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Reducing Energy Consumption for Air-Conditioning by Commissioning and Optimized System Operation

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Abstract. The contribution of buildings towards energy consumption has dramatically increased over the past decade. According to the EC's Joint Research Centre, HVAC systems in Europe were estimated to account for approximately 11% of electricity consumed in Europe [1] and with associated CO₂ emissions highly contribute to global climate change. This paper deals with the electricity consumption of air-conditioning systems in buildings in the Czech Republic. The paper presents results of actual measurements in 15 mostly office buildings over a 5 year period. The extensive analysis of measured data is presented in graphs and tables. A considerable difference in the electricity consumptions for cooling between the various administrative buildings is identified. The advanced commissioning of air-conditioning systems and its general application in the Czech buildings is presented in the paper as well. Energy consumption measurements, proper operation and application of advanced commissioning are identified as important methods tool to reduce energy consumption of air-conditioning systems in existing buildings.

1. Introduction

Increasing energy performance of buildings is one of the most important current issue of European Union and Czech Republic in these days. Energy consumption for cooling and air conditioning in summer time is one of the major parts of whole energy consumption of modern buildings. However, there is almost no dealing with this issue in Czech Republic and serious measurement results of cooling consumptions are missing. Cooling energy consumptions of buildings are not available for detailed assessment of buildings energy performance as well as for regular inspection of air condition systems according to current Czech legislation. [4]

The aim of this paper is to demonstrate cooling energy consumptions of 15 buildings. These data were obtained during real field monitoring of these buildings during a period of 5 years.

Possible influences of cooling energy consumptions are evaluated in this paper and the results of analysis from measured data are shown. Based on the results from data analysis, main tools, which appeared to be essential for decreasing the energy consumption for cooling, are discussed.

2. Energy measurement

The energy consumption for cooling was measured in real operation of 15 buildings. Most of them were situated in Prague. Different types (library, shopping center, hotel), ages and sizes of buildings



were included in the measurement campaign. However most of the measured considered buildings were modern office buildings. Among many different air conditioning (AC) systems, the most common one was water system with fan coil units in combination with air handling unit for isothermal supply of fresh air. The energy consumption for cooling of those buildings is represented by electricity consumption of the chillers, which has the crucial contribution on cooling energy consumption and which has been equipped with dataloggers in previous years. Measuring was conducted between years 2012 and 2016 (for most of the buildings) and detailed 15-minute interval electricity consumption data was obtained.

Generally, different time resolution of energy consumption measuring can be chosen. For rough energy performance evaluation or comparison are even monthly electricity consumption data sufficient. However only detailed (e.g. 15-minute) data enable optimization and fault detection in operation of an air-conditioning system and chillers.

Processing of obtained energy consumption data was quite difficult, especially due to frequent errors in measured data caused by missing data and discontinuities in case of several buildings. Few of monitored buildings couldn't even be included in results because of the data insufficiency.

3. Results of measurement

For comparison purposes measured electricity consumption was normalized by air-conditioned floor area. For objective comparison is necessary to use a proper floor area for normalization. Because of the fact, that it is often problematic to get an accurate air-conditioned floor area, the possibility of using another reference floor area was analysed. The most promising appeared to be using of a total energy reference area which is easily accessible from energy performance certificate (implementation of energy performance of buildings directive). However closer comparison of exact air-conditioned area and the total energy reference area of analysed buildings showed, that difference between these floor areas varies (compared relatively) from building to building and is too large to be applicable for normalization of an energy consumption of chillers. For getting an objective and comparable energy consumptions for cooling is necessary to use an exact air-conditioned floor area for normalization.

The results of average annual consumptions for cooling are shown in **Table 1**.

Table 1. A list of the buildings and electricity energy consumptions of the chillers

Building number	Building type	Consumption [kWh/m ² /a]					Average
		2012	2013	2014	2015	2016	
1	Admin.	11,5					11,5
2	Admin.	37,4	35,1	28,9	34,6	33,7	33,9
3	Shopping center	11,0	6,7	7,9	8,1	6,2	8,0
4	Admin.	16,6	13,7	12,2	13,7	13,8	14,0
5	Admin.		15,4	16,2	13,6	9,6	13,7
6	Admin.	25,9	23,3	24,2	27,1	24,0	24,9
7	Admin.	32,5	22,0	28,0	16,9	26,2	25,1
8	Admin.	14,2	15,0	11,9	14,8	12,4	13,7
9	Admin.	33,1	24,4	27,1	25,1	21,4	26,2
10	Hotel		22,6	16,3	28,3	23,2	22,6
11	Admin.	32,7	35,2	30,1	25,7	30,8	30,9
12	Admin.		16,6	19,3	19,7		18,5
13	Admin.	12,3	10,4	11,4	12,2	8,5	11,8
14	Admin.	14,7	11,1	22,4	21,0	18,1	17,5
15	Public	4,5	2,3	1,9	6,5	6,6	3,7
		Average consumption [kWh/m ² /a]					
		22,4	17,1	17,5	18,1	16,7	18,4

The results of the average annual consumptions for individual buildings clearly show, that there are significant differences between analyzed buildings. The values of the average annual energy consumption vary from a 3,7 kWh/m²/a to 33,9 kWh/m²/a for a building with the biggest average cooling energy consumption. Total average annual energy consumption for cooling of analyzed building portfolio quotes 18,4 kWh/m²/a and the value of weighted average (weighted by air-conditioned floor area) is 13,4 kWh/m²/a.

Despite expectations, diversity in consumption remains, even if just one type of a building (office building) is compared. This can be seen in **Figure 1**. The total average annual consumption of analyzed office buildings is 20,1 kWh/m²/a and the value of weighted average is 14,2 kWh/m²/a. Based on the deviation of individual energy consumption of each building from a total average of whole building portfolio were established three categories: buildings with low energy consumption (deviation greater than 35 %) buildings with medium energy consumption (deviation lower than 35 %) and buildings with high energy consumption (deviation greater than 35 %).

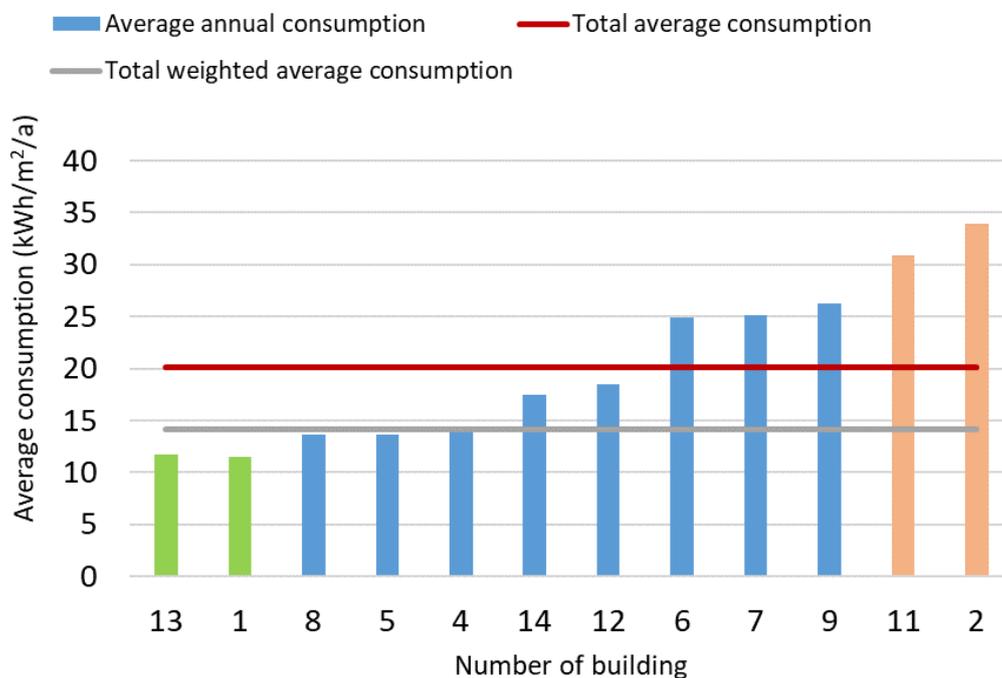


Figure 1. Average annual consumptions of office buildings

4. Analysis of the consumptions

Based on the measured data, potential impacts on the energy consumption. Analysis was conducted based on the sorting of buildings by their cooling energy consumptions and by finding their relationships with a set of selected possible influences such as design parameters (shading, glazing percentage, EER of cooling source, type of AC system, cold storage), operation specifics (using of free cooling, cooling source operation) and an external influence (outside air temperature). Due to the relatively small number of analysed buildings, it was possible to use this manual straightforward comparison method with the aim of finding the significant influences. If there was not a clear evidence of correspondence between of a building energy performance and an investigated influence (e.g. energy performance of buildings with greater EER of their chillers was clearly better compared to buildings with worse chiller's EER), the influence was not considered as dominant. For objective comparison, just building of one type (office buildings) were used for an analysis. Only three of analysed influences showed up as significant. It was influence of shading, outside air temperature and influence of operation of an air conditioning system.

4.1. Influence of shading

Different extent and technological level of shading was identified through out the analyzed building portfolio. In case of a few buildings, the shading was realized by very sophisticated automatic shading system and was constructed on all facades. However, there were still a few buildings with no shading at all, or with totally insufficient shading in form of a manually controlled internal shading elements.

Regardless of the glazing percentage of individual facades, cooling energy consumption of buildings with systematically solved shading was demonstrably lower. On the other hand, buildings with insufficient or no shading had highest consumption among the analyzed buildings.

4.2. Influence of the temperature

In order to resolve the influence of an outside air temperature on the cooling energy demand, a dependence of the measured energy consumption on the temperature was created. At first a dependence of an average annual energy consumption on average summer (May–September) temperature of an outside air was investigated. Despite the expectation any dependence between these two variables was not identified. Explanation of the independency could be minor variation of average summer air temperatures, which were with a range of 16,14 °C to 17,26 °C for Prague and for Central Bohemia based on the Czech meteorological institute data.

The dependence is shown in **Figure 2**.

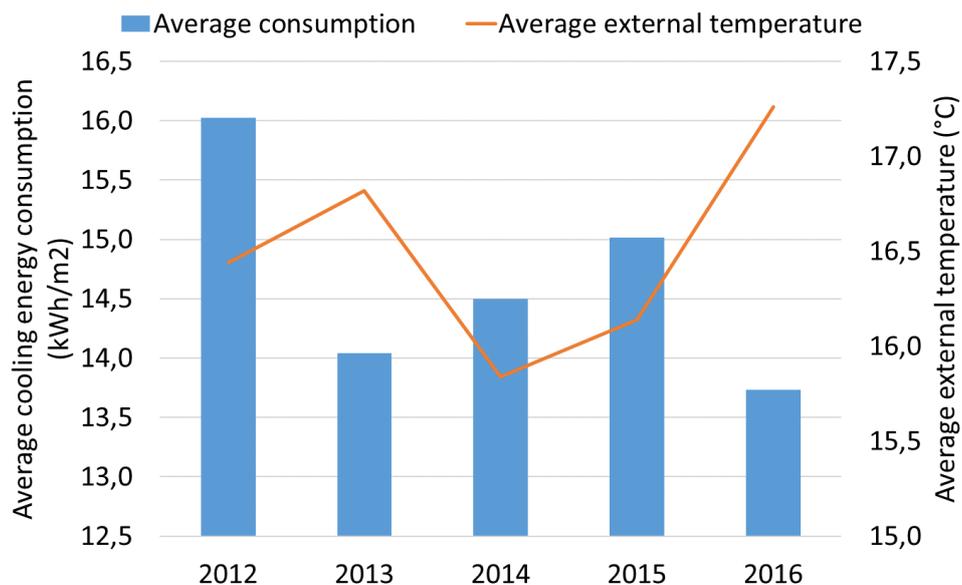


Figure 2. Dependence of average annual cooling energy consumption on outside air temperature

On the other side a strong dependence was identified between monthly cooling energy consumption and monthly average outside air temperature. In **Figure 3** a relative distribution of individual buildings energy consumptions during a year is shown in a context of correspondent monthly outside air temperatures (dashed line). It is evident, that consumption curves with their shapes almost copy the line, which represent the outside air temperature.

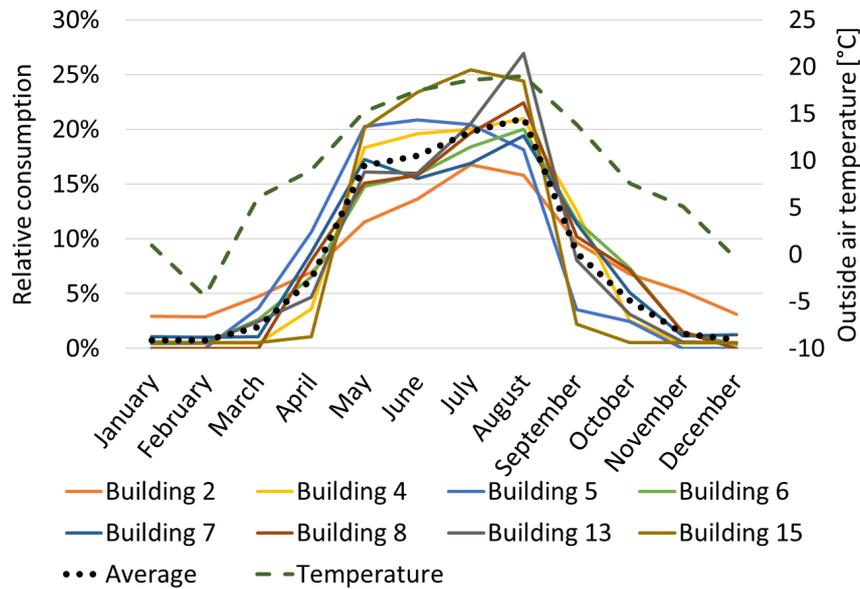


Figure 3. Monthly energy consumptions dependence on outside air temperature in 2012

4.3. Influence of control strategy

Operation of an air-conditioned system was investigated on its energy consumption dominant component, which is the chiller. Using detailed 15-minute electricity consumption data, dependence of power demand on time, was constructed and analysed. It has been found out, that chillers are often operated distinctly differently in particular buildings and the chiller attenuation during a weekend is used just in few buildings. However, this chiller attenuation was investigated as an effective measure for increasing the energy performance of a chiller. In buildings where have been turned off the chiller during the weekend had a significantly lower cooling energy consumption in comparison to other buildings. Decrease of an energy consumption was also identified in case of one building, during a year when chiller attenuation was used.

Due to obtained knowledge based on the detail analysis of chiller’s power demand, weekend attenuation of a chiller can be recommended as an effective measure for increasing energy performance.

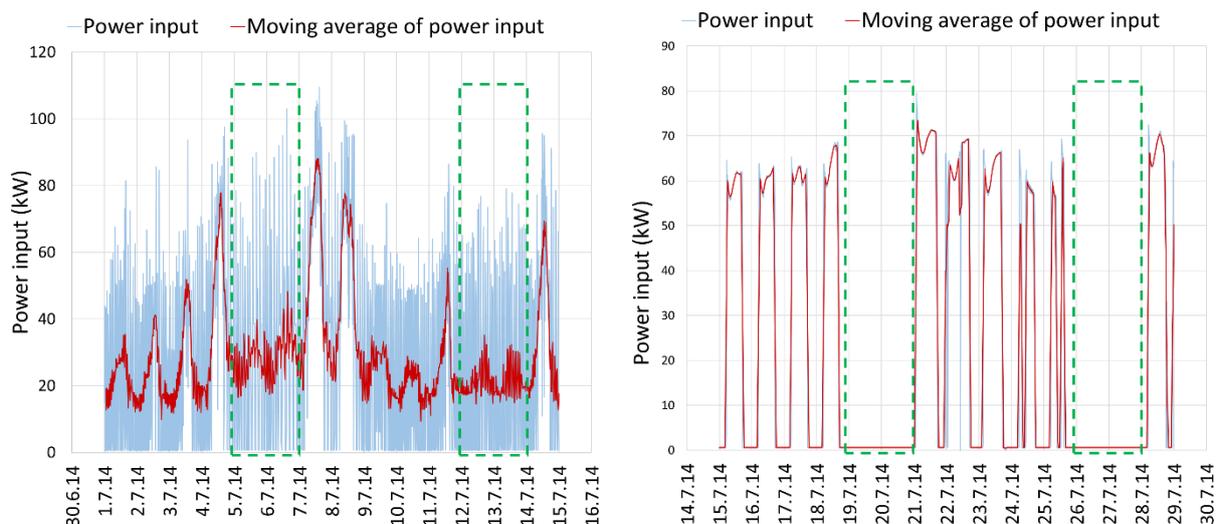


Figure 4. Course of chiller power input in the building n.6 with obvious cycling period and absence of attenuation during weekend (left), course of chiller power input in building n.1 with continuous power regulation and attenuations during weekends (right)

In case of the two analysed buildings, significant drops of chiller annual energy consumptions were detected. Possible influence of e.g. warmer summer was eliminated based on the previous analysis and there was no other obvious reason for these kind of drops in consumption. For more information the management of concerned buildings was contacted, and it has been found out, that during time when building was monitored, facility company who operated technical systems was changed for a several times. After closer look at measured data in context of these obtained information, there was clear evidence of relationship between drops of cooling energy consumption and a facility management replacement. It must be mentioned that due to the type and use of concerned buildings, it is highly unlikely, that these drops or decreases in energy consumption respectively, was reached for a price of insufficient indoor quality. The assumption can be made, that these drops in consumption was caused by different control strategies of facility companies.

Significant decreases and increases of chiller energy consumption due to unspecified interventions in control system conducted by different facility companies can be seen in **Figure 4**. Decrease of chiller consumption in office building between 2012 and 2013 is demonstrated in **Figure 4** (left). Relative change of chiller energy consumption in a building of library is shown in **Figure 4** (right). There were three facility companies, which operated this building during 7 years of monitoring (labelled as company A, B and C in the graph). Due to obviously different attitude to control system of each facility management, were measured completely different cooling energy consumptions.

This is a solid evidence out of real operation, that buildings are very likely operated with considerable inefficiency dependently on control strategy and on a will of energy management to deal with decreasing an energy consumption of a building. Real operation energy consumption of an individual technical systems is very often, due to a lack of proper measurement, completely unknown and far away from intended design operation. However, by proper commissioning, (systematic process conducted to confirm that a building and its component systems conform to the design intent and are operated with maximal efficiency), can be reached significant savings of an energy consumption. Probably the most comprehensive analysis of building commissioning was conducted by Lawrence Berkeley National Laboratory based upon a database of 643 buildings. This thorough meta-analysis of commissioning experience has revealed that one third of projects, for which data were available, revealed more than 10 000 energy- related deficiencies. Correction of this deficiencies resulted in 16% median whole-building energy savings in existing buildings and the payback time of commissioning was 1.1 years. [3] [4]

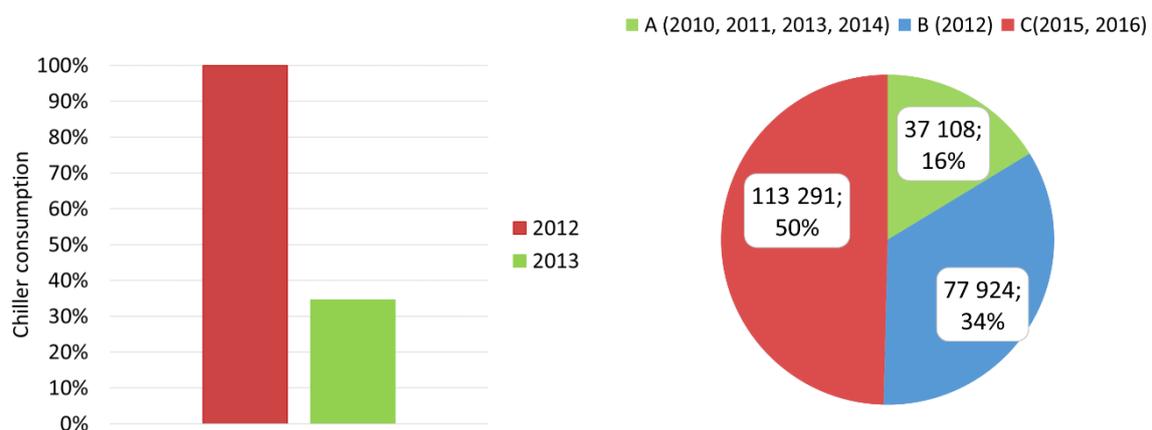


Figure 5. Decrease of chiller energy consumption in building n.5 due to change of air conditioning system control (left), relative chiller energy consumptions in building n.1 depending on control strategy of air conditioning system (right)

5. Conclusion

This article shows the importance of detailed energy consumption measuring. It is a necessary approach for any kind of energy consumption and building operation optimization. However sophisticated data monitoring which could provide detailed data for thorough analysis is still missing in many buildings. The electricity consumption for cooling of 15 analyzed buildings in the Czech Republic varies from 2 to 37 kWh/m²/a, with an average of 18,4 kWh/m²/a.

Based on the measured consumption data during real operation, significant differences in consumption between individual years in cases of two buildings was identified. It was assumed that these differences were caused by building operation inefficiency and indicates a significant potential for increasing building performance. Based on the conducted data analysis, specific ways to decrease the cooling energy consumption would be to use window shading and weekend attenuation of chillers.

It can also be concluded that to reach a low or net-zero energy building, it is necessary to optimize the building and systems design, but it is also essential that the building and systems are properly commissioned by systematic analyzing energy consumption during real operation.

Acknowledgments

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