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CLIMATE CONTROL IN BUILDINGS

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ABSTRACT

One of the most critical challenges facing society today is climate change and thus the need to realize massive energy savings. Since buildings account for about 40% of global final energy use, energy efficient building climate control can have an important contribution. The energy performance of buildings has attracted substantial attention due to the significant energy-saving potential. As a semi-open high-space building, the railway station is obviously different from other public buildings and even traditional stations in terms of energy consumption and internal environment. As a new type of large-scale public building, railway stations are developing fast throughout the world. In general, most of the newly built stations have large, tall and open space like waiting hall and ticketing lobby, with large area of glass curtain wall or skylight. Such features may contribute to higher energy demand of the stations, especially for HVAC system.

Keywords: climate control, air infiltration, energy consumption, lightening environment.

1.0 Introduction

The world is advancing in terms of the strength of the economy and the affluence of society. More and more people live in modern style buildings which mostly adopt a brick or concrete building type from western cold climate style. This style is not particularly suitable for the tropical climate area due to the excess heat stored in the building walls and the poor ventilation. However, it is widely accepted and it is popular throughout the country. In addition, several convenient appliances are well equipped in buildings such as air conditioning system, water heating unit, refrigeration, lighting, microwave, computer, large screen television and so on. This has become common for buildings in urban area. Statistically, the building sector has shared nearly one-fourth of annual electrical energy consumption (Department of Alternative

Energy Development and Efficiency, 2008). It has dramatically increased in the last decade and hence requires high attention.

There are no other building components, in residential and commercial buildings that would greater care than an air conditioning system. A climate change study suggested a relationship between an increasing world temperature and an installation rate of heating ventilating and air conditioning (HVAC). Moreover, a conventional source of energy from fossil has been largely taken for generating electricity, a final energy requirement, also concerned by energy conservation.

Heating, Ventilation, and Air Conditioning (HVAC) units are complex systems that coordinate incorporate mechanical and electrical components using data processing algorithms, designed to control the climate within buildings. Standard HVAC systems typically use a small number of thermostats, together with simple temperature regularization loops (Freire, Oliveira, & Mendes, 2008), to follow a temperature set point and ignore other variables, such as humidity and flow velocity. The multi-dimensional nature of human comfort lead to the adoption of the Predicted Mean Vote (PMV) index (Fanger, 2017) in the the ASHRAE 55 Standard (ANSI/ASHRAE, 2010) to quantify indoor thermal comfort. Our effort in this paper is motivated by our interest to explicitly incorporate PMVbased comfort measurements to the HVAC actuation loop with distributed-parameter Computer Fluid Dynamic (CFD) model.

In European countries, 76 % of the building sector energy is used by systems for heating, ventilation and air-conditioning (HVAC) (Department of Alternative Energy Development and Efficiency, 2008). A key element for reducing this part is to improve the associated building automation system (BAS), and such measures have the possibility of yielding a number of benefits. First, they can coincide with the primary function of achieving a desirable indoor climate. Second, they have the possibility to be overall effective since the control system determines the operation of the entire HVAC system, and therefore has a decisive role when it comes to the associated energy usage. Third, to a certain level, energy savings are possible without any major retrofits of the HVAC system or building.

A building and its spaces are continuously affected by internal and external indoor climate disturbances in terms of heat, air-emission and humidity sinks/gains. The purpose of the BAS is to adapt the operation of the HVAC system so that a desirable indoor climate is maintained throughout the building for all possible conditions. Hence, the BAS acts as an interface between the building and the HVAC system, and as an HVAC system alone only can be operated either at full capacity or to be completely off, the purpose of the BAS is to manage everything in between - that is, all part load scenarios. For buildings in general, this is the absolutely most common operational mode, which means that the BAS plays a crucial role in providing HVAC services during most of a buildings life-time.

A way of improving the BAS is to increase the adaptation to prevailing conditions by incorporating relevant information about the control task, building and HVAC characteristics, the activities inside the building, the ambient climate etc. That is, to provide a holistic view of the systems, the processes as well as present events and their consequences in time. By doing so, the prerequisites of achieving a desirable indoor climate from a static and dynamical point of view could be estimated in advance - before any deviations from considered comfort regions occur. Also, the control activity could be planned ahead by anticipating future demands, which opens up for the possibility of optimizing the operation by deciding on the most preferable counteractions for changed conditions.

2.0 Energy Consumption of Railway Station: An Overview

Buildings are responsible for approximately 40% of the total world annual energy consumption, most of which is used for the lighting and the HVAC (Heating Ventilation Air Conditioning) systems (Omer, 2008). Due to the remarkable energy-saving potential, many studies (Bracke, Delghust, Laverge, & Janssens, 2019; Zhou & Lin, 2008; Doctor-Pingel, Vardhan, Manu, Brager, & Rawal, 2019; Hoyt, Arens, & Zhang, 2015) have focused on the energy-saving evaluation of public buildings. As an important and special branch of public buildings, traffic transportation buildings like railway stations have characteristics of large space span, various functions, high density of people, and long operation time of air conditioning system. Energy consumption and energy-saving approaches of these kind of buildings are also quite different from those of common public buildings (Song, Wang, & Li, 2016).

With the fast development across the globe, building energy consumption has become a hot topic. Nowadays, buildings account for more than 20% of the world's total primary energy consumption, and further in depth, more than a quarter of the building energy is consumed by public buildings, especially large scale public buildings (Omer, 2008). Meanwhile, railway construction is experiencing a high-pace development. According to the Medium and Long-term Development Plan of Railway, the total operating length of domestic railway will exceed

5,100,000 km at the end of 2022. Meanwhile, more than seventy thousand rail-way stations will be built or reconstructed during this time period.

Among all kinds of railway station, high-speed railway stations (HSRS) built in recent years are drawing more and more attention. Different from other types of building or traditional railway stations, HSRS usually have large, tall and open spaces like waiting hall and ticket lobby, with large area of glass curtain wall or skylight, and have high density of passengers. Such features may probably contribute to higher energy demand of the stations, especially for HVAC system. Specifically, space cooling and heating load may be substantially influenced by the internal heat caused by high density of passengers and equipment, the solar radiation passing through the glass curtain wall or skylight, and the large amounts of air infiltration through the open doors at the entrances and exits.

Since HVAC is the largest consumer in public buildings, and cooling/heating load is the primary energy demand for HVAC system, the first step of energy saving for HSRS is to get a clear knowledge about the characteristics of space cooling and heating load, identify dominant factors and make sure which parts should be emphasized.

In this field, some efforts have been done during the past few years. Some researchers (Liu & Lin, 2011; Wang, Lin, & Zhu, 2011) tried to study the relationship between HVAC energy demand and factors like window-wall ratio or heat transfer coefficient of building envelop, in order to propose energy saving suggestions for the design of new stations. However, such researches are aimed for the optimization design, instead of energy saving for existing stations. And most of these researches merely discuss total energy demand of a station, while the formation of the total load and the proportion for each part remain unclear. Besides, current researches mainly focus on large space like waiting hall, lacking the comparative analysis between different spaces in a station.

3.0 Description of Energy Use Characteristics

In order to discover the current situation and characteristics of the energy consumption of railway stations, it is necessary to investigate the energy consumption data of railway stations of different scales in different climate regions for analysis and collation. According to the Design Standard for Energy Efficiency of Public Buildings, five climates are considered, including severe cold (A), cold (B), cold winter and hot summer (C), warm winter and hot summer (D,) and temperate (E) (Figure1). According to the Code for Design of Railway Station, of stations with a number of passengers dispatched during the peak hour, more than

5000 are large ones and within that, between 1000 and 5000 are medium-sized ones. In this paper, a total of 15 large and medium-sized stations are selected for measurements. The basic information for the selected railway stations is shown in Table1.

Energy consumption of the high-speed railway station comes from the data statistics of the station operation department. Annual and monthly building energy consumption of 2018 is read out by the meters of the distribution station. Energy consumption of items (including lighting, elevator, HVAC system, etc.) is separated by the equipment number and the energy use recorded. During the heating period, energy consumption is calculated by reading the boiler gas meter or by heating.

4.0 Heating, Ventilation and Air-Conditioning (HVAC) Systems

The purpose of an HVAC system is to maintain a desirable climate in a given space, typically through the operation of various equipment and appliances for heating, cooling and/or air-renewal. In accordance to the principal characterisation in figure 1, an HVAC system can be divided into subsystems for generation, distribution and supply. The purpose of the generation parts is to provide the building with cooling and/or heating energy through the operation of one or several units, such as boilers, district heating substations, cooling machines etc. The energy is in turn transported via carriers in the distribution system to various zones of the building, where some kind of service for a maintained indoor climate is provided through terminal units.

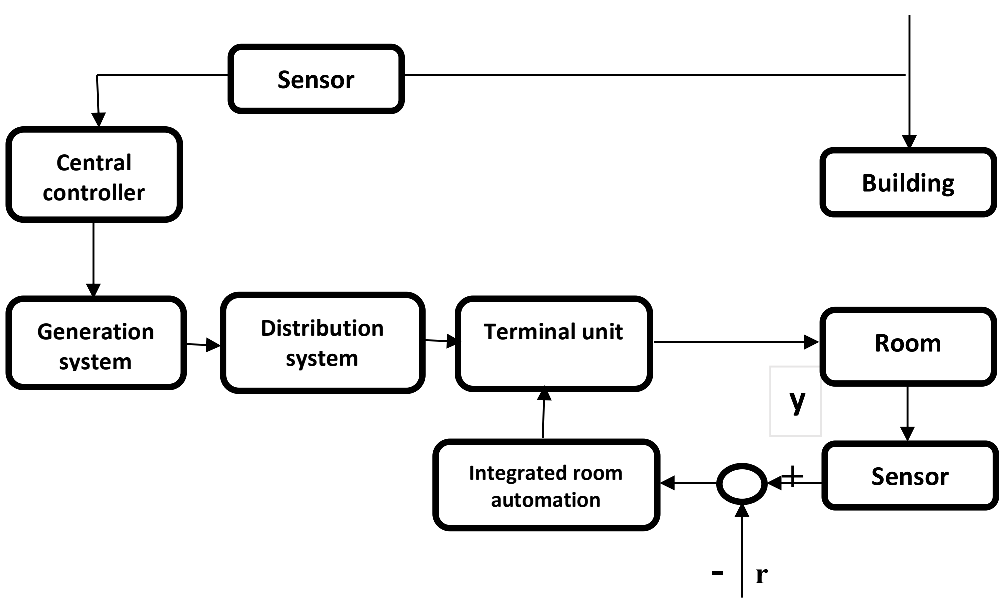

Figure 1. Principal characterisation of a building HVAC system: uc = control signal(s), r = setpoint(s), y = measured controlled variable(s).

Typical heating and cooling carriers in buildings are air and water, and the associated parts of the HVAC system is referred to ventilation- and hydronic- (or water-based) systems, respectively. Common terminal units in the hydronic part are radiators, chilled beams or fan-coils, and these are used to supply or extract heat in a space for covering heat deficits or to remove heat surpluses. In turn, the primary purpose of the ventilation system can also be to manage heat surpluses/deficits (referred to as an all-air system), or to provide an air-renewal in the room (referred to as hygienic ventilation (Maripuu, 2009)). These services are commonly associated with diffusers as terminal units but there are also other examples such as inductors or ventilation-connected fan-coils.

The mutual task of all controllers that are involved in the operation of an HVAC system is referred to as building automation. When it comes to indoor climate control, a distinction can be made between controllers that act on a local respectively on a central building level. The generation part of the HVAC system is typically automated centrally, and the associated controllers then determine the temperature levels of heating and cooling carries in the distribution system. In turn, local controllers are involved in a task referred to as integrated room automation and are used to determine the transfer conditions on room level – from the distribution system via the terminal units. This is primary done by changing the flow rate of carriers, but there are also examples of supporting functions for varying the temperature (e.g. re-heaters in ventilation systems).

5.0 Controllers and Control Systems

A general control system typically consists of the three following components, while translations into building automation terms are provided in parenthesis;

- A system of sensors for gathering relevant information (indoor climate disturbances, state of controlled variables) from within and around the controlled process (conditioned space).
- A controller for transforming the sensor outputs (measurements) into control signals.
- An actuator (HVAC system component) for transforming control signals into physical actions (heating, cooling or ventilation) on the controlled variables (indoor climate indicators).

5.1 Conventional central controllers

Central controllers are commonly used to provide the generation system with setpoints for supply temperature levels of heating and/or cooling carriers (see fig. 1). Since the associated distribution system stretches out to the entire building, these temperatures should preferable suite the whole range of demands within the conditioned zones simultaneously. A common conventional approach is to use an open-loop structure where the output explicitly is determined as a function of the OAT, such that a decreased input is met by an increased output and vice versa. Even though an understandable choice, because the entire building is affected by OAT variations, there might be several more or less influential disturbances that are not accounted for using this approach.

A relatively common way of improving the performance of the controller type is to incorporate additional features and/or more process information - without changing the overall principle. For example, measuring representative room temperatures means that the supply can be adjusted accordingly, in order to fit local needs more precisely via feed-back. Another method is to employ time-scheduled control that varies according to a predetermined pattern. In this way, distinctions can be made between e.g. day and night in office buildings to employ relaxed comfort constraints during commonly vacant periods. It is furthermore possible to utilize information about other disturbances with a presumed or known impact on the indoor climate (such as solar radiation, wind etc), along with the OAT in the open-loop.

5.2 Conventional controllers for integrated room automation

Controllers for integrated room automation are employed to adjust the supply of heating, cooling and/or ventilation in a certain space of a building. The absolutely most common type is feed-back, whose main task is indirect compensation of indoor climate disturbances by maintaining a constant (or periodically constant) set-point.

In figure 2, a principle block-scheme of a typical feed-back is illustrated. Control signals (uc) are generated by processing a control error (e), which is formed by comparing measured (or actual) values of the controlled variable to a set-point (y respectively r in fig. 1). Different controller variants are enabled through a selection of three basic control error processing modules, referred to as Proportional- (P), Integrating- (I) and Derivative- (D) actions. The following text focuses on the three most common combinations: P, PI and PID, whereof the PI primary was considered in this work. As all three modules are included in figure 2, the illustrated example is a PID while other variants could be formed by simply removing either the D- or/and the I-action without changing the overall structure.

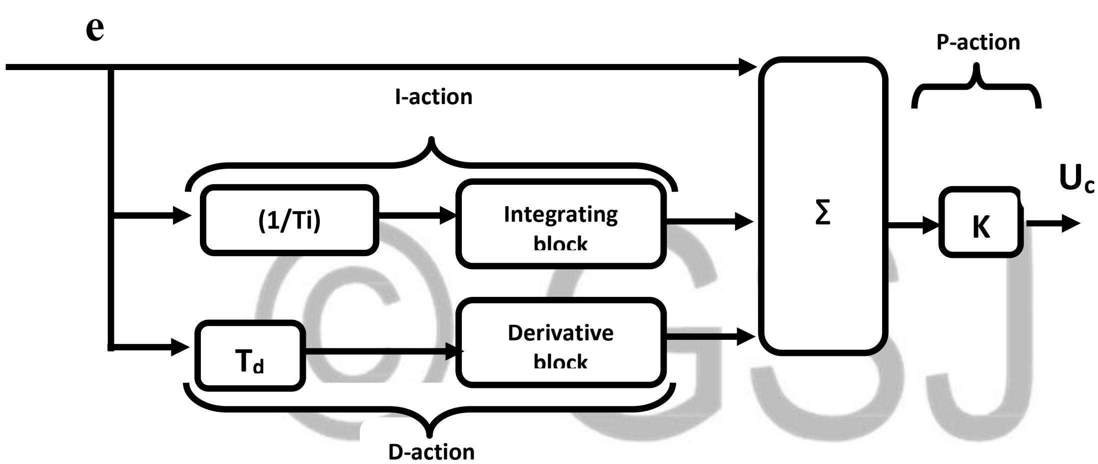

Figure 2. Schematics of a feed-back controller.

5.3 Model-based controllers in general

Any building is constantly affected by intermittent disturbances of external and/or internal origins which together determine the required amount of heating, cooling and ventilation for maintaining a desirable indoor climate. The variety and impacts are primary dependent on the type of building, the activities within and on the ambient conditions. For example, in modern offices with tight and well insulated envelopes, people, lighting and equipment are dominating during office hours, while the ambience then is of minor importance. Vice versa, the OAT will be decisive for the annual heating demand in residential buildings that are located in regions of cold and temperate climates.

In contrast to conventional BASs that primary act on set-point deviations, model-based controllers can be used for an increased adaptation to prevailing conditions. For example, conventional BAS are commonly associated to considerable lags, and are primary capable of maintaining a desirable indoor climate during fairly constant conditions. In turn, mismatches between supply and demand typically occur for more varying disturbances, with a decreased indoor climate quality and/or an increased energy usage as a consequence. On the other hand, model-based controllers can in theory achieve a lag-free routine, with instantaneous and perfect responses to every registered change. Moreover, while conventional BASs are divided into a large number of individual controllers that are locked to restricted tasks, the entire system and every possibility can be taken into account by model-based. For example, the HVAC operation can be optimized to minimize the usage of energy at the same time as free or low-cost sources are prioritized by incorporating information about spot-prizes.

5.4 Model predictive controllers (MPC)

Several works that had identified model-based controllers as a promising technology for building automation were cited earlier in this paper. The absolute majority considered a type called MPC (Model Predictive Controller), whose most characteristic features is that the control procedure is formulated as an optimization problem. Typically, information about indoor climate disturbances and present state of the controlled variables is provided to a detailed and accurate dynamic control model. From these sets, the future behaviour of the process is predicted over a predetermined time-horizon, while an algorithm searches for future control signals that fulfil some given criteria; such as minimizing energy usage while maintaining comfort (Yu & Loftness, 2013)

Given the extensive control model, the optimization algorithm and the prediction features, MPC is obviously a complex technology and not realistic for considering in typical buildings without major retrofits. Further, the design is more or less locked by its characteristic features and the margin for a reduced complexity is therefore limited. On the other hand, the benefits of MPCs are enormous, and were considered as a main motivation to this work, while acknowledging the need for simpler and more standardized solutions. MPCs have therefore been used as reference cases in several of the appended papers and the following section provides an extensive review about the general concept.

An MPC controller can both be designed with an open- or feed-back structure. The only input to an open-loop MPC is the initial state (information about where the process starts from) and the solution is a complete sequence of control signals over the considered time-horizon. Since the solution isn't updated along the way, the control model has to describe the process perfectly within the current range of operation in order to avoid a non-optimal process trajectory.

In the area of indoor climate control, most previous publications considered a type of feed-back MPC referred to as a receding horizon controller (RHC). By measuring the present state, the optimization problem is solved over a long but finite time-horizon. However, only the first step of the resulting control signal sequence is implemented. The time-horizon is then moved forward and the procedure is repeated until the system has converged to the final state at time N. Thus, the solution of a RHC is an open-loop control signal sequence, but since the calculation is performed in each time-step for the present state, the overall behaviour corresponds to an MPC with feed-back function (Borelli, Bemporad, & Morari, 2010). An RHC has some benefits which make is especially suitable in building automation applications, but one aspect must also be considered as potentially problematic.

Since the present state is measured at each time-step, an RHC is robust to disturbances and modelling errors, and both stability and persistent feasibility can furthermore be explicitly guaranteed. On the other hand, one of the main issue of the RHC design process is to determine N so that these desirable features are inherited. For computational reasons, N should be kept small, but must at the same time be sufficiently large for the process to be able to converge to the final state (Prívara, Siroký, Ferkl, & Cigler, 2010)

6.0 Conclusion

In order for humans to occupy indoor spaces, the thermal comfort plays a crucial role. Cultural and personal experience could have an effect to human comfort experience. Duration of stay in one climate condition also affect the human adaptation to the level of comfort this is known as adaptive comfort model. Important factors to create building thermal comfort are air movement, air velocity, temperature and humidity. Three ways of heat transfer, conduction convection and radiation, are involved the heat flow to the building. An ambient air draws by the chimney to the ceiling and also flows into a building openings, windows and doors, this causes a movement of air and benefits the natural ventilation.

The influential factor affecting the building energy consumption is the building envelope, especially the selection of materials and design, and also the surroundings such as plant and vegetation to benefit the natural ventilation. Other important factors include the efficient lighting, heat ventilation and air conditioning (HVAC) systems. The building envelope, cooling system and appliances should be carefully considered in the design of buildings, particularly in tropical climates. The climate has an important effect on the selection of a suitable technology for building such as a cooling system and high efficient appliances. Finally, thermal comfort should be achieved at low building energy consumption where natural ventilation is based.

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