Information model development for the quality assurance of technical equipment in small buildings

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Abstract. Ensuring energy quality, i.e. compliance with specified or standardised energy performance indicators of buildings over the entire life cycle, can reduce the climate impact of the building sector. In this work, the causes for quality deficiencies in small building services installations as well as the structure of actors interacting with building services were analysed. On this basis, we developed a solution approach in the form of an information model including a catalogue of all requirements and the necessary content to address and improve the quality assurance of HVAC in small buildings. This information model will serve as the basis for future digital tools that can perform (partially) automated heating load calculations and the design of heating systems, improve installation logistics and installation quality through providing information and the necessary processing, and enable improved hydraulic balancing and control.

1. Introduction

1.1. Building sector and climate protection

In order to achieve climate targets, the building sector plays a significant role as it is responsible for 34 % (2019) of the total CO₂ emissions in Germany [1]. The current instruments like the EPBD [1] are probably not sufficient as emissions from buildings have been reduced by 11.9 % from 1990 to 2019 and the target for 2030 is 66 %. In Germany, the largest share in the CO₂-emissions (39 %) is attributable to the 15,75 million small buildings (single- and two-family houses), where energy quality assurance plays a subordinate role; the focus is on meeting comfort requirements [2].

1.2. State of the art and research question

Small and customized single- and two-family houses do not receive complex planning of building technologies by engineers and are not controlled by facility management during operation. On the one hand, craftsmen often take over the entire planning, installation, and commissioning of the building services and quality assurance is often reduced to prescribed checks. On the other hand, the requirements for data sets are naturally lower for small buildings than for larger ones, which facilitates the use of digital tools as the completeness of data is easier and quicker to capture.

In this building type, the energy consumption of Heating, Ventilation and Air conditioning (HVAC) systems is often higher than planned (see Figure 1). A fundamental problem here is an existing and increasing shortage of skilled workers in the craft sector and the increasing complexity and lack of robustness (heat pumps) of the systems with higher plant diversity and more hybrid systems [3]. These circumstances lead to problems in the design and installation of building services due to time and cost

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pressure. The structural capacity shortage in skilled workforce will not be resolved in the short term and thus digital tools can remedy to identify and tackle quality issues in the performance of small buildings.

Current methods for the design of HVAC include calculation tools, commissioning processes and planning guidelines. The planning tools are mainly based on the EnEV [1] and DIN V 18599 [4] and digital methods as BIM are playing an increasing role, as does simulation (e. g. EnergyPlus). Nevertheless, these methods are mainly used for large projects and require a high level of expertise.

With an appropriate information model, tools can use stored data to automate processes in the execution of building services in small buildings for improved quality assurance. Through improved information processing and enrichment, workflows and decisions can be improved and partially automated. Based on this hypothesis, the research question is: What significance can an information model have for improving the quality assurance of facilities in small buildings?

In the case of large buildings, a specialist planner carries out the planning of technical building systems and the BIM method is already being increasingly used. In small buildings, systems are mostly planned by craftsmen and digital methods are not applied. Digital information tools could be used to address energy efficiency and quality assurance in small buildings.

2. Methodology
For the development of digital methods regarding quality assurance in small buildings, we followed two different approaches and analyzed different methods. On the one hand, we used a bottom-up approach to analyze case studies and identify problems that occur in practice at component and system level. On the other hand, we applied a top-down approach to screen different technologies of building systems. We have therefore conducted a stakeholder and failure analysis for building technologies to provide the basis for the development of digital solutions. The analysis is based on a literature review to identify and quantify the main problems in building systems and the stakeholders involved. Additionally, we investigated an internal project in the crafts sector on the implementation of heat pump systems and conducted an expert survey of 25 craftsmen, planners and constructors. We then used these sources to qualitatively analyse sources of problems.

In a first synthesis, the prerequisites for a solution approach were worked out based on the failure and actor analysis. The results were then summarized in an information model that addresses the identified problems and should be integrated into the existing processes of the actors involved. For this purpose, the necessary requirements and contents were defined in a solution-oriented manner. Basically, there is a risk that the scientific analyses do not exactly correlate with the deficits identified by the actors. Practical experience and exchange with them are thus indispensable, especially to develop solutions.

3. Key problems and stakeholders in small buildings
3.1. Fault analysis building services
The analysis revealed that central problems are a lack of planning depth with a focus on comfort requirements and incorrect or missing calculation leading to incorrect dimensioning (50 - 66 %) and poor interaction of the different systems [6]. To still meet the comfort requirements, the systems have an over-complexity, such as different thermal storages or multiple valves [3]. Solving this problem offers a potential energy saving of 15 – 30 % (see Table 1). Common problems that occur due to errors during the installation phase are incorrect positioning or failure of a component (especially with heat pumps). Installation errors for these problems are incorrect assembly, positioning, and unintentional destruction of components. Inadequate commissioning also often leads to high temperatures in the supply systems,
unsuitable thermostat settings and excessive volume flows. The faults responsible for this are usually a lack of hydraulic balancing, incorrect setting values and a lack of verification [6, 7]. Operating errors often lead to excessive volume flows, insufficient heating output and inadequate setback operation. Responsible for this are operating errors and lack of operational monitoring [7]. Table 1 summaries the results within the scope of the error analysis. Apart from the lack of skilled workers, missing documents or wrong input parameters could be identified as the main causes.

Table 1. Failure evaluation of technical building services

| Life phase     | Identified problems                           | Frequency                     | Energy saving potential | Rating |
|----------------|----------------------------------------------|-------------------------------|-------------------------|--------|
| Planning       | Incorrect dimensioning                       | 62% [8] 50 – 66% (boiler) [6] | 15 – 30% [8] 15 – 20% (HP) [9] | Critical |
| Planning       | Wrong/Missing Components                     | Not quantifiable              | Depending on error      | Medium |
| Execution      | Installation faults and missing preparation  | 26.9% - 45.4% (HP) [7], identified in intern projects | Depending on error, critical for HP | Critical |
| Commissioning  | Deficits in the regulation                   | > 50% with factory settings [10] | 8 -15% [11] 10 – 30% [12] | Medium |
| Commissioning  | Missing hydraulic balancing                  | 81.9% [13] 78% [6]           | 10 – 30% [8] 12 – 26% [11] | Critical |
| Commissioning  | Lack of control                              | Not quantifiable              | Not quantifiable        | Low    |
| Operation      | Operating time adjustment                    | 42% [6]                       | old building: 10% [14] new building 3% [14] | Medium |
| Operation      | Component failure                            | Depending on plant            | Depending on plant      | Medium |

3.2. Stakeholder roles and responsibilities
Different actors are involved during the life phases of building services in small buildings. The manufactured components of HVAC systems have different quality levels that affect the longevity, adaptability and maintenance [15]. The owner, who is often also the builder, takes the initiative of the construction process. He is the highest authority of the project and responsible for defining and controlling the goals in terms of comfort, efficiency and use [5]. Since the building owner depends on consultations with planers and craftsmen, the creation of an awareness of construction quality and the associated formation of knowledge can pay off in concrete quality requirements. User behavior directly influences functionality, energy quality and comfort during the operation phase [15]. Craftsmen play an important role in small buildings because, in addition to execution, they also take on planning tasks such as determining requirements, calculating the design of systems and components, and comparing variants [5]. In terms of quality, they therefore play a significant role as they represent a potential for error and at the same time are crucial in achieving high energy efficiency. In large buildings, there is typically a facility manager who monitors the systems. In smaller buildings, operators are craftsmen who, if problems are found, take over the rectification [15].

4. Development solution approach / synthesis
A central problem for the craft sector is the increasing complexity and lack of robustness of innovative and hybrid systems, as well as the lack of skilled workers. Lack of system understanding leads to system designs based on experience and estimates rather than individual planning. An information model that includes essential data to simplify and automate processes and calculations could address the mentioned obstacles. It is suggested that this can lead to a reduction in the need for skilled craftsmen to deliver high-quality construction services, speeding up processes and ensuring quality. In addition, work can be documented and retrieved centrally. Tools can use the data to identify different processes and sources of problems. This leads to four types of tools (see Figure 2):
A planning tool can use the information to simplify and automate the planning of building services to reduce mis-dimensioning, which has been identified as a major problem.

An installation tool can support processes to avoid installation errors by providing information during the execution.

A commissioning tool can use data to calculate, plan and support control and commissioning management, as hydraulic balancing and adjusted control settings are often missing.

A monitoring system can control the operation.

Without limiting its general validity, the use and possible benefits of an information model are outlined using the example of hydraulic balancing. To be able to carry out a hydraulic balancing, the data of the building and the envelope is necessary for the heating load calculation according to DIN EN 12831 [16]. In addition, the information about heat generation, heat distribution and heat dissipation must be available. To ensure data availability, an automatic checklist can instruct the architect and craftsmen to enter the building data into the model. The craftsman can use a tool to perform an automatic heating load calculation and (partially) automate the design of the heating system with the data model. The planned system is stored in the model. The data can be entered and read out via a desktop interface, with which the calculation and display tools can be used, or via a mobile interface with a smartphone from the construction site. Based on the existing data, the hydraulic balancing can be automated, documented back to the model and used by the craftsmen. Both the mobile and desktop interfaces of the tools can show the actors missing data for the calculation through an error message (e.g. push notification) as well as the calculated adjustment values. On the one hand, automation and error feedback create a tool for saving time, as the documentation has to be done anyway and is stored centrally so that it not has to be done multiple times; on the other hand, calculations with missing data can be avoided and accelerated. The equivalent process chains can be developed for the other identified failures using the model. For existing buildings, the existing plans can be used to create a model.

5. Catalogue of information model classification

5.1. Requirements and qualities
To be used in practice and to achieve the quality potentials mentioned, the exchange and access to the model must be possible centrally and easily in a suitable format, the installation aids must be available on a mobile basis and it must be possible to integrate the tools into current work processes. This includes data procurement and data maintenance. The software should therefore be intuitive and easy to use. There should be a simple interface that, in addition to desktop use, also allows mobile access.
by the craftsman with his smartphone from the construction site and simplified input into the model without additional effort for the actors involved.

5.2. Content and functions
The information model must contain certain data to address the identified causes of the problems. This includes topological information to represent the relationships of the components in the system, as well as attributes and information of the building and the system, such as building data, metrological data, installation information or data for heating load calculation and system design (cf. Figure 3). Tools can use the data to (partially)-automate processes such as the heating load calculation and the subsequent design of the heating system. The information model and the associated tools should actively support the actors involved in the implementation of the technical building systems in their work processes, achieve an increase in efficiency by reducing fault sources and ensure the quality over the life phases in new and existing buildings. Figure 3 shows the requirements, contents, and functions of the model.

6. Initial principles of the model
BIM is a digital data representation of the physical and functional properties of a facility or building that can improve decision-making in construction processes and thus efficiency. The standard data exchange format in openBIM projects is IFC [17]. This can be used to describe complex models that contain a lot of data and graphical 3D representations. For small buildings, it is important to reduce this complexity to the bare minimum to address the problems and processes, but not to become complicated. Otherwise, the inhibition threshold is too high and the effort too great to integrate it into existing workflows. For high acceptance, it should also have an affordable cost structure and be easy to use. Due to the limited amount of data, it can be understood as a subset of IFC. A 3D representation is not necessary but semantic information is crucial.

The information model consists of zones according to DIN 18599 [5] with different information and the building systems, which mainly describes the heating system, the ventilation system, and the sanitary facilities. Figure 4 illustrates the structure of the model. With its information, easy access, overhaul capability and automation tools, the model can improve quality assurance of building services processes. Decisions and work are based on building information and related calculations and can be checked at any time by mobile availability. The right data to automate process steps and calculations are needed to support the actors. For example, the systems are already comprehensively calculated, and adjustments of the heating curve or the hydraulic balancing can be carried out with digital tools. With a digital checklist and documentation, the work processes of the actors can be recorded and read, so the condition and status of the plant is clear.
7. Conclusion

In the execution of building services in small buildings, craftsmen play a central role in planning, installation and quality assurance. The increasing shortage of skilled workers in the craft sector exacerbates the situation of inadequate quality assurance. In practice, energy consumption usually deviates upwards from the possible values. In the failure analysis we carried out, the central problems are presented and quantified (see Table 1). From the results, we developed a solution approach in the form of an information model that can be integrated into the current work processes to improve the quality assurance of building services in small buildings by containing the required data. In the future, software tools that using this data will be developed. These tools could automate calculations such as a heating load calculation for better planning, an installation tool could simplify logistics and improve installation quality. Furthermore, the model information could be used to calculate optimal control and hydraulic balancing, and a monitoring system could improve operation by matching operating and maintenance parameters with the model. The tool developments are the next steps in our work.

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