Process Control on Workplace Level – User Comfort Energy Optimalization

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ABSTRACT

Utility building developments in the near future face two mayor challenges. These challenges are closely related. The first one is the pressure to reduce the amount of energy needed to acclimatize the building and the second is to increase the comfort level provided by the building. These two problems can be solved by the implementation of Individual Comfort Systems (ICS). An ICS should be able to assess the comfort state of the occupant at the desk and able to act upon upcoming discomfort. But to really reduce energy load of the building, the challenge of providing the best comfort for all people present in an office is a combined effort between ICS and building climate installation. The system should cooperate in a multi-agent system within a nano grid, connected to a micro-grid on building level and eventually to a Smart grid. This way, comfort demand is matched directly to energy supply in a multi-agent system, making the most effective use of available resources. The article provides an literature overview and ideas for further research.

INTRODUCTION

In 2011, a plan of action for energy reduction in the built environment was presented by the Dutch Ministry of the Interior and Kingdom Relations in which a number of agreements made to reduce the environmental impact of buildings were summarized (Anon 2011). Two agreements are of interest for office buildings. In the “More with less” agreement in 2008, the building sector and the government agreed that 3.2 million buildings in the Netherlands will be made 20-30% more energy efficient before 2020. In the “Lente akkoord” (Spring agreement) in 2008, the sector agreed to an improvement of energy performance of newly built buildings of 25% in 2011 and 50% 2015 compared to the Building Code of 2007. The countries of the European Union agreed upon a combined effort to reduce CO_2 emissions of 20% in 2020 compared to 1990 overall. In the rest of the world the trend towards more energy efficiency and reduction greenhouse gas emissions is similar. These agreements and the pressure to reduce costs are the reasons that nowadays reduction of energy use plays a prominent role in the design of new buildings as well as facility management of existing buildings.

In Europe within the European Union KP7 framework there are projects like GreenerBuildings which developed a recognition system that performs indoor activity recognition (GreenerBuildings 2012). The Smart Energy Efficient Middleware for Public Spaces (in short, SEEMPubS) aims at raising users’ awareness of energy consumption in public spaces and at involving the users themselves in the global process finalized to achieve the main objective, i.e. energy efficiency (SEEMPubS 2012).

The Knowledge-based energy management for public buildings through holistic information modeling and 3D visualization (in short KnoholEM) project’s main aim is the engineering of a holistic intelligent energy management solution is based on knowledge representation technologies (KnoholEM 2012).

The Energy consumption prediction with building usage measurements for software-based decision support (in short, EnPROVE) project approach is based on the monitoring of the building usage by a wireless sensor network to build adequate energy consumption models by monitoring building usage which can be seen as looking at users (in particular, user behavior) (EnPROVE 2012).

The Positive Energy Buildings through Better Control Decisions’ (in short, PEBBLE) Project is about utilizing harmoniously and most effectively all installed systems in a building, taking into account human factors and adapting the decisions in (almost) real-time as and when uncertainties occur. The building architecture considers a building (renewable sources, passive systems, HVAC systems, and users) that interacts with control-decision and optimization tools through an adequate networking/communication infrastructure (PEBBLE 2012).

Although considerable energy reductions have already been achieved with focus on only the energetic properties of building shells, end of this road could be in sight. Further reductions could lead to a decrease in comfort level of the building occupants. New concepts for comfort have to be developed to be able to achieve all the goals stated above.

The most important research on thermal comfort was carried out by P.O. Fanger in the late 1960's (Fanger 1970). He constructed a system based on the Predicted Mean Vote (PMV). On the PMV/PPD model is the basis of the most important indoor climate standards in Europe, ISO 7730-2005 (ISO 2005) and America, ANSI/ ASHRAE Standard 55-2004 (ANSI/ASHRAE 2010; Olesen & Brager 2004).

When using the PMV-PPD system however, installations of buildings are designed with 20% of the occupants at any time in lower then optimal comfort conditions. Comfort of office buildings occupants is closely related to their productivity (Lan et al. 2011; Leaman & Bordass 1999). A decrease in comfort level leads to a decrease in productivity, which is costly to a company. When the focus of both the building sector and the facility management is on energy reduction rather than occupant comfort, than it is most likely to push the boundaries of thermal comfort. But the saving in energy costs of compromising thermal comfort will be lost hundred-fold in loss of productivity (Kosonen & Tan 2004).

The two problems explained above can be addressed by using Individual Comfort Systems (ICS). To further develop this type of system, the Process Control on Workplace Level project was started. Such a system acts to increase the comfort level of one person at one desk on top of a base level comfort provided by a room level system.

Using an ICS is more energy efficient as well, because the climate in the room can be controlled within a much wider temperature range, the individual climate is only controlled when people are actually present at the desk instead of for the whole room at once. Placing the climate systems close to the person, makes the energy transfer more efficient. Recent scientific studies show that significant amount of energy savings can be achieved: an experiment of the later carried out under laboratory conditions proves that an additional savings of 25% is achievable (Van Oeffelen et al. 2010) when individual heating is applied in workplaces based on user needs as compared to lowering the overall temperature of the building during heating season.

Since the ICS is an add-on to the current building installation, and it functions within a room, the boundary to the area where the ICS works and where the room level system needs to take over is not clear. To function in the most optimal way, without a rebound effect, the ICS and the room level system need to cooperate in fulfilling the occupants' comfort demand. Up until a certain point, the building can be free running and the ICS can compensate for the slight difference between the room and the demanded temperature. But when the demand gets bigger, it might be more efficient to heat or cool the entire room using the economy of scale of the big system.

Within this project, possible process control strategies will be studied that could be implemented in a control module on workplace level to manage and reduce the energy demand using two way communication and coordination with the Building Energy Management System (BEMS).

THERMAL COMFORT IN BUILDING CLIMATE SYSTEMS

In buildings nowadays, the design and control of the indoor climate is based on the work of Fanger, connected the local environment directly to the subjective thermal sensation of people. Later models and control strategies are based upon that. The adaptive model for example (van der Linden et al. 2006) included the added effects of the outside environment (which includes changing clothes and psychological adaptation).

Predictive Control

By using a predictive approach to the thermal comfort need profile of occupants the individual perceived thermal comfort and the future energy use can be predicted better. Therefore the individual thermal comfort needs of the occupant should become the leading new approach for predictive process control of HVAC systems (Yu et al. 2007). Predictive control is widely adopted for optimizing building behavior to save energy and improve comfort, however this does not include the predictive comfort preference of the building occupants . Occupants are normally represented in the design of a HVAC system by Fanger's comfort model. An increasing volume of research shows that dynamic thermal perception and adaptive response is significant for occupants' comfort (Schwede 2007). While Fanger is criticized for using the 'standard' occupant with defined clothing and activity level, most adaptive comfort research uses the 'statistical' occupant (van der Linden et al. 2006) under static conditions with statistical clothing and activity levels derived from the statistical analysis in large databases. In both cases, the individual occupant for whom the specific environment was designed was not considered.

Even when all requirements are within the given range, the resulting actual climate can turn out differently. The thermal environment in an office is not always optimal from an energy saving and occupant satisfaction perspective (Murakami et al. 2007). For example some occupants feel cold in an office where air temperature is controlled based on thermal standards such as PMV and ISO 7730 (Murakami et al. 2007). The main reason for this issue is that air-conditioning systems are controlled without taking the occupants' needs into account. This was also pointed out by field surveys carried out by (Leaman & Bordass 1999; Leaman & Bordass 2001)

Individual Differences

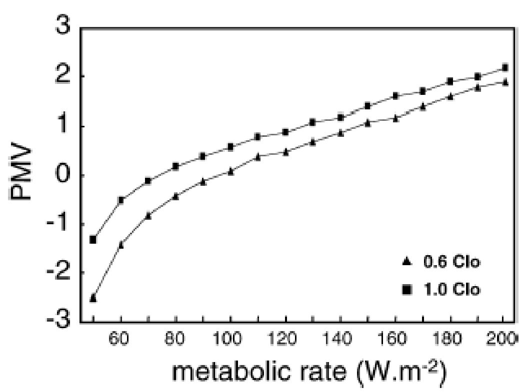
All these things are indirectly relating measurable parameters, like inside and outside environmental factors, but this is still an approximation based on a large group of people. That will only lead to a maximum percentage of satisfied building occupant.

While clothing of men in office buildings during the year only slightly changes, the women dress more according to the outdoor climate. Experiments show that the clo-value can even be 0.3 for women in summer (Darmawan 1999). This experiment show that in one office, the clo-value can vary between 0.3 and 0.8 clo. Fig. 1A shows the PMV as a function of metabolic rate and clothing value. It is shown that a large difference can be seen, especially at low metabolic rates. This figure emphasizes that difference in clothing results in a large spread in PMV-rating. In one office, comfort temperatures can vary from 21 to 26 ^{o}C, considering different clothing values. This is also shown in Fig.1B. The figure shows the dependence of dissatisfaction on the room temperature in relation to the type of clothing (Fröhlich 2004). That is why personal factors and clothing are important aspects.

user is already uncomfortable. And lack of knowledge and inexperience could lead to an even more uncomfortable situation and also to excessive energy use. Unfortunately, the necessary precision for control and efficiency was not achieved. New technological processes are therefore necessary based on these new scientific insights

Physiology and Individual Control

The closest we can get to the thermal sensation, which is used as an indication of thermal comfort, is to measure the response of the person's thermoregulatory system. The thermal neutral zone is defined as the range of environmental temperatures where a person does not desire a higher or lower temperature. The thermal neutral zone and the small dissipations from there can be defined as the range in which the thermoregulatory system does not have to take drastic measures to compensate for the lack of environmental comfort. The thermal comfort zone is somewhat wider then that depending on other environmental parameters like radiation and air velocity. Mild cold is sometimes found to be stimulating and a higher air velocity is regarded as comfortable at a higher temperature. The response of the thermoregulatory system can be detected. In a colder environment, vasoconstriction leads to a reduction in skin temperature of the fingers, toes and nose and vasodilation leads to a higher mean skin temperature which eventually leads to sweating and lowering of the skin temperature in the places where sweating is most effective.



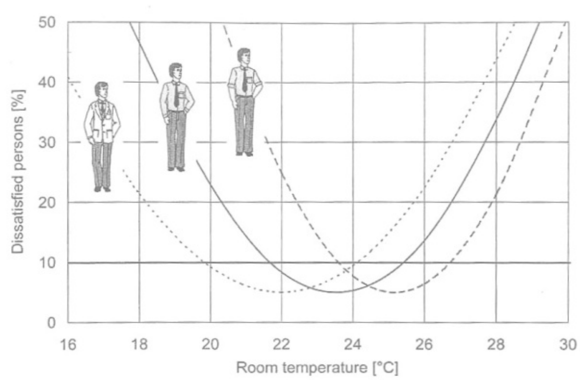


Figure 1: (A) PMV as a function of metabolic rate (air temperature 22 oC, air speed 0.15 m/s, air pressure 1 kPa) (Havenith et al. 2002), (B) Dependence of dissatisfaction in relation to clothing (Fröhlich 2004)

Previous ICS systems had either constant or user operable controls. For the user, this requires some knowledge of the system and the actuators. Whether and how the user will interact with the system is dependent on the type of user (Haldi & Robinson 2008), but it will happen mostly when the

When these responses of the user can be monitored remotely by a local climate control system, the input can be used for determining the current state of thermal comfort. This could in than be used as an input for the system to decide on a way to mitigate the upcoming problem, even before the user is consciously aware of the discomfort.

For detection of cool discomfort, the reduction in skin temperature of fingers and nose can be detected using a thermal image from an infra-red camera. This concept is proven by (Vissers 2012; Zhang 2003; Alahmer et al. 2011; Turner et al. 1996).

For the warm discomfort, little is known of the exact mechanism of vasodilation and onset of sweating. There is reason to believe that onset of sweating happens within the thermal neutral zone, already leading to dropping of skin temperature, for example on the forehead. This concept however is not yet proven and the effect might be too small to measure with certainty from a thermal image. The onset of sweating is another indicator, measured in laboratory condition by either skin conductivity or sweat rate in a ventilated tube. The first method is dependent on skin health as well as psychological factors (in certain places, sweat response is more responsive to psychological rather than thermoregulatory factors, those are used in lie detector tests among others), but is cheap and fast. The second method is very precise, but requires a large and costly device. The disadvantage of both is that detectors have to be placed on the skin directly, which is okay in a laboratory setting, but considered too much of an invasion of private space in an office environment. A remote detection method is considered, but no results can be reported at the moment.

INDIVIDUAL COMFORT SYSTEM LAYOUT

Manipulating the local environment directly around an office worker can be very effective from both comfort and energy perspective. The elements within such a system are shown in a schematic in figure 2.

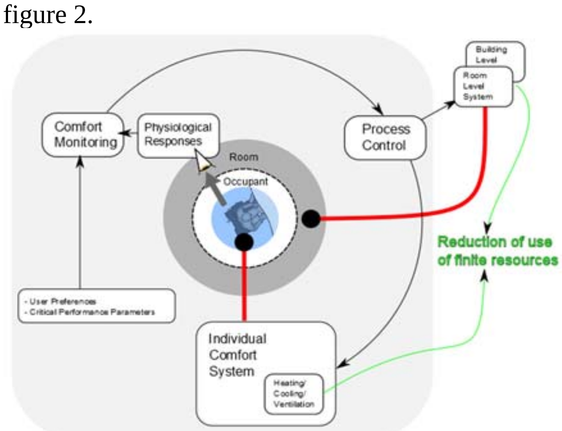


Figure *2*: Lay-out of ICS including subsystems

The system consists of actuators for creating the micro-climate, for example by heating, cooling and ventilating. The actuators are operated by a system that takes into account some of the physiological responses of the human body that indicate upcoming discomfort as described in the previous section, as well as the preferences of the occupant himself. For the most effective operation, the local system is connected to the building's climate installation, so the mitigation of discomfort of every individual occupant can be coordinated and managed. The project Process Control on Workplace Level (PCWL) aims to achieve further reductions in energy consumption within commercial buildings by making this innovative approach practically applicable. These subsystems are explained more extensively below.

<u>Actuators</u>

Some systems for actuation were tested separately. Radiation panels for heating and cooling are studied extensively (Filippini 2009; Van Oeffelen et al. 2010), as well as systems for personal ventilation (Filippini 2009; Melikov 2004; Melikov et al. 2002). Personal ventilation increases the amount of fresh air in the breathing zone substantially, which could also be used for reducing the ventilation demand, even when increasing the air quality in the breathing zone (Dalewski et al. 2012).

More extensive systems, using combinations of multiple elements were also tested. The most notable among these is a system using a palm and foot warmer, a hand cooling device and a ventilation system aimed at the head (Zhang et al. 2010) and a system with heated radiation panels on the floor and under the desk, a heated chair (conduction) and a ventilation system blowing from under the desk and from the top of the monitor aimed at the face (Watanabe et al. 2010).

Panels for heating and cooling that are situated at some distance from the occupant have only limited effect and seem to be quite energy intensive (Vissers 2012). A more promising method was found in radiation lamps on the hands. The radiation heats up the surfaces, but also the hands directly, working from both sides. This and the fact these are faster and better directed at the required spot then for example a mat under the keyboard makes this is system worth of further investigation. The system as is proposed consists of local heating and ventilators for cooling and increasing of ventilation effectiveness.

WORKPLACE CONTROL

The system is to be controlled via a smart system that is capable of interpreting all the information on the current state of individual comfort. The system then negotiates with other systems in the same room and the building climate system to get to the best solution to provide comfort. The interpretation of the comfort indicators is based on the application of a thermo physiological model, ThermoSEM (Kingma 2012; Schellen 2012; Schellen et al. 2013). This model will be further extended.

When the mode of actuation is known and the state of thermal comfort can be estimated from the monitoring of physiological indicators, these to need to be connected and the whole system than is to be integrated in the building. In Fig. 3, the main comfort advantage of ICSs is shown.

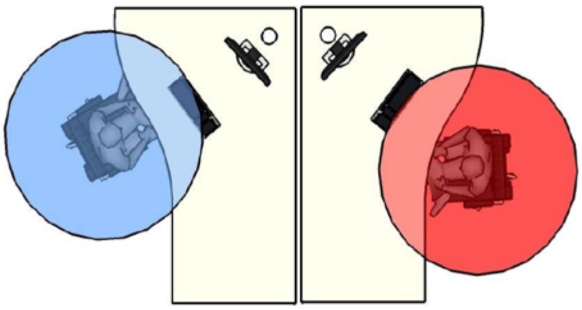


Figure 3: The ideal situation at workplace level, occupants can select their individual preference: one person likes it a little warmer the other person a little colder

The process control in an ICS should be able to operate autonomously, but the real advantage comes in the connection to the Building Energy Management System (BEMS). Current BEMSs are not capable to focus on dynamic changes in supply to perform intelligent functions or show adaptive behavior in changing circumstances (Dounis & Caraiscos 2009). Recent scientific studies show that significant amount of energy reduction can be achieved with the use of Individual Comfort Systems (ICS).

SMART GRID SYSTEMS

Smart grids are a plan for the future of energy distribution. The idea is based upon the inclusion of renewable energy sources at different levels in the system. At the moment, the electricuity grid is build up as a top – down system in which the electricity plants are at the top, distribution in the middle and use at the bottom and at intermediate level for industrial applications. Renewable energy sources usually are not able to match the big gas fired, coal fired or nuclear plants in terms of power and voltage output. They have to be connected at intermediate (wind farms) or low level (building bound Combined Heat and Power (CHP) systems or photovoltaïc (PV) panels. To make the most use of the available energy at all levels in the grid system, the system is made smart, in that, information from all levels is combined.

User behavior is the key to profit which can occur in the whole energy system (production, transport as well as consumption) (Blom et al. 2012). Essential in the notion of Smart Grids & nanoGrids is the occurrence of a two way communication between energy consumers and energy producers. The proposed system, with connections from nanoGrid up to Smart grid is illustrated in Fig. 4

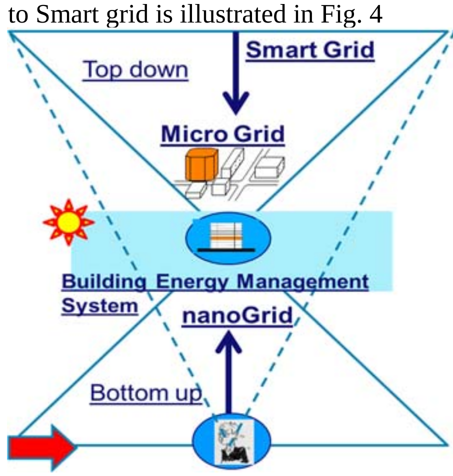


Figure 4: From Nano Grid to Smart Grid

The inclusion of ICT to the existing BEMS makes it possible to better manage, guide and control the energy flow. As the customer is the key, we in our research try to get as close as possible to the real needs of the customer/occupants on workplace level.

A new kind of BEMS can be developed that can be connected to this system. Such a new BEMS offers new opportunities for reduction of the energy consumption. As the new technology which is intended to be developed is more decentralized on workplace level it can be used in most of the existing offices. This means that there is a huge potential for application, which can results in a major reduction of the energy demand within the built environment. The necessity of an integrated intelligent building management system where all the critical performance indicators for energy consumption and perceived thermal comfort can participate as parameters in the process control.

Energy management within buildings becomes more important and should dynamically optimize the process control of the HVAC systems within a building. The application of Smart Grids is one of the important technological strategies to achieve the goals of energy reduction. It enables a more optimal integration of the renewable energy and also leads to a higher efficiency of the energy distribution and thus to less CO_2 emissions.

MULTI-AGENT SYSTEM

A hierarchical functional decomposition approach will be used to structure the energy infrastructure of a building (Zeiler & Savanovic 2009). This approach is illustrated in fig. % and makes it possible to study the energy flow connected to comfort (heating, cooling, ventilation and lighting) and energy demand within a building on the different levels of hierarchical functional abstraction. This also enables a closer analysis of the energy demands on specific levels enabling the building of a more detailed process representation of the energy demand of the whole building with emphasis on the workplace level.

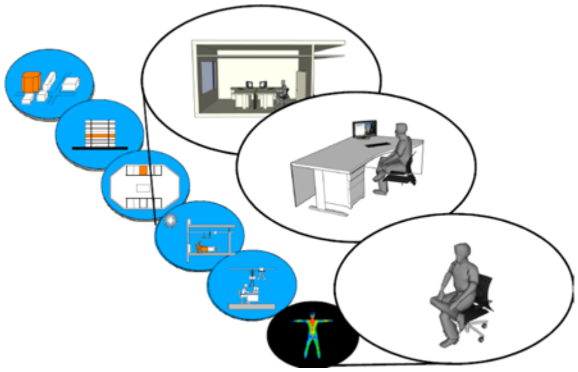


Figure 5:Hierarchical functional decomposition of the built environment with focus on room level, workplace level and individual level

This modular system approach on building level forms the basis of defining different agents within the common hybrid agent platform for the process control system. By making a coupling with the BEMS of the building all the necessary data will be made available to investigate the behavior of the process control strategy compared to real historical data of before the intervention.

Multi agent systems are used for many different tasks in the built environment (Dounis & Caraiscos 2009; Klein et al. 2011)[Lee 2010, Ramchum et al. 2011]. These systems rely on integration with facility systems and applications, however up to now most applications are still in the development stage, based on simulations and without integration with the BEMS. Our approach will include real time actual energy consumption in buildings and optimization of the interaction with the Smart Grid. It will address novel scenarios that requires agents to negotiate with groups of building occupants as opposed to previous works which focused on agent's negotiation with individual occupants(Kwak et al. 2012).

In analogy with the approach that will be used in related to other PhD projects (PRCL: Development of a Micro grid strategy for Process Control on Room Level & Smart grid – BEMS: the art of optimizing) and the approach presented by (Yeh et al. 2009) will be used, which consists of a protocol stack with the following layers:

- User layer: defines how a user can access the system through the user interface
- Service layer: defines the rules by which the system provides and manages its services
- Profile layer: maintains all profiles for users, sensor nodes, power-line control devices, and rules
- Sensor layer: controls the actions of sensor nodes
- Actuator layer: provides an abstraction of electrical appliances to upper layers

FURTHER RESEARCH

In this research, an individual comfort system is developed. The focus is mainly on the process control level. Based on the abstract representation of occupant and workplace and room, the influences of different characteristic parameters for comfort and energy consumption are determined on workplace level. In a rapid prototyping approach, process control modules for the different functionalities will be implemented on top of the existing BEMS process control of the Kropman office in Breda. Some of these measurements will provide the data and information for this project as well about;

A. Occupancy
B. Energy use for HVAC systems
C. Energy use of electrical appliances
D. The energy demand for the Smart Grid
E. The energy offer by the Smart Grid
F. Actual weather conditions and weather predictions

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