Ing. Jakub ŠIMEK [1)]
Ing. Miloš LAIN, Ph.D. [1),2)]

[1)]*Department of Environmental Engineering Faculty of Mechanical Engineering, Czech Technical University in Prague*
[2)]*University Centre for Energy Efficient Buildings, Czech Technical University in Prague*

Energy Consumption, Operation and Commissioning of Buildings

Spotřeba energie, provozování a commissioning budov

The issue of energy consumption is becoming the main topic in many fields. Buildings that consume over 40 % of all the primary energy in developed countries, together with a significant contribution of CO_2 emissions [1], currently receive a considerable amount of attention. The paper deals with the issue of energy consumption of HVAC systems of buildings during their real operation and with process of their commissioning. The commissioning is solved both in general terms and as a mean of achieving the correct and energy efficient operation of buildings. Special attention is paid to the situation in the Czech Republic.
Keywords: *Building energy consumption, commissioning, building operation*

Problematika spotřeby energie se stává v posledních letech ústředním tématem v mnoha oblastech. Budovám, které ve vyspělých státech spotřebovávají přes 40 % veškeré primární energie spolu s významným podílem na emisích CO_2 [1], tak momentálně náleží značná pozornost. Příspěvek se zabývá problematikou energetické spotřeby technických systémů budov při jejich reálném provozu a commissioningem, a to jak v obecné rovině, tak jako prostředkem pro jejich správný a energeticky efektivní provoz. Zvláštní pozornost je věnována situaci v České republice.
Klíčová slova: *spotřeba energie budov, commissioning, provozování budov*

INTRODUCTION

The environmental and political aspects of the efforts to minimise the European Union's dependence on fossil fuels is a significant driving force leading to pressure to reduce energy consumption and the use of renewable sources. According to the Energy Performance of Buildings Directive (EPBD) 2018 [2], buildings in the European Union are responsible for 36 % of CO2 emissions and for almost 50 % of the energy consumption used for heating and cooling, of which 80 % is in buildings. This puts the minimisation of the energy consumption together with the maximum possible decarbonisation of the building stock at the forefront of the current European Union priorities in the area. In technical practice, we are increasingly meeting stringent requirements for both the thermal properties of building materials and the ever-increasing requirements for the energy efficiency of heat and cooling sources and other building technical equipment. However, only little attention is paid to how these technologies are operated and whether they actually work in an energy-efficient way, as was intended in their design, despite the fact that many studies [3], [4], [5] prove that not only the design, but also the correct operation of these systems has a major impact on the energy consumption.

The existing Czech legislation in this area is also still inadequate, although the new EPBD 2018, partially addresses the real operation of buildings and it can be expected that some measures aimed at the energy efficient real operation of buildings will be adopted within its implementation. Also, the phase of putting a building into operation does not actually help to solve the optimal operation of the technical systems. This part of a building's life-cycle is very often reduced to the verification of the principal functionality of the systems and the ability to achieve the required indoor environment level only. However, it should be noted that the ability of a technical system to provide the required microclimate conditions in a building does not necessarily mean that the system is operated optimally, i.e., with the minimum energy consumption while maintaining the required interior comfort level. Thus, the potential of advanced technologies and the sophisticated design of the entire system at the design stage may not be properly utilised in the real building operation.

The aim of this paper is to point out the problematic areas associated with the real operation of buildings and answer the question whether this issue is truly actual and whether it is expedient to spend energy in an effort to optimise their operation. Furthermore, this article deals with the method of a building's commissioning. First, it deals with this often incorrectly understood concept in general, then as a "tool" for the energy efficient and sustainable operation of a building.

ENERGY CONSUMPTION OF BUILDINGS IN REAL OPERATION

For the purposes of the objective evaluation of the real operation of buildings in the Czech Republic, it is generally very difficult to obtain any relevant data. Unfortunately, the detailed monitoring of the operation, analysis of the historical data and its evaluation are still the exceptions. This contribution, thus, partly follows up on the article "Reducing Energy Consumption for Air-Conditioning by Commissioning and Optimized System Operation" [6] which analysed the real energy consumption of the cooling sources of fifteen buildings situated in Czech Republic over the course of five years of their operation. One of the conclusions of this paper was the finding that the energy consumption for cooling per square meter of air-conditioned area was fundamentally different even within buildings with the same use (office buildings) as can be seen in Fig. 1. The detailed analysis showed different approaches in the operating strategy of the cooling sources and dramatic changes in the consumption for two buildings after the change of the management company, which operated the technical systems of the buildings. These findings observed on the analysed building sample, led to the conclusion that buildings are not operating efficiently in terms of energy consumption and that detailed monitoring is essential to optimise their operation.

The situation elsewhere in the world is illustrated by the outputs from several large-scale projects. In Europe, for example, a very large iServ

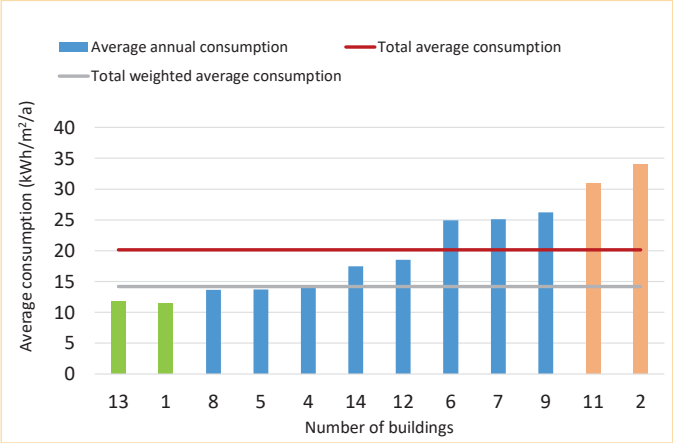

Fig. 1 The average annual consumption of office buildings

project was devoted to energy consumption in buildings, specifically to HVAC systems, which took place between 2011 and 2014. With a budget of over 3 million Euros, this project has mapped 2831 HVAC systems in 330 buildings across 16 European Union countries through continuous measurement and benchmarking. The aim of this project was, among other things, to highlight the importance of consumption monitoring, which can provide feedback from a building's operation and give the possibility to take energy saving measures. By applying this approach, the buildings involved in the project have achieved an average electricity savings of over 9 %. For some buildings, the savings were even 33 %. The author of the project states that applying this approach across Europe could save between 0.3 % and 5 % of the total electricity consumption across the EU and savings of over 20 billion Euros per year could be achieved at a cost of only about 1-3 billion Euros.

In general, most studies or research which deals with the energy consumption of buildings in their real operation, comes with a common conclusion, that most buildings are not functioning properly, and by optimising their operation, significant energy savings can be achieved.

ENERGY PERFORMANCE OF BUILDINGS DIRECTIVE - EPBD 2018

The main legislative document dealing more comprehensively with the energy consumption of buildings is the Energy Performance of Buildings directive (EPBD). Within the national implementation of this directive from 2002 and 2010, the energy performance certificates of buildings (Decree No 148/2007 Coll.) and the so-called reference building for the calculation of reference values in the calculation of the energy performance certificate of buildings (Decree No 78/2013 Coll.) were introduced [7]. However, only the current 2018 directive, which is to be implemented by 10 March 2020, deals more strongly with the consumption of buildings in real operation. [2]

The Directive now places great emphasis on existing buildings. The text appeals to the need to renovate the existing building stock and "transform" it into nearly zero-energy buildings and achieve a greenhouse gas emission reduction of 80 to 95 % by 2050. The directive no longer deals with the energy consumption of buildings only, but also addresses the issues of a healthy indoor environment. Saving measures should, therefore, be comprehensive and not only address the building envelope, but also the technical systems, with the aim of reducing energy consumption while increasing the visual and thermal comfort.

The directive further states the findings concerning the lack of effectiveness of the method of inspection of HVAC systems as they "do not ensure the initial or continuous economy of such technical systems". According to the directive, the aim of carrying out inspections should be to improve the energy performance of the HVAC systems under real operating conditions. Emphasis is placed on the ability of the systems to increase their performance under dynamically changing conditions, such as partial load operating conditions, where the system only operates with part of its nominal power. The possibility of replacing inspections by building automation and electronic monitoring of building technical systems is also listed. Building automation and control are even considered, in the case of large, non-residential buildings with large systems, as the most cost-effective alternatives to inspections with the serious potential for cost-effective and significant energy savings.

The new Directive places a great deal of emphasis on automation, as it is required to equip non-residential buildings above an effective rated heating or combined heating and ventilation system output of 290 kW with a building's automation and control systems by 2025. It states, in detail, that these buildings' automation and control systems will be able to:

- ❑ Continuously monitor and analyse the energy consumption and to enable its regulation
- ❑ Compare the energy efficiency of a building by reference, identify the losses in the performance of the building's technical system and to inform about possibilities how to improve the energy efficiency
- ❑ Enable communication with the building technical systems and other appliances it the building, as well as interoperability with the building technical systems that includes equipment from different manufacturers

Increased pressure towards reducing the consumption of buildings in their real operation is certainly a positive step. However, how specifically the Directive will be implemented in the national laws and regulations and what these methods and requirements will actually mean in practice is now only a question.

COMMISSIONING

Commissioning (Cx) is a term, which is still not widely publicised and correctly understood in the Czech Republic, but also, in many other countries and often even among the professional public. Often, the interpretation of commissioning can be seen as a process of "putting a building into operation". That is, the phase after constructing the building and before handing it over to the investor to just verify its basic functionality. However, this interpretation is slightly misleading, because Cx is a much broader term and "putting a building into operation" is only part of it according to the generally accepted interpretations and definitions of this term.

A building commissioning is a systematic process of managing the quality of the design, construction and operation of the building and its systems [8]. Cx ensures that the building has met the investor's needs and requirements and that it works efficiently energy-wise. The definition of commissioning according to the IEA (International Energy Agency) Annex 40 [9] characterises commissioning as: "a quality-oriented process for achieving, verifying, and documenting whether the performance of a building's systems and assemblies meet defined objectives and criteria". This internationally established definition is very close to the one used by ASHRAE (The American Society of Heating, Refrigeration and Air-conditioning Engineers) Standard 202 and Guideline 0, which defines Cx as "A quality-focused process for enhancing the delivery of a project. The process focuses upon verifying and documenting that all of the commissioned systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner's Project Requirements."

However, what can we imagine under these definitions in practice? In general, the commissioning of buildings is very broadly concerned with the energy-efficient, faultless and sustainable operation of buildings and their technical systems from the early design stage to full operation. Its methods and tools are primarily intended to ensure that advanced building components and systems efficiently work as a whole energy-wise and reach their technical potential. In the building operation phase, these are primarily tools for fault detection and diagnosis and optimisation. The design phase of the building is then generally associated with a large number of possible variants of a building's construction and HVAC system configuration. The Cx instruments in this case should assist in the assessment of the different design alternatives. Documentation of the investor requirements, the target values (e.g., energy consumption) and other important decisions and knowledge gained during the design stage of the building is also very important. The loss of information due to the lack of interconnection of the individual phases such as the design, construction, operation or change of use or owner, together with the incomplete or outdated documentation, is one of the main obstacles to the subsequent commissioning in existing buildings and a frequent cause of considerable operation issues associated with energy overconsumption. Cx tools should, therefore, also help manage information throughout the building's life cycle.

In the European Union, two large-scale projects under the Energy Conservation in Buildings and Community Systems (ECBCS) programme under the International Energy Agency (IAE) have dealt with building commissioning. These were Annex 40 (2000 – 2005) and Annex 47 (2005 – 2009) programmes, in which a number of foreign countries, universities and organisations, including the Czech Republic, participated. This research was prompted by previous projects, which came to the conclusion that most buildings do not work and never worked correctly [10]. Another impulse was the findings that by re-commissioning an HVAC system, it is possible to reach 20 – 30 % of energy savings [5]. Mills [4], who conducted research in the US under the Lawrence Berkeley National Laboratory even presents commissioning as today's most cost-effective strategy to reduce energy consumption, costs, and greenhouse gas emissions in buildings. This claim is based on a very extensive research study which analysed, in detail, the commissioning of buildings, based on a database of 643 buildings. This extensive analysis revealed that one-third of the projects for which the data were available contained more than 10 000 energy problems. The correction of these problems led to a median overall energy savings of 16 % and a commissioning payback period of 1.1 years.

In practise, four types of commissioning can be distinguished. This is an initial-commissioning, which starts during the project phase and continues through the construction to the operation of the fully occupied building. [11] The aim is to ensure that the building "behaves" as expected. Retro-commissioning is a Cx that is applied to an existing building that was never applied to that building before. Its aim is to improve the operation of the building primarily by changing the operation parameters, such as the schedule of the operation of air handling units, the application of setback regimes, optimisation of the ventilation (a necessary amount of fresh air), or by fault detection and diagnostics. Re-commissioning is a Cx type where a building that has historically gone through the Cx process will undergo another Cx process to verify or improve the building's operation. An ongoing-commissioning (also known as continuous Cx) is a Cx process performed on an ongoing basis to maintain, improve and optimise the initial commissioning of a building's systems. This continuous Cx, which is based on the continuous monitoring and a data analysis, is essential for the sustainability of energy savings, the service life of the installed technology and other savings resulting from the continuous optimisation of the operations. Thus, commissioning is not just putting the building into operation, but a holistic process that should ideally accompany the entire building process from defining the investor's requirements, through the design stage and the construction stage to the full operation of the building. An overview of the overall Cx processes and the individual types is shown in Fig. 2.

The aim of these research programmes was to enable the effective development of a common understanding of Cx, as well as to develop, validate and document commissioning tools and to initiate further research to improve the operational energy performance of buildings with a focus on HVAC systems and the related control systems. Great attention has been paid to commissioning of advanced HVAC systems, which are essential for modern low-energy buildings in order to achieve minimum or near to zero primary energy consumption and CO2 emissions. One of the main motivations for the development of the commissioning in this area is the move from the intuitive approach that is currently used in most cases of building operations to a more systematic approach aimed at achieving substantial energy savings.

Specifically, a number of methodological instructions or tools have been developed on the issue of monitoring and the use of sensors, visualisation and the analysis of measured data or tools for the detection and diagnosis of faults. Great attention was paid to the work with the data. In the case of advanced air-conditioning systems, it is necessary to process extreme amounts of data for the needs of Cx and, without the use of computer technologies, it is not possible to process such an amount of data and obtain the necessary information out of them. Within the project outputs, several tools for the data processing and visualisation, optimisation and fault detection were introduced to facilitate the identification and realisation of potential energy savings. The appropriate visualisation of the data proved to be absolutely essential for revealing

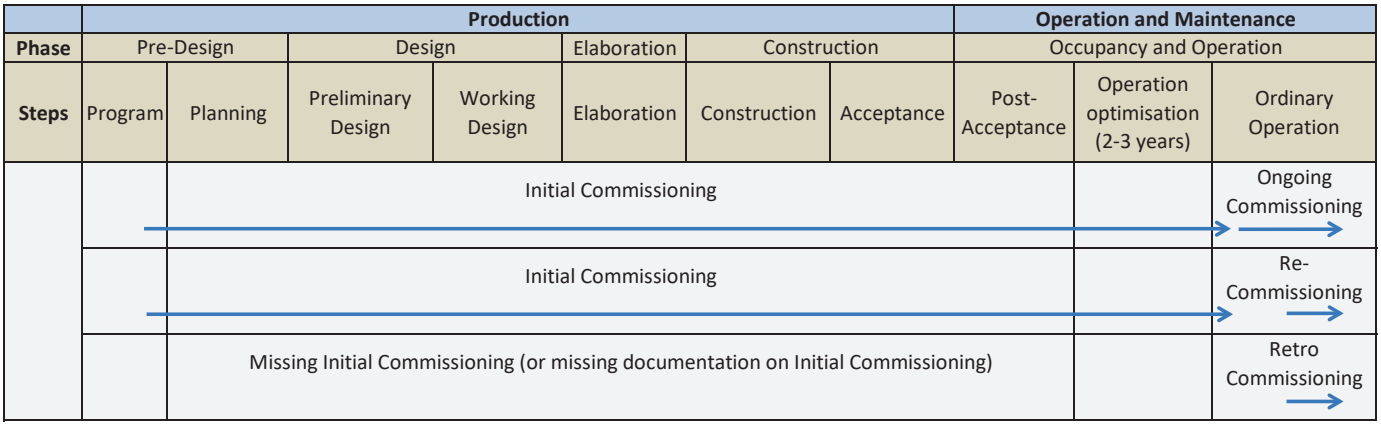

Fig. 2 The commissioning process (modified according to [8])

hidden information about the system's operation. On the other hand, the lack of analytical tools in the operation of a building often leads to overly conservative decisions on the choice of the set-points or the schedule of the operation of the individual equipment. Common examples of such conservative decisions are over-ventilation, the unnecessary operation of technical systems outside the operating hours of a building, or unnecessarily high temperature settings in the winter and too low ones in the summer.

One of the main barriers for the spreading of Cx in the market is, according to the research project results, the lack of commissioning methods and tools (especially automatic) and technologies needed for the energy efficient operation and reaching the potential of advanced components and systems of modern buildings. Further research in this field is, thus, absolutely necessary. This is especially true for advanced and extensive systems of modern and low-energy buildings. The dynamics and interactions of the individual subsystems of these complicated HVAC systems require special effort and special tools for the Cx process. Especially in these cases, increasing the efficiency of a single subsystem does not always mean an improvement within the whole system.

The main functions, for which the existence of specialised tools would make commissioning work more efficient, were listed:

- Assessment of a system's operation under the given operation conditions, including consideration of the weather conditions to assess whether the system has met the design requirements
- Fault detection and diagnostics
- Optimisation of the HVAC systems using computer simulation tools

Annex 47 also mapped the status of building Cx in the countries involved in the project. In the case of Europe, the commissioning process outside the UK was more or less new. However, the Cx process and particularly its objectives largely correspond to the EPBD objectives set by the European Commission. As a result, many national research programmes have introduced commissioning tools as a means of achieving the requirements of the Directive (EPBD). The use of Cx and its tools to achieve the objectives of the Directive is likely to have a great impact in the future, especially in view of the new EPBD 2018, which is already more concerned with the real operation of buildings.

In most European countries, however, Cx tasks are still focused only on the handover phase of the building, which, in many cases, means only a rough check of the completeness of the installation and verification of the principle functionality of the systems. This often chaotic and underestimated final phase of the building construction, together with the absence of the subsequent optimisation of its operation, leads to excessive and unnecessary energy consumption or to the reduced quality of the indoor environment. Unfortunately, the Czech Republic is no exception.

CONCLUSION

Given the high share of the total primary consumption by the building stock and the increasing demand for high-quality indoor environments, there is increasing pressure to optimise the operation of HVAC systems. The recently published European Union Directive on the Energy Performance of Buildings (EPBD 2018) also puts pressure on reducing the consumption of buildings in their actual operation and on the quality of the indoor environment [2].

In the case of environmental engineering, optimal operation is generally meant to ensure the requirements for the indoor environment quality with the minimum energy consumption. The advanced technologies and HVAC systems components used in large and modern, low-energy buildings have considerable potential for energy-efficient operations, but these technologies constantly increase the complexity of the installed systems and the impact of the interactions of the individual subsystems.

However, according to the available studies (e.g., [4], [12]), buildings usually do not operate as intended and their energy consumption is often higher than expected at the design stage of the building. To overcome this problem for non-residential buildings, a commissioning process has been introduced in recent years. By applying this process, significant energy savings can be reached and its tools and procedures help to ensure that buildings are operated correctly, energy efficiently and as required by the investor. A number of commissioning tools and technologies are needed to achieve energy-efficient operations and reach the potential of the advanced components and systems. However, further research is absolutely necessary for their development, for understanding their value and potential when applied to real projects and for achieving a nearly zero-energy building concept [13], [8].

In order for the Commissioning process to be used more widely, the whole process needs to be better standardised and practically applicable tools needs to be developed. However, at least understanding this concept and its significance and understanding the construction of the building and its subsequent operation and optimisation as a necessarily consecutive process, can mean a significant shift towards improving the real energy performance of buildings, while increasing the service life of the technical systems and the quality of the indoor environment.

Contact: Jakub.Simek@fs.cvut.cz

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