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Energy savings through implementation of a multi-state Time Control Program (TCP) in demand-controlled ventilation of commercial buildings

Thomas Kitzberger, Jan Kotik*, Matthias Schmöllerl, Tobias Pröll

Department of Material Sciences and Process Engineering, Institute for Chemical and Energy Engineering (IVET), University of Natural Resources and Life Sciences, Peter-Jordan Straße 82, Vienna 1190, Austria

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ABSTRACT

Regarding the energy intensity/consumption of all technical building services, HVAC systems are by far the most energy-intensive ones, when it comes to commercial buildings such as R&D Institutions/Universities, office buildings, hospitals and other buildings of similar use. As far as overall costs for HVAC systems are concerned, it can generally be stated that the initial investment costs for building services (e.g. for ventilation) are by far lower than the operating costs after a certain operating period. This paper presents a widely applicable, yet simple approach to reduce energy consumption of air handling units in a commercially operated building. The implementation of a Time Control Program (TCP) using multi-state operation by resetting the duct pressure values according to the well-known fan affinity laws yields respectable savings in energy consumption. Yet the expenditure of time for the implementation of these simple and effective measures has to be considered: a lot of time-consuming measurements and organizational briefings have to be performed regarding the size and complexity of a typical university building. In practice, savings of up to 55% in electrical as well as 39% in thermal energy can be achieved regarding one specific AHU with bad (24h-'comfort'-operation) initial set-up. It can be assumed, that far too many university/commercial R&D buildings of younger age (<15 years) in Austria are scarcely equipped with adequate metering or even automated energy monitoring systems, which would highly facilitate energy analyses and push the realization of crucial measures to reduce energy consumption.

1. Introduction

Several technological and technical advancements in building services have been developed, engineered and deployed in commercial, non-residential buildings in the past 15 years: Integration of renewable energy sources through solar thermal/photovoltaic units and use of rejected or geothermal heat through heat pumps, comfortable air handling units with heat recovery and the possibility to use low temperature heating systems combined with highly efficient building envelopes to name a few.

All these building services are well managed by more or less complex control algorithms in a Building Automation and Control System (*BACS*). Recent studies focus on different control strategies for subsystems of buildings services. Newest advancements include variable duct pressure control concerning fan operation of air handling units (*AHU*) [1–4].

Furthermore, the installation of frequency converters (e.g. for electric motors of fan units), newly developed pipe insulation materials, pressure-loss optimized engineering of air duct and heating water pipe systems with sophisticated 3D-modeling tools and precisely made calculations, together with risen efficiencies of electronically commutated (*EC*-) electric motors, optimized pumps and air handling units have led to a significant reduction of the planned/proposed energy consumption of non-residential buildings.

In spite of all this technological progress, commercial (university) buildings rarely reach their anticipated behavior in terms of energy consumption, often significantly exceeding the expectations in a negative sense [5,6]. In general, it can be stated that energy consumption of the whole (both residential and commercial) building stock in developed countries is rising steadily reaching figures between 20% and 40% of the overall energy consumption and herby already exceeding the other major energy consuming sectors, i.e. industry and transportation, as shown in literature [7].

Furthermore, detailed performance analyses of commercial buildings can be found in a study from Germany [8] and a critical

* Corresponding author.
E-mail address: jan.kotik@boku.ac.at (J. Kotik).

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review on improving energy efficiency of operating both commercial and institutional buildings has been presented by Ruparathna et al. [9].

While the energy savings potential in small to large office buildings is definitely not negligible as deducted by Azar and Menassa [10] in their comprehensive framework to quantify energy savings possibilities in commercial buildings, the potential seems to be far higher in more sophisticated buildings such as R&D Institutions and Universities due to their more complex requirements.

An IEA-metastudy [11] with more than 200 analyzed buildings gives insight into the most frequent deficiencies observed during re-commissioning: Air handling units, hot water supply and air conditioning/cold water generation are being identified as excessive energy consumers. The authors summarize three main reasons that lead to the given deficiencies: 1) Faulty plant design, 2) shortcomings in the construction and installation phase and 3) inadequate operation and insufficient maintenance.

The following reasons for potential errors and observed deviations from design values in operation are specified [12,13]:

- Faulty Time Control Programs (e.g. excessive run-time hours of air handling units).
- Simultaneous heating and cooling.
- Faulty set (nominal) values.
- Poorly calibrated sensors, bad sensor-placement.
- Manually adjusted set-values to compensate for inadequate operation/function.
- Wrongly installed technical components.

Regarding the energy intensity/consumption of all building services, HVAC systems are by far the most energy-intensive ones regarding R&D Institutions/Universities [7]. Therefore, continuous monitoring, measuring and improving HVAC subsystems are essential tasks in increasing energy efficiency and lowering energy consumption of commercial buildings [14]. As proposed by Wang et al. [13], already small measures such as re-setting of certain control parameters to nominal values or adapting them to actual demands such as reducing or increasing temperature values by small increments can lead to energy savings of up to 30% [15]. Specific requirements for HVAC systems as well as regulatory measures to increase efficiencies of such systems are described by Perez-Lombard et al. [16]. As far as overall costs for HVAC systems are concerned, it can be stated in general that, in respect to a life time of a commercial building of around 30 years, the initial investment costs for building services (e.g. for ventilation) are by far lower than the operating/maintenance costs after a certain operating period (usually 6–10 years), depending on size and complexity of the given building [17]. Therefore, simple, financially non-intensive measures to reduce energy consumption and thus reducing operating costs can lead to significant energy/cost savings as described e.g. by Escriva-Escriva [18].

2. Objectives

The main aim of this article is to provide generalized information on how to increase energy efficiency and reduce energy consumption respectively in demand-controlled ventilation of commercial buildings. For this purpose, two case studies are presented and evaluated, which deal with the implementation of a *T*ime *C*ontrol *P*rogram (TCP) for air handling units (AHU) in the ventilation system of two main teaching and research facilities (university buildings) in Vienna and Tulln, Austria. Therefore, as depicted in Fig. 1, three critical issues are being addressed in this article to achieve this aim.

The two presented case studies include information on the type of the investigated commercial buildings together with some characteristic buildings' data. Also, the technical infrastructure, i.e. the installed ventilation system as well as AHU-control strategies within the Building Automation and Control System (BACS) are described in required detail. The methodology of successfully implementing a TCP for AHU-control is presented together with underlining necessary measurements and 'time and effort' considerations. Generated electrical and thermal energy consumption figures are presented and discussed for both case studies. Finally, specific numbers of successfully achieved and potential energy savings through TCP implementation are given, the TCP applicability critically examined and the most important influencing factors concerning TCP-profitability discussed.

3. Methodology

In order to analyze and quantify potential savings in energy consumption during operation, the building services, i.e. the technical infrastructure of the research and teaching facilities, has to be studied and analyzed in detail in terms of energy intensity and -consumption. Only a reliable and precise comparison of the energy demand before and after optimization procedures yields realistic final data for energy and cost savings.

As supposed, the ventilation and air-conditioning system for laboratories, special research chambers as well as offices and general areas, is responsible for nearly half of the specific total energy consumption of the investigated buildings. It consists of several main air-handling units in each case. Therefore, a more detailed investigation of the parameter setup of the control system for these energy-intensive air handling units has been conducted to evaluate certain technical measures to improve performance and thus reducing operational costs.

3.1. Influencing control parameters and general procedure

Fig. 2 shows a schematic overview of a typical air handling unit providing conditioned air through a duct system to various zones with different requirements.

Outdoor air (*ODA*) enters the air handling unit through an insect grill and gets filtered in a fine filter. In modern AHU's, air flow passes a heat recovery unit and, in doing so, extracted air (*ETA*) provides pre-conditioning of supply air (*SUP*) mainly at cold ambient temperatures. In case of low temperature differences in ETA and SUP, which would result in no heat recovery at all or even reversed heat transfer, a by-pass reduces pressure losses and eliminates undesirable thermal exchange in the heat recovery unit. The pre-conditioned air stream is heated up to a desired temperature in the heating coil unit. The cooling coil has two functions: on the one hand cooling the air on hot days, on the other hand dehumidifying the air stream with cooling under the dew point, which leads to condensation of water. Afterwards, the air stream is heated up again to the desired SUP air temperature.

Thereby a fan has to overcome all pressure losses in the whole air handling system thus pushing the air throw the duct system.

Usually, and still the norm with modern commercial buildings (in Austria), a fixed duct pressure control (1), as depicted in Fig. 2, is used to ensure sufficient air supply. Nowadays, variable duct pressure control systems with special control algorithms are being scientifically investigated [1,3], their advantageous operational efficiency being increasingly proofed [2,4]. Various products using static pressure reset control are readily available on the market, for example by Belimo (CH), Schneider Elektronik (DE), Sauter (CH), Pichler (DE), Halton (FI) to name a few. Still, this optimized control technology is far from being wide-spread when it comes to realized applications in ventilation control of commercial buildings. There seems to be a great lack of proper experimental data and real 'proof of efficiency' based on measurements concerning the achievable energy savings.