Energy and Buildings 82 (2014) 406–415

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Alternative strategies for supply air temperature control in office buildings

Mattias Gruber*, Anders Trüschel, Jan-Olof Dalenbäck

Chalmers University of Technology, Energy and Environment, Building Services Engineering, Sweden

ARTICLE INFO

Article history:
Received 2 April 2014
Received in revised form 4 June 2014
Accepted 25 June 2014
Available online 28 July 2014

Keywords:
Heating, ventilation and air-conditioning
Building automation
Supply air temperature control
Optimal control
Office buildings
Genetic algorithm
Energy efficiency
Indoor air quality
Thermal comfort

ABSTRACT

A key element for a reduced energy usage in the building sector is to improve the systems for indoor climate control. But, it is important that such measures are fairly simple and easy to implement in order to facilitate a widespread utilization. In this work, four alternative strategies for supply air temperature control in offices were investigated through simulations. Their level of complexity stretches from linear SISO (single-input, single-output) structures with standard inputs to an optimal algorithm with information about the entire set of disturbances acting on the building. The study was conducted with a conventional outdoor-air-temperature based method as benchmark, and two different heating, ventilation and air-conditioning (HVAC) systems as well as two types of building structures were taken into account. Compared to the benchmark, all alternative strategies resulted in lower energy usages while thermal comfort and indoor air quality were satisfied, and simple strategies could perform almost equally well as more complex. But, it was also shown that the benefits were highly dependent on the considered HVAC system and somewhat dependent on the considered building structures.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Approximately 40% of the global final energy is used in buildings, and in the European countries, 76% of this share goes towards systems for heating, ventilation and air-conditioning (HVAC). The purpose of an HVAC system is to achieve a desirable indoor climate and a key element for reducing the associated energy usage is to improve the building automation system. Many systems for indoor climate control consist of both local (on room level) and central components, and since their functions in many cases coincide, an important aspect in this context is to synchronize their operation. [1]

An established technology for ventilation system control is DCV (demand controlled ventilation). The supply air flow rate to each space is then controlled individually and a common application is to use zone measurements (typically temperature or CO_2) as input to a feed-back loop. The supply air temperature (SAT) is in turn first and foremost controlled centrally which means that the level should suite the entire range of demands within the building zones simultaneously. Conventionally, SAT control strategies are often based on external disturbances, and typically the outdoor air temperature (OAT) since the whole building is affected by its variations. This means that the SAT is increased for decreased OATs and vice versa [2]. But, such strategy can be problematic in office buildings since internal disturbances (such as people, lighting and equipment) are commonly dominating over the external climate during working hours. Then, a cooling demand can be expected almost regardless of the OAT (especially in modern office buildings with tight and well insulated envelopes), at the same time as the quality of the indoor climate is of utmost importance. Unsuitable supply air temperatures in certain zones can partly be compensated for by local components, but with an increased energy usage as a consequence. However, in more severe cases, the function of the HVAC system can be compromised.

An emerging technology for achieving a SAT control that coincides with the remaining functions in DCV systems is to treat the HVAC operation as a global optimization problem by involving various objectives and variables. For example, an entire building's energy usage can be minimized at the same time as the quality of the indoor climate is ensured. This approach has been studied in several previous works, as for example in [3], where the solver genetic algorithm (GA) was used in an office environment during two summer weeks by incorporating thermal climate and energy for air-handling in the objective function. A similar investigation was presented in [4], and it was found that up to 30% of

* Corresponding author. Tel.: +46 317721168; fax: +46 317721152.
E-mail addresses: mattias.gruber@chalmers.se, mgriu03@hotmail.com (M. Gruber).

http://dx.doi.org/10.1016/j.enbuild.2014.06.056
0378-7788/© 2014 Elsevier B.V. All rights reserved.

Nomenclature

C	thermal capacity [J/°C]
c	CO_2 concentration [ppm]
c_p	specific heat capacity [J/(kg K)]
E	total energy, weighted sum of energy types [W]
$\dot{M}$, $\dot{c}$	CO_2 flow rate [ml/s]
Q	thermal energy [J]
$\dot{Q}$	thermal power [W]
t	Celsius temperature [°C]
V	volume [m^3]
$\dot{V}$	volume flow rate [m^3/s]
W	electric work [J]
$\dot{W}$	electric power [W]

Greek letters

τ	time [s]
ρ	density [kg/m^3]

Subscripts

max	maximum
min	minimum
r	room
s	supply
tot	total
vent	ventilation

the energy could be saved by employing GA for SAT control in an educational environment instead of maintaining a constant level. These findings are moreover consistent with the reported results of [5] where genetic fuzzy optimization was used for climate control in an academic building scale model. Compared to maintaining constant SAT levels between 12 and 14 °C, the strategy yielded energy savings between 54 and 61% during summer and winter ambient conditions, and this range was furthermore assessed as equivalent to savings between 29 and 36% on an annual basis. A final example of an investigation considering SAT control through global optimization algorithms is [6] in which GA was evaluated for ventilation system control in a multi-zone simulation platform. Simplified adaptive control models of the process were used to estimate the response to various external and internal conditions while the solver searched for a trade-off between air-handling energy and comfort aspects. Simulations were conducted for four different weather conditions and it was found that up to about 40% of the energy could be saved using the optimal approach compared to maintaining constant setpoints. A bit different approach to the same problem was in turn chosen in [7]. Instead of using numerical tools, expressions for the HVAC energy usage were formulated for a number of conditions and the optimal SAT was derived analytically. The theory was applied on a ventilation system in an office building and an energy saving potential between 8 and 27% compared to constant setpoint cases was indicated.

1.1. Background and purpose

In the light of the previously cited works, it is clear that optimal SAT control strategies have a large potential for reducing the HVAC energy usage while maintaining a desirable indoor climate. However, a major drawback is that the associated level of complexity normally is high since a complete model of the process (building and HVAC system) is required together with extensive information about internal and external conditions. The process model is used to predict the influence of choosing a certain SAT under the present conditions, and an optimization algorithm typically performs a search to find the most appropriate level. Even though physical models have the potential of describing the process sufficiently accurate, a large number of parameters would then be required whereof several are uncertain or hard to determine. Another alternative is black-box models that are constructed from observed data in terms of input/output measurements. But since the accuracy immediately becomes uncertain when operated in a range from where the training data lack information, the commissioning phase can be an extensive process. When it comes to gathering information about internal and external conditions, the customary set can be divided into a number of disturbances whereof several could be determined using established measurement technology (for example OAT, lighting, solar radiation). But for others, this is not an option (considering people and infiltration flow rate for example) without involving models for predictions and/or estimations, and these are typically afflicted with the same problem as the process models [8].

The aim of the present paper is to contribute in the search for simple SAT control strategies with a potential of reducing energy usage while achieving a desirable indoor climate. The investigation was performed in a simulated office environment and the core consists of three SISO (Single-Input, Single-Output) strategies that primarily are based on information inside the building through standard inputs. While a conventional OAT-based strategy was included as a benchmark, the upper boundary of potential energy savings was represented by an optimal algorithm, and it was furthermore examined if patterns in the solution could be utilized to formulate a more general and simple strategy.

During simulations of a 11 room office building over two working weeks of Swedish summer and winter respectively, all strategies were individually evaluated for generating central SAT setpoints in two different DCV-HVAC system applications: an all-air system with re-heaters in each room, and a system with hygienic ventilation and local water-based cooling and heating. In both cases, the thermal climate and indoor air quality (IAQ) within the zones were controlled with temperature and CO_2 as indicators, respectively. The investigation was moreover conducted for different variants of the building and the results are presented as the total energy used by the HVAC system during the simulated periods.

This paper is organized as follows: first, the simulation platform, including HVAC system and building, is presented together with its considered variants and simulated conditions. This is followed by a description of the evaluated SAT control strategies, and finally, the results from the study are presented and discussed.

2. Simulation framework

The investigation is based on simulations performed in MATLAB® Simulink® and the platform consists of a building and an HVAC part. These are in turn made up from a large number of component models with one-dimensional equations used to describe how the simulated variables vary over the platform. The controlled variables of the rooms (CO_2 and temperature) were calculated by physical balance equations and the relations between pressure and flow in the HVAC system were based on empirical data. In this section, the modelling approach is first described briefly and if more detailed information is desired reference [9] or [10] can be considered. Further on, the variants of the building and HVAC system are introduced which is followed by a description of the disturbances that were considered.

2.1. Building platform

The building part is presented in Fig. 1. It was modelled to represent part of a floor in a modern office building with tight and well

Download English Version:

https://daneshyari.com/en/article/262682

Download Persian Version:

https://daneshyari.com/article/262682

Daneshyari.com