEQ and energy use. The question "is there a strategy for ..." led to a positive response in most cases: 19 positive responses for OM, 17 for IEQ and 18 for energy use. This was a positive result, but deeper analysis of the qualitative data revealed that many respondents understood "a strategy" more as a representation of the fact that they "had an idea of how operations are to be carried out" than a written document. For OM strategies, a written strategy was mentioned in only five cases. Most of them mentioned that service and maintenance contracts, service schedules or operating manuals came "when the house was built". The situation was worse in the case of IEQ strategy. In six cases, the respondents mentioned that there "somehow was a strategy" in their organization. The rest stated that there was "something", but it was not summarized in a specific document. For example: - Question: *"Is there a precise indoor climate strategy?"* And answer: *"Yes, but it is not written down. We are probably going to have something written down in a year or two. We agree upon what the aim regarding indoor climate is. It is to make it simple, well, we want to have a BMS, records and measurements -which we spend a lot of time talking about-, ppm-measurements, temperature measurements, allowing us to keep track of our indoor climate conditions."* The example illustrates how the respondent had a strong focus on what is needed to measure and track the indoor climate, whereas requirements or goals regarding particular IEQ parameters are not mentioned.

The respondents were also asked about background for IEQ strategies in their organizations. Most mentioned that the strategies were based on current standards, guidelines by the Danish Working Environment Authority and/or building regulations. These answers show that building operators were generally aware of the relevant legislation and requirements that define IEQ and provide guidelines for building operation. Despite the fact that standards were mentioned most, it was clear from the interviews that guidelines by the Danish Working Environment Authority were of major importance during daily work of building operators. This was because most organizations must conduct so-called workplace assessments at regular intervals. Workplace assessments include more topics than IEQ, but if answers of employees indicate problems with IEQ, these are communicated directly to the work safety committee in the organization. This creates an effective pressure on the building operators because they want to keep complaints at a minimum.

Eighteen respondents mentioned that there was an "energy use related strategy". Only four respondents responded that there was no such strategy and one did not know. The most frequently, simple reduction of energy use was mentioned as a background for energy strategy, followed by financial considerations and reduction of CO_2 emissions. Fifteen respondents mentioned that there was a target for reducing energy use. The goal was often defined as a percentage of energy use reduction per year. There were two cases where the target was defined as a reduction of CO_2 emissions per year. In 17 cases, respondents stated that their companies had implemented an IT system for energy management.

IEQ requirements and control

Fig. 2 summarizes temperature requirements from 14 cases. The figure shows the allowed room temperature range. In most cases the temperature range was around 2 °C between 22 °C and 24 °C. It is only in case number 17 where temperatures were allowed to rise to 26 °C, which is maximum temperature recommended by Danish standard (Danish Standardisation Authority, 1995). The maximum temperature permitted in the Danish Working Environment Authority's guidance is 25 °C (Danish Working Environment Authority, 2008), and it was projected in the maximum temperature limits for most cases. The survey showed that in most cases the respondents actually mentioned values about 1 °C below the limit to stay on the "safe side". There were five cases where the respondents did not mention temperature range, but only a certain temperature level. It was visible from the interviews that the respondents in these cases confused the requirements for room temperature and room temperature set point.

The next interesting result was that, in only three cases, the respondents mentioned tolerance requirements for exceeding temperature limits, which is an important parameter in evaluation of thermal environment. Especially on the "warm" side of the allowed room temperature range, many buildings have problems complying with requirements due to lack of solar shading or cooling. The building regulations (Ministry of Transport Buildings and Housing, 2018). refer in this case directly to the Danish standard (Danish Standardisation Authority, 1995), which allows for a maximum of 100 hours per year with temperatures > 26 °C and a maximum of 25 hours with temperature > 27 °C. At the same time, the Danish Working Environment Authority (Danish Working Environment Authority, 2008) does not provide any precise guidance. Most of the respondents did not mention these recommendations. These results obviously cannot be generalized to all office buildings in Denmark. However, they indicate that the difference between temperature requirements and a set point value seems to be unclear to many building operators.

It is worth mentioning that, in several cases, the building operators did not directly determine the temperature set point, because users could adjust thermostatic valves on radiators in individual rooms. As one respondent said: *"It is individual control with respect to the thermostats. People will typically have 22 °C. If there is anything else they want, then can set it up themselves. They get the temperature they want."*

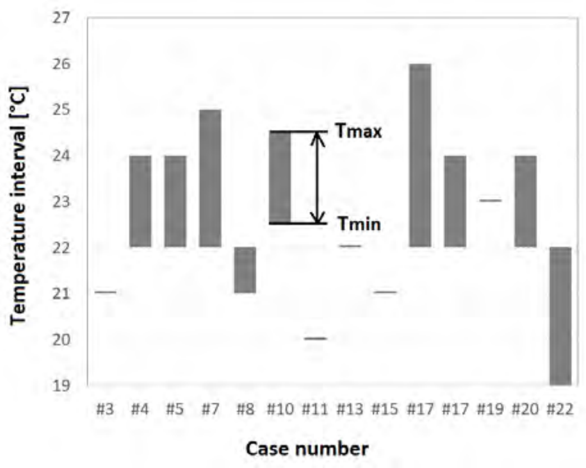

Fig. 2. Room temperature requirements (bars indicate a temperature interval; horizontal line indicates that a single value, not temperature interval was mentioned as a requirement).

In terms of requirements for air quality, the answers showed similar trends as for temperature. Again, there was confusion between requirements and set point values used in the ventilation system. In only three cases, operating personnel reported requirements regarding air velocity. None of the respondents mentioned the so-called Draught Rate (DR) (International Standardization Organisation, 2005) or the correlation between turbulence intensity and sensation of draught, which is defined in Danish thermal comfort standard (Danish Standardisation Authority, 1995) as well as directly cited in the Danish building regulation (Ministry of Transport, Buildings and Housing, 2018).

Solar shading systems in most cases were automatically controlled, but users had possibility to override control actions manually. Despite that, the solar shading systems were causing many operational-related problems. Several respondents mentioned problems with control algorithms, resulting in a frequent movement of sunshade screens that the users perceived as very disturbing. Further, problems with blocked visibility during sunny days and faults on both manual and automatic control were mentioned. The following quote illustrates the above-mentioned challenges: *"In the older buildings, we have outside blinds you can turn manually. It works well, they are durable and people can operate them themselves. In the new buildings, there is a mix. .... There we have a clean glasshouse built 6 years ago. There are some screens that you operate automatically and it is an Italian system that does not work properly so we keep it in position the whole summer. Then people say that no light is coming in, but if we take them out of position, it will be too hot. Then you have to choose."*

Education regarding IEQ and building automation

Sixteen respondents answered that they had previously participated in IEQ related education/training, at the same time 12 respondents did not participated in any IEQ related education. In contrast, 23 respondents answered that they participated in education/training related to BMS, while four did not. The results indicate that there was more emphasis on the use of building automation, which has its practical reasons. It is possible to say that building operators got a lot of knowledge on "how" (using BMS), but less knowledge of "what" (different IEQ parameters, comfort models, comfort limits, etc.). This leads to the situation, that advanced functions of BMS allowing for a certain analysis of the data collected in the building are not used in practice as building operators do not see the need for analysis.

Fig. 3 illustrates how the respondents assessed the education/training regarding IEQ and BMS they have received.

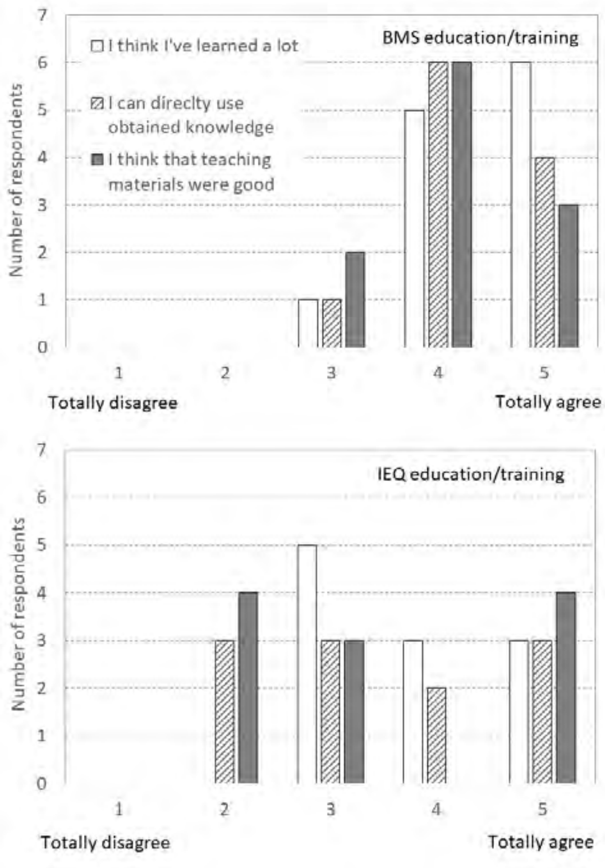

Fig. 3. Evaluation of training/education related to BMS (top) and IEQ (bottom).

The respondents clearly evaluated BMS related education as more useful. The teaching materials related to BMS courses were also considered to be better. Several respondents actually mentioned that they were unsatisfied with content and quality of the IEQ -related courses.

DISCUSSION

The present survey provides an insight into competencies, daily practices and challenges of building operators from 23 companies/institutions in Denmark. The reason why so many respondents with a leading/managerial role participated in the survey was that these employees were often a main contact to the case. Even though they were asked to make their subordinate employees available for interview, quite often the manager himself decided to participate. The most common argument was that their employees (building operators) always had a lot of work and did not have time for discussions with researchers. In most cases, respondents were responsible for several buildings and these building portfolios were highly heterogeneous. The results suggest that a building operator is often considered as a "handyman" that can do all kinds of jobs. It seems that even if there is a problem they do not know the solution for; they are still expected to deal with that because the building should "just work". This brings them under a notable pressure. If there are no occupant complaints, they do their job right. This is an impression based on the interviews conducted during the study. Many respondents were aware of the fact, that it would be better if they had spent time on tasks that improve the IEQ and building performance in a broader time perspective. Principally, they lacked time and knowledge to take such action. It seems that building operators often lacked methods and tools for simple but effective IEQ analysis. Respondents' own statements about missing information confirmed the need for more knowledge in this area. Although they generally assessed their competences as sufficient, they demanded more knowledge about IEQ and BMS. It can be recommended to reflect this need when new training or education for building operators is to be prepared.

Amount of respondents who participated in education/training related to IEQ was unexpectedly high in the study - 52%. When this fact is set into context with other results, showing lack of knowledge regarding IEQ requirements, thresholds or analysis, one can speculate that the education might lack an appropriate curriculum and that the knowledge disseminated is not directly applicable in practice. In opposite, the education focused on building automation (BMS) was evaluated as more beneficial. The BMS courses are often focused on advanced use of the systems, but from the study does not imply that the building operators would vastly use this knowledge on daily basis. Nevertheless, the connection between the curriculum and practice seems to be clearer for the respondents.

Results from the study reveal that occupants are often those who decide how the IEQ is managed in the building. This is the overall goal of reducing the number of complaints that drives building operator's actions. This approach is generally correct, but the data collected in the survey indicate that a well-defined operating strategy related to IEQ would release some of the pressure from building operators as well as support more consistent IEQ management. Resolving particular complaints without having a reference in the form of a predefined strategy leads to individual actions not a comprehensive optimization. In most cases, a well described strategy was missing. The situation was better when building operation was outsourced to an external FM company. In these cases, a particular form of strategy was included in service agreements. It was interesting that it was only strategy related to IEQ or OM, which was mentioned in these cases, but not a strategy in relation to energy-effectivity. It can be related to the fact that current legislation defines requirements for energy-efficient construction, but not directly to energy-efficient operation.

The IEQ management strategy does not need to be a thick and hard to read document. It should rather be understood as a simple collection of requirements and practices. Several current standards can serve as a basis for such strategy. For example the international standard EN 16798-2 (European Standard, 2019), which is extensively used during design, but its application in operational phase is limited.

CONCLUSIONS

Thirty building operation professionals from 23 companies/institutions in Denmark were interviewed regarding their competencies, daily practices and challenges related to IEQ and energy use in office buildings.

Most respondents were trained engineers, heating, ventilating and plumbing technicians or electricians competent to work as building operators.

Respondents assessed their skills as appropriate with respect to their current professions, but they missed practice-oriented knowledge regarding IEQ management.

In most cases, a well-defined strategy regarding IEQ was missing. Measures focused on IEQ optimization/management were mostly driven by occupant complaints.

Building operators had a general interest in analysis of the IEQ in their buildings, but their knowledge of related standards and requirements turned up to be rather superficial.

Education/training related to BMS was assessed as more applicable in daily practice. The IEQ related education lacked a link to the building operators' everyday practice.

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