Occupant-oriented energy control by taking the human in the control loop of building systems

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ABSTRACT

A novel approach is presented for building comfort control, focused around the occupant. The user influence on building performances increases when we built our buildings less energy demanding. Therefore optimizing the energy efficiency without taking the user into account is not going to be very effective. In the presented bottom-up system approach, the user is the leading factor in the building by taking control of the building services. Custom sensing by smart sensors makes it possible to measure the position of the occupant in the building and to distribute the energy to those spots where needed. As a case study, we monitored, at the 4th floor of an engineering company, the positions of the building occupants and the most important user actions on building performance, electrical appliances. Applying a building model in HAMBase showed great improvements in the reduction of energy usage as a result of a user-centric energy control system, while maintaining the comfort level.

INTRODUCTION

In the Netherlands, the energy use in the built environment accounts for nearly 40% of the total energy use. Most of this energy (nearly 87% for non-residential) is used for building systems with the goal of providing comfort for the occupants in buildings. The perception of comfort in the indoor environment is a complex process consisting of several aspects like physical wellbeing, privacy, acoustics, visual comfort, air quality, materials, ergonomics, spatial design etc. Complaints about thermal comfort are the most common complaints in office buildings.

In practice, the intended comfort level and energy performance of the building design are mostly not achieved, resulting in higher energy use, more sickness absence and lower productivity of the building occupants. The reasons for the inferior performance of the building systems are diverse and are mainly located in the field of applied technologies and insufficient attention to the influence of occupant behaviour, while the latter one is of great importance [1]. Occupant behaviour is the adaptive actions of the occupants, in response to discomforting environmental stimuli, in an attempt to restore their comfort [2]. The great importance of user behaviour on building performances is also stated by Hoes, who concluded that the influence of user behaviour on building performance increases when we built our building more energy efficient [3]. As a result optimizing the energy efficiency of the building without taking the user into account is not going to work [4].

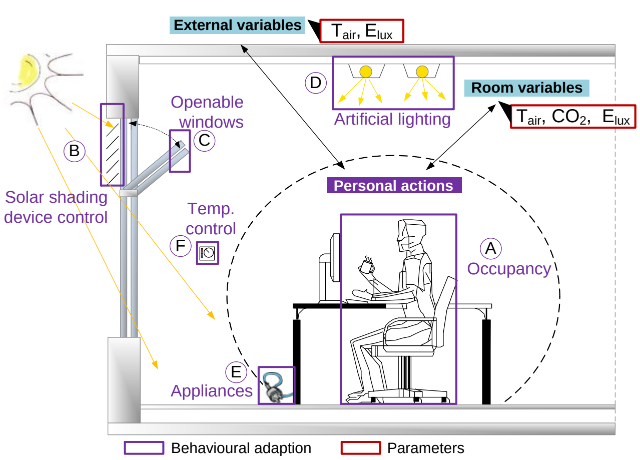


Figure 2 Personal actions of the building occupant and physical parameters influencing the comfort level of the building occupant

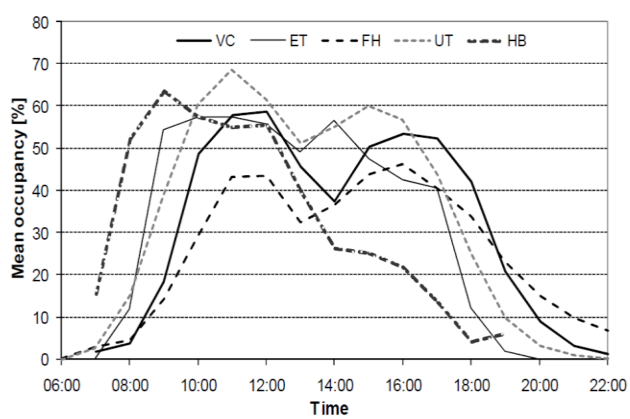


Figure 1 Mean occupancy level for a reference day. VC: International organization (Vienna); FH: University (Vienna); ET: Telecom. services (Eisenstadt); UT: Insurance (Vienna); HB: State government (Hartberg) [Mahdavi, 2008]

An important factor in the field of user behaviour is the presence of the occupants within the building. It was observed that workplaces of office buildings were not occupied for a large percentage of time [5]. Figure 1 shows the extracted behavioural trends for groups of building occupants from long-term observational data. These values represent the presence at the users' workstations, not merely the presence in the building. The problem here is that patterns obtained from one building cannot be transposed to other buildings without extensive calibration measures, considering differences in buildings' use, context, systems, etc. [6].

Parys divided the research towards user behavioural into six fields, shown in Figure 2. Occupancy can be considered as one of the research fields in user behaviour. Because, being present within the building is clearly a necessary condition to interact with it. The other research fields are the control of solar shading (B), window deployment (C), control of the lighting (D), the use of electrical appliances (E) and the control of the thermal environment (F) by the occupant. This list is not exhaustive as it is restricted to actions that change the environment and thus influence the building's energy demands [7]. Other adaptive actions like adjusting clothing, having a drink or changing the activity level, better known as personal or intermediate actions, are not included. Interactions with the buildings' environmental systems are difficult or even impossible to predict at the level of an individual person [6]. The building occupant performs these control actions to improve his personal comfort level. Removing these possibilities from the building occupant to influence his environment is not an option, because the ability to self-regulate his environment are critical factors for satisfaction of the occupant [8].

HUMAN IN THE LOOP APPROACH

Recent developments regarding thermal comfort and occupant behavior in the built environment is discussed using the bottom-up approach. Based on this approach the human is the leading factor in the design and control of HVAC systems. Nowadays the user is not central in the design where building systems are mainly controlled on building level with (limited) possibilities for adjustment of the indoor conditions on floor and room level. Hereby the considerable differences in thermoregulation between individuals are not included in the HVAC control [9].

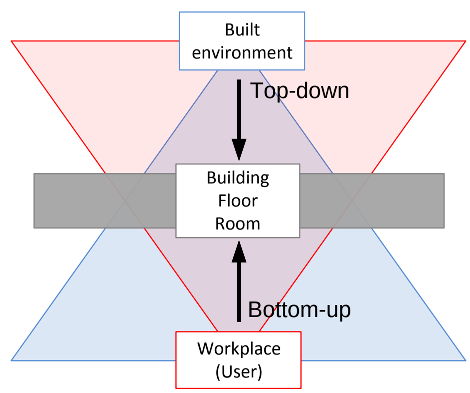


Figure 3 Traditional top-down approach for building system design and new introduced bottom-up approach with the human as leading factor

This bottom-up approach focusses on the well-being of the individual and the energy demand for optimal comfort of the individual. The energy for providing comfort needs only to be sent to those spots in the building where needed.

To enhance this bottom-up approach a new control strategy is introduced where the human is taken into the control loop of the building services systems to enhance a more direct and better interaction between technological systems and the human being. The goal of obtaining comfort conditions and simultaneously energy conservation in a building is reached by the application of intelligent control systems [10]. Intelligent control strategies need to be developed, where it is important to monitor the individuals in the building. With energy efficient buildings the relation between behaviour and energy consumption has become significant, and should be looked into [11].Therefore, it is required to implement the actual dynamic changing individual comfort needs and the behaviour of individual building occupants in intelligent control strategies for building services systems to achieve the highest comfort level and biggest energy savings.

OBJECTIVE

The behavioural research has mainly been focused on residential and office buildings. Here, only the applications within office buildings are considered. The aim is to determine the possibilities for sending the energy to those spots where needed for the provision of comfort by localization of the occupant in the building. Therefore it is needed to determine if it is possible to localize the occupant, with minimal or no hinder for the building occupant. When the occupant is localized, only his location needs to be conditioned optimally. The non-occupied spots of the building can have low demands regarding the indoor climate. In this research the energy saving potential is determined when energy is sent to those spots where needed. The proposed principal is presented in Figure 4. This figure shows how the building occupant could be leading in the system control, applying the individual preferences by measuring the occupant position and behaviour. In order to control the operation of building systems an intelligent supervisor coordinates the system [12]. The input signals are diverse, including the user position but also other external variables like weather data. The intelligent coordinator makes its decision and sends acknowledge signals to the individual building systems. To apply the individual preferences while maintaining the comfort level, individual controlled systems with local HVAC options show high potential, as developed in recent research [13, 14].

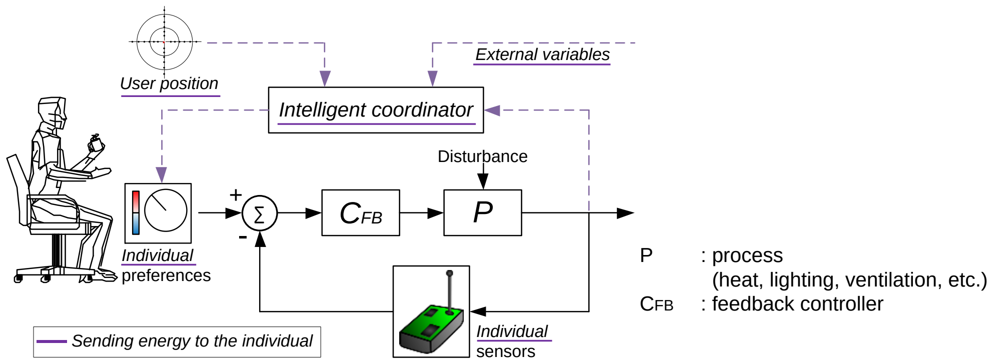


Figure 4 Proposed block diagram of the controlled system, the controller-agents, and the intelligent coordinator for taking the human in the control loop of building systems

Finally, the occupant behaviour from workplace to building level needs to modelled, to investigate the influences of this model on the resulting energy and comfort performances of the combination building- and occupant behaviour. Therefore a new approach of building simulation will be proposed.

METHOD

By taking the human in the control loop of building systems it is possible to apply the bottom-up approach with the human as leading subject in the built environment. To accomplish this, the building occupant needs to be measured and monitored.

This research used a case study to capture data from a real situation without making assumptions for building and user behaviour. The measurements were performed on the fourth floor of Royal Haskoning, an international engineering company in The Netherlands, Rotterdam (Figure 5).

A

Properties	
meeting room	(yellow)
open-plan office	(red)
corridor/staircase	(blue)
cell office	(green)
Year of completion	2006
Floor surface	ca. 500 m^2
Employees	ca. 35 persons
Type workplace	flexible office space
Type of work	computer / desk work, design, calculation
HVAC system	district heating, cooling machine
room conditioning	induction unit
HVAC control	room level

B

C

Figure 5 Floor plan of the case study floor (A) with the important properties of the floor (B) and a picture of the building from the outside (C)

An analysis was made to determine the most influencing building parameters and user actions on the case study building performances. Via a walkthrough survey, consisting of interviews and measurements during a week, the magnitude of the different user actions were determined. The observed data was converted to yearly data, determining the influence on the energy use of the HVAC system for this fourth floor. The results are presented in Figure 7 where it is shown that artificial lighting and appliances have the highest influence on building energy demand. For validating these results a simulation was made using VABI Elements, the most common Dutch software tool for building energy performance analysis. The building parameters and user actions were varied within a predetermined bandwidth. The sensitivities of these variables are shown in Figure 6. It can be concluded that the magnitude of human influences is much higher than the building parameters, underlining the importance of user behaviour. The use of electrical appliances is the most influencing variable on building performance.

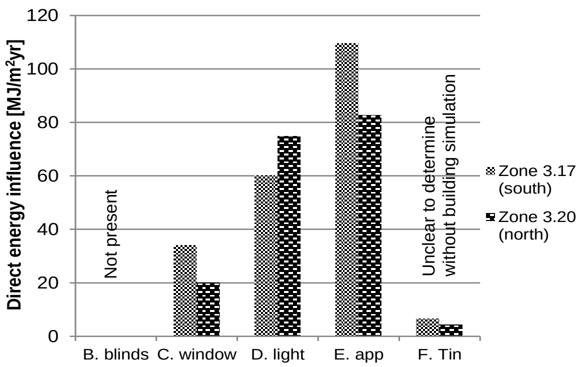


Figure 7 Direct influence of user actions on energy performance per year based on walkthrough survey for a north oriented open-office and south oriented cell office

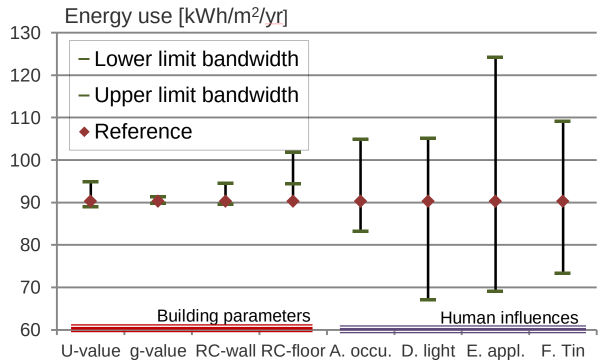


Figure 6 Total energy demand reference year for the sum of heating and cooling within a predetermined bandwidth for building parameters (red) and behavioural adaption (purple)

POSITION

Applying the bottom-up approach, with the human in the control loop of building services systems can only be done if users can be located within the building. Low-budget wireless sensor networks with portable nodes show high potential for real-time localization and monitoring of building occupants [15]. Therefore static wireless sensor nodes were mounted on the walls and communicate with mobile nodes (or in the future smartphones) carried by the occupant to determine the position of the occupant on workplace level. The measurement set-up is schematically shown in Figure 8. An example of an applied static node is shown in Figure 9.

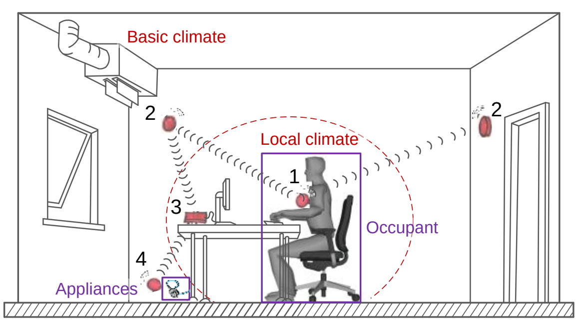


Figure 8 A wireless sensor network (2) tracks the mobile node (1) of the occupant and the energy use of appliances (4) and uses the real-time data for the building system control (3)

Figure 9 Example of a static node that tracks the position of the building occupant by wireless communicating with the occupant sensor

The wireless static nodes for position tracking of the occupants were placed on points of interest e.g. the workplaces, printer, coffee machine and toilet. Based on the signal strength the nodes identify in which zone the occupant is located. Because of the hinder of the signal through hard materials like internal walls, the mesh becomes more accurate by separating the zones (Figure 10).

APPLIANCES

In every zone one power logger was installed, for measuring the energy use and to get an estimation of the heat production in that zone. During the first analysis it became clear that there was not a strong correlation between occupancy and electrical appliances use, because also during the weekend there was an electrical demand by standby appliances. In previous research Parys concluded that the operation of office equipment is obviously not driven by indoor environmental quality motives. Therefore it is more logical to link the ratio of internal heat gains over the nominal power of office equipment to the occupancy rate. Research so far has mainly only focuses on the definition of diversity profiles, which provide averaged relative figures of internal heat gains [7].

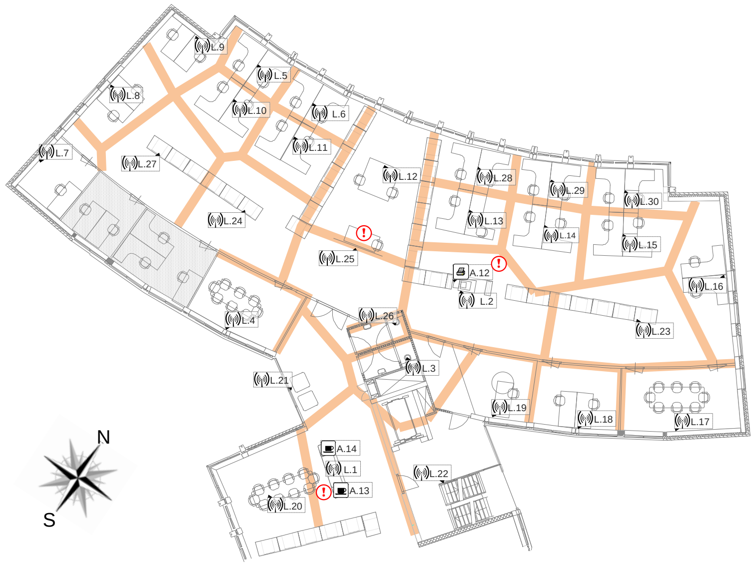


Figure 10 Positions of the static nodes creating a mesh of the zones for measuring the position of the building occupants on the floor. The transition region between the zones is marked by the broad orange line

PRELIMINARY RESULTS

The results of the first measurement period are used for estimating the energy saving potential applying the new proposed bottom-up approach. Therefore the building is modeled in HAMBase, making use of the Matlab - Simulink software environment. Three situations are modelled:

- Energy demand using input parameters as assumed in the design phase of the building systems.
- Applying real data obtained from the measurements in the case study building, using the gained temperature set points, and profiles of electrical appliances energy use;
- Implementing the new approach where energy is sent to those spots where needed, e.g. the positions of the building occupant.

The measurements are during the winter, when there was only a heating demand. The acquired profiles for electrical appliances use and occupancy patterns are also applied in the summer situation. The applied values in the simulation are presented in Figure 11.

Simulation input		A. Design	B. Measured	C. New approach
Appliances		10W/m^2	Measured profiles	Measured profiles
Lighting	Power	10W/m^2	Installed power zone	Installed power zone
	Schedule	8-18hr	Measured profiles	Measured profiles
Metabolism	Power	10W/m^2	1 Met/prs	1 Met/prs
	Schedule	8-18hr	Measured profiles	Measured profiles
T [°C] (heating)	Day	22 (8-17hr)	22 (8-19hr)	If present 22 else 19
	Night	19	19	19
T [°C] (cooling)	Day	24	23	If present 23 else 25
	Night	25	25	25

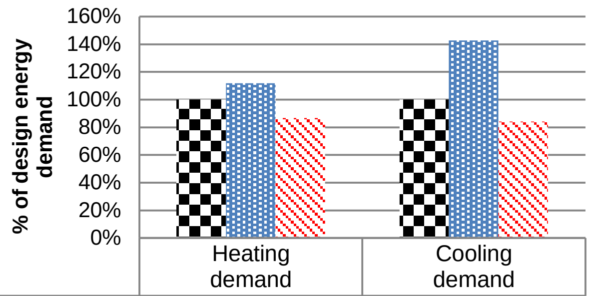
Figure 11 Simulation input data with three different reference data, as the building is designed, the actual profiles as measured in the building and the actual profiles in combination of applying the new bottom-up approach where the energy for heating and cooling is only used where needed.

Both the model based on measurements, representing the actual energy demand, and the new proposed approach makes use of profiles. The model is divided in the zones as shown in Figure 10 having an own measured profile for every zone for the occupancy, lighting and electrical appliances.

Results of the simulation are presented in Figure 12. It is shown that the actual energy use is higher than designed. Mainly the cooling demand shows an increase (+43%) compared to the designed situation. Based on the first data it can be concluded that energy savings can be gained when energy is sent to those spots where needed, especially for the cooling demand.

FURTHER RESEARCH

For better results with higher signification the measurements were continued for several weeks. From the captured data the following can be derived: more data will improve the accuracy of the model for building performance analysis, include the PMV value to verify that the comfort level will be maintained, look if there is a correlation between occupancy (spots) and the use of electrical appliances and verify if occupancy and important spots in the building can be found.



	Heating demand	Cooling demand
A. Design	100%	100%
B. Measured	112%	143%
C. New approach	87%	84%

Figure 12 Results of the HAMBase simulation for the three different situations in both heating and cooling situation. The actual measured energy demand are higher as designed in both situation, while in the new approach the heating and cooling demand is lower

Several methods have been developed to describe human behaviour and how to include it in building performance analysis [4,16,17,18]. However, only a few studies successfully demonstrate energy reduction from real occupancy behavioural patterns that have been determined. New developments in the area of modelling of people, building and installations, uses Archi Bond Graphs and Qualitative Archi Bond Graphs [19]. To include all kind of building subsystems, goods and most of all people, QABGs offer a qualitative and quantitative energy-based unified representation for building design. They can be applied in the conceptual as well as in the intermediate and final design stages. QABGs can represent both static and dynamic aspects of buildings, as well as people's behaviours and building's energy flows. QABG is a promising technology which enables to include the human in the control loop of building systems [20]. Until now no research had the availability of this amount and accurate data as captured by these measurements. With this data it will be possible to make a big step in the development of this new modeling approach with the human as central point of interest.

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