Annex 8

Performance Operation Test

Case: Renovating a school

EFFECT4buildings Toolbox:
Multi Service Contracting; Annex 8

EFFECT4buildings

The project "Effective Financing Tools for implementing Energy Efficiency in Buildings" (EFFECT4buildings) develops in collaboration with public building managers a comprehensive decision-making support toolbox with a set of financial instruments: **Financial calculation tools**; **Bundling**; **Funding**; **Convincing decision makers**; **Energy Performance Contract**; **Multi Service Contract**; **Green Lease Contract**; **Prosumerism**. The tools and instruments chosen by the project has the biggest potential to help building managers to overcome financial barriers, based on nearly 40 interviews with the target group. The project improves these tools through different real cases.

To make sure building managers invest in the best available solutions, more knowledge on different possibilities is needed as well as confirmation from colleagues that the solutions performs well. EFFECT4buildings mapped **technological solutions** for energy efficiency in buildings with the aim to share knowledge and experiences of energy efficiency solutions among building managers in the Baltic Sea Region.

This document is a part of the Multi Service Contracting (MSC) toolbox and has been developed by Dansk Energi Management (DEM). It presents recommendations for designing a test scheme and experiences testing user feedback from online surveys combined with data mining in relation to MSC.

Partners

Länsstyrelsen Dalarnas län; Lappeenrannan seudun Ympäristötoimi (Lappeenranta, Lemi, Luumäki, Savitaipale, Taipalsaari); Hedmark Fylkeskommune; Vidzeme (Ceļš ved augšup!); Gate 21; Stowarzyszenie Gmin i Powiatów Małopolski; Tehnopol; Riigi Kinnisvara; ByggDialog Dalarna

EFFECT4buildings project is implemented with the support from the EU funding Programme Interreg Baltic Sea Region (European Regional Development Fund) and Norwegian national funding. The aim of the project is to improve the capacity of public building managers in the Baltic Sea Region by providing them a comprehensive decision-making support toolbox with a set of financial instruments to unlock the investments and lower the risks of implementing energy efficiency measures in buildings owned by public stakeholders. More information: http://www.effect4buildings.se/

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CASE – Performance Operation Test

Introduction

This case was prepared as part of the Effect4Buildings project in collaboration between Gate21, Egedal Municipality and DEM. The case deals with an energy renovation of primarily technical systems at Boesagerskolen, Flodvej 89, DK-2765 Smørum, Denmark.

Prior to the renovation itself, an energy audit was conducted in the spring of 2015. The audit was supported by an online questionnaire and indoor climate measurements. Based on the energy audit from 2015, a project was designed in 2017 containing profitable energy efficiency initiatives such as replacing the ventilation system, optimising the heating system, replacing and optimising the building management system (BMS) and deploying new artificial lighting. In the spring of 2018, a contract was signed with a main contractor. During the project, the BMS subcontractor went bankrupt, causing a significant extension of the project, which was handed over in February 2020.

The case contains observations, analyses and recommendations on how selected and relevant parameters can be set up and evaluated in a renovation project conducted as an MSC project. In addition, assessments and methods of quantification of indoor climate performance are given.

Background for the methods used

The method used in this case is a spin-off from a development project called eSnap (supported by the Danish Energy Agency) with participation of i.e. the Technical University of Denmark, Aarhus University and DEM. The purpose of this development project is to digitise the workflow in connection with an energy audit in which relationships between data for temperature, electricity consumption, indoor climate and weather are analysed and used to improve the quality of an energy audit process.

In this case, the methods from the eSnap project are used to analyse the performance of the technical systems in operation. Operation is characterised as being a period of so-called normal use of the building in different seasons. Furthermore, users must be present in the building in the same number and length of time that they are expected to be in daily life.

Performance Operation Test – a new concept?

We have chosen to name the method "Performance Operation Test" as the concept is monitoring the current operating status of a technical system and does not depend on several theoretical assumptions. In the building industry in general, "Commissioning[1]" has been used for years to qualify a system's overall performance at handover. Later on, official requirements have been set in the Danish building code for functional testing of selected major technical systems at handover. The functional testing should ensure that the systems operate as designed in the project including performance, but the functional testing is only a snapshot in connection to the handover of a system and not a continuous measurement over a given

[1] The commissioning process is presented in MSC tool 7, "Introduction to performance verification during implementation", to be found on www.effect4buildings.se.

operating period. This case study will explore the potential for demonstrating the essential parts of the functional testing of an operating period using simple data sets. Performance Operation Test differs from functional testing by analysing the actual operation of the technical systems after handover has occurred.

Rules and logic for operating – example of a ventilation system

The method is based on setting up rules and logic for when and to what extent a technical system should be operating in relation to a given need. The main logic apparent from the Sankey graph in Figure 1: Logic and rules for testing the operation of a ventilation system:

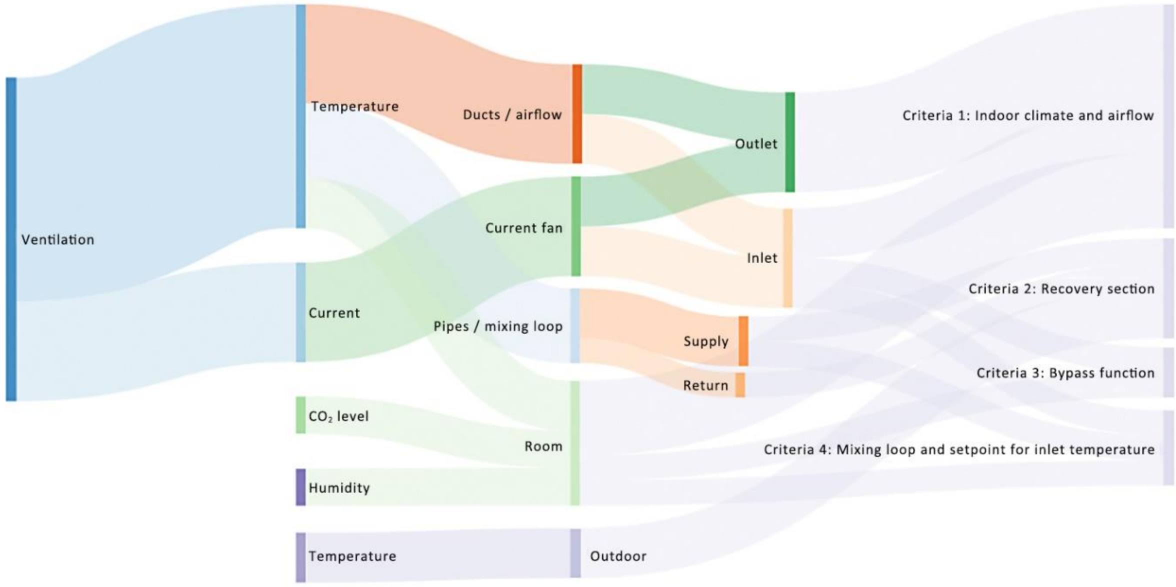

Figure 1 Logic and rules for testing the operation of a ventilation system

The logic is defined by how ventilation should operate optimally, where the collected independent third-party data is analysed continuously. The analyses must be possible without use of data from the building automation system. In this case, errors were particularly found in the building automation system, which had not been discovered without the use of independent third-party data. The analysed topics for Performance Operation Test for a ventilation system are given by:

Table 1: Criteria for operation testing of a ventilation system

Criteria	Subject analysed	Completed analysis of the topic
# 1	At CO_2 levels above 1000 ppm in a room, ventilation systems must ventilate at a maximum, while CO_2 levels must approach the outdoor state (approx. 400 ppm) outside operating hours.	Testing whether the system is running when there is activity in the room. Testing whether people are in the building outside working hours, which means that the ventilation system should be on.
# 2	At outdoor temperatures above 17°C, the heating coil must be turned off.	Testing if the heat recovery function works as intended.
# 3	At indoor temperature >23°C, supply air temperature should approach outdoor temperature (electricity consumption is maximum)	Testing both if the fan is running when it is hot in the room, but also if there is a functional bypass in the unit.
# 4	Inlet temperature above 22°C or 26°C should not occur	Testing if the heating coil heats up the supply air unnecessarily as an unnecessarily high supply air temperature will create both a worse atmospheric and thermal indoor climate and at the same time consume

		unnecessary energy.

Similar test schemes can be prepared for other major energy-consuming systems such as hot water systems, radiator systems or cooling systems. When setting up the monitoring programme, it is recommendable to create synergies across datasets by capturing data that can be utilised and which may influence other systems in the building.

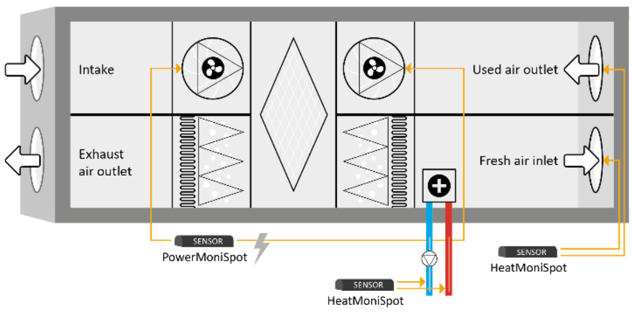

Figure 1: Location of IoT-sensors on a ventilation system

Data is captured around the building automation system by mounting relevant IoT (Internet of Things) sensors on both the ventilation system pipes, ducts and cables as well as sensors in selected representative rooms served by the individual ventilation system. The IoT sensors are installed by an independent third party, which we learned were a good idea since several deficiencies were noted in both the HVAC system and the building management system. IoT sensors are mounted on the ventilation systems as shown in Figure 2.

In addition, an online questionnaire survey was conducted to provide user feedback on the improvements seen in the renovation. The questionnaire can be accessed as tool 4.3, "Template example – Questionnaire for users on energy and indoor climate"[2]. The questionnaire survey was thus carried out both before and after renovation, which also applies to measurements of the indoor climate. Furthermore, the questionnaire entailed some in-depth interviews with technical staff and management to gain a more comprehensive understanding and supplement the quantitative data. The quantitative data from a questionnaire must always be supplemented by qualitative data in the form of e.g. in-depth comments and/or follow-up interviews.

Testing of a Performance Operation Test at a school renovation

In 2015 DEM conducted an energy audit at Boesagerskolen in the municipality of Egedal. As part of the energy audit, DEM also completed indoor climate measurements and a user survey on the same property. Based on this data, a renovation project was defined, designed and implemented during the years 2018-2020. Among other things, the project established new ventilation systems and updated the building automation.

In the fall of 2019, a follow-up monitoring programme was launched in connection with the Performance Operation Test. The monitoring programme included a follow-up user survey and new indoor climate measurements of the same rooms and the ventilation systems were applied with IoT sensors as shown in Figure 2.

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[2] To be found on, www.effect4buildings.se.

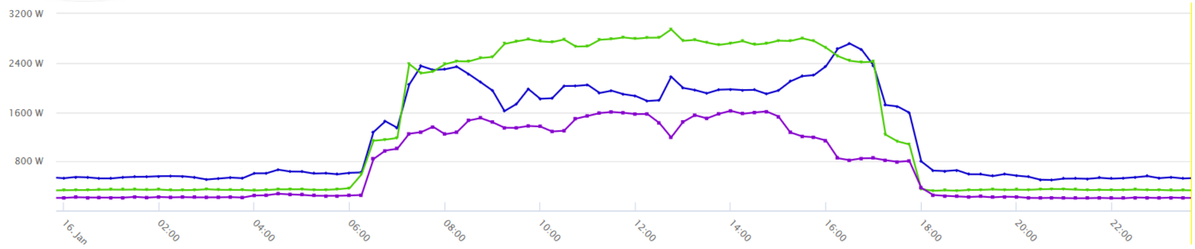

Figure 3 : The graph shows the operation during a typical weekday for, among others, ventilation system VE01 (green curve) , where it is seen that the system runs with maximum power during daytime and approx. 25% of the wattage outside operating hours.

The Figure 3 measurements show a disproportionate electricity consumption at night, which may indicate that ventilation is operating during the night (electricity consumption is greater than expected standby consumption). Based on further analysis, it has been found that the ventilation system and the BMS (Building Management System) did not communicate correctly with each other. The entered operating times in the BMS were not sent to the ventilation system which means that the system was operating constantly.

In addition, it was found that supply air temperature was not set correctly, but was set about 4 °C higher than desired.

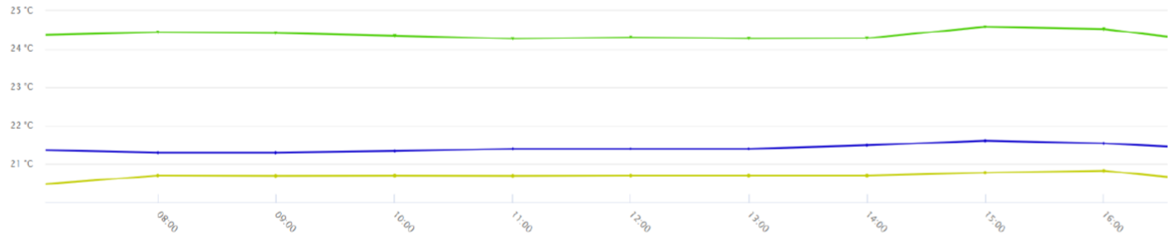

Figure 4: The temperatures for fresh air inlet and exhaust ducts of VE01 during a typical school day. It is seen that the temperatures are quite high and that the fresh air inlet temperature is approx. 24.4°C (green curve) and used air outlet temperature approx. 21.4°C (blue curve).

Indoor climate – can performance be measured?

The indoor climate is measured by both user feedback and by setting up indoor climate meters in selected rooms. User feedback was acquired through an online questionnaire, which was sent out to all staff at the school. The answers were then quantified on a scale of 0-5 points and consolidated. The results are shown in Figure 5, where there is a significant improvement of the experienced atmospheric and acoustic indoor climate. On the other hand, there had not been a significant improvement in the thermal indoor climate, since the heating system was not properly balanced when conducting the follow-up questionnaire survey. This observation shows that the timing of the follow-up questionnaire survey should have been different.

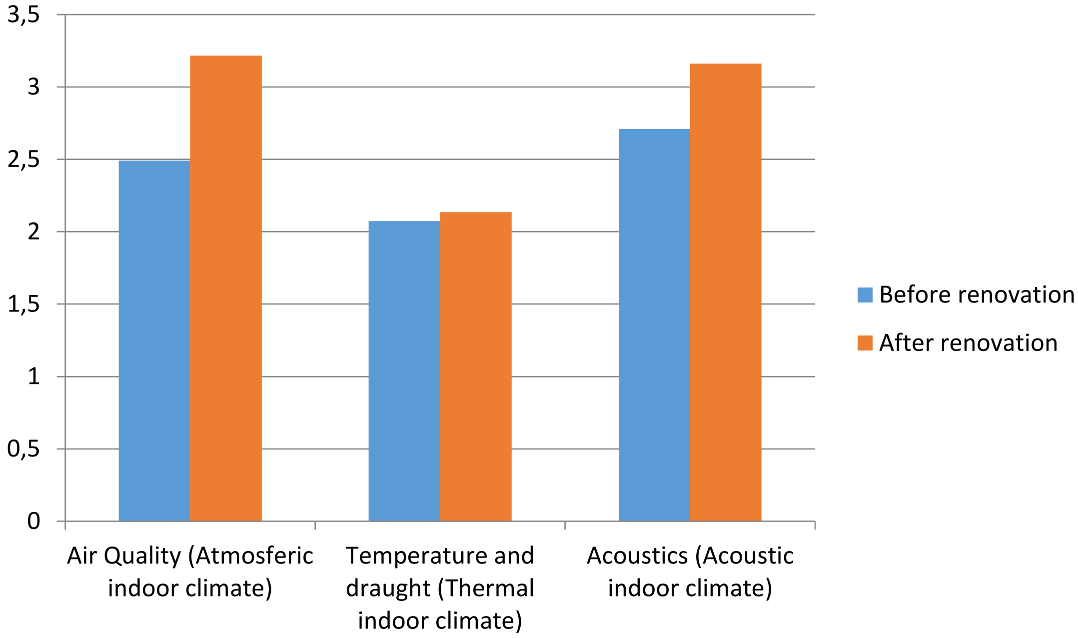

Figure 5: User feedback on experienced indoor climate – before and after renovation

In a representative room at the school, the CO_2 level in the room was measured. The measurements indicate – as does the user feedback – a clear improvement of the atmospheric indoor climate:

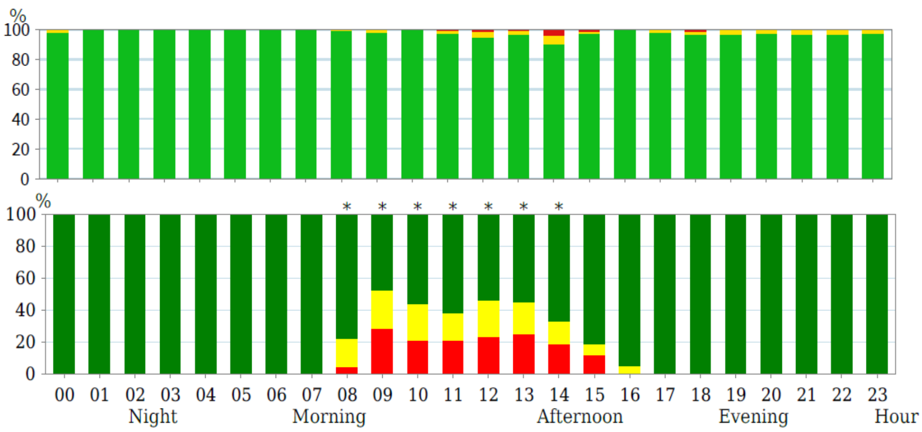

Figure 6: Indoor climate measurements in a representative room. Top: After renovation. Bottom: Before renovation. Red: CO_2 level above 1000 ppm. Yellow: 800-1000 ppm. Green: Under 800 ppm.

Recommendations for using a Performance Operation Test as a concept

The case has shown the importance of continuously following up on relevant operating parameters to ensure performance for both energy and indoor climate. Several factors were pointed out by the independent sensor data which would not have been discovered when reviewing the BMS system itself. During the test, we also learned that independent sensor data can be a good source of documentation of the operation of the technical systems in the first years after handover. The data may form the basis for recording errors and deficiencies in connection with the 1-year inspection, which is why the monitoring programme is also recommended to be in operation no later than the first day after handover.

In connection with testing the concept of Performance Operation Test in Boesagerskolen, we have gained the following experience:

- It is recommended to start the Performance Operation Test process early in the design process, so the questionnaire survey and monitoring programme are designed properly.
- The questionnaire must be launched at the right time. Prior to the renovation, the questionnaire must be sent out early enough for the results to be utilised in the design phase. The follow-up questionnaire must only be sent once all deficiencies have been rectified and acknowledged by the contractor.
- The quantitative data from a questionnaire must always be supplemented by qualitative data in the form of e.g. in-depth comments and/or follow-up interviews.
- Be sure to define the monitoring programme so secondary systems that can influence primary systems are also monitored, and synergies are created across datasets.
- It is recommended that the monitoring programme continues until the 1-year inspection, so the developer has documentation of the operation of the technical plants for the entire year.

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