This summary is based on the work of the winner, R.Maaijen, at REHVA student competition in Timisoara during REHVA Annual meeting, 2012. The full length article with the references is available at the journal website, http://www.rehva.eu/en/rehva-european-hvac-journal.

Human centered energy control: taking the occupancy in the control loop of building systems

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Introduction

Traditional comfort control focusses on indoor temperature regulation with a uniform thermal environment. Due to individual differences it is not possible to provide an optimal perceived comfort level to all office workers. In response of discomfort, the building user performs actions to restore his individual comfort. An undesired effect of these actions is that the energy use of the building comfort systems often increases. We present a new HVAC control strategy based on the actual demand and indoor localization of the individual building user. In this way we supply energy for comfort only to those positions where needed. With critical performance indicators we looked for the most important parameter (e.g. human actions and building parameters) on building comfort and energy performances. The objective of this critical performance indicator process control strategy is to reduce the energy demand, while maintaining thermal comfort of the individual building occupant. With our new approach nearly 30% energy savings can be achieved on heating demand and up to 38% energy savings on cooling demand compared with current energy demand.

The satisfaction of the occupants with their thermal environment mainly determines the success of the application of HVAC systems. However, in practice the intended energy efficiency as well as comfort level of these HVAC systems is not achieved, resulting in more sickness absence, lower productivity and higher energy costs. To meet the demand for both a more comfortable indoor environment and building energy savings, it is necessary to implement knowledge of the building user in the building comfort control strategy.

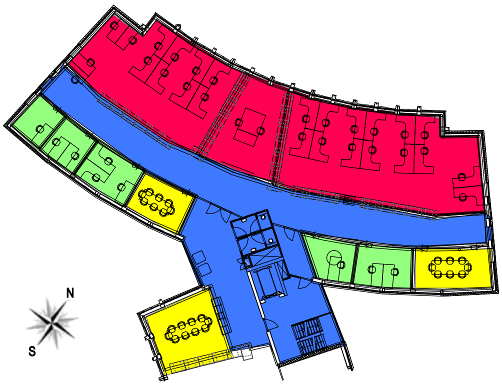
Human in the loop

To achieve the savings it is necessary that the HVAC systems automatically adapts to the actual individual needs. This requires a method where the user with his individual needs is included in the control loop of building comfort systems. Within this research this method is called the 'human in the loop approach'. Literature shows that workplaces in office buildings are unoccupied for a large percentage of time, and differ between buildings [Mahdavi et al., 2011].

The idea is that when the actual need for comfort of the individual building user is addressed, this will lead to reduction of the energy consumption by the building systems. Thereby, the control objective is to look how the individual building occupants use their building and if commonly used occupancy spots can be recognized. RFID technology is proposed for building user indoor locating system, because of its accuracy for location estimation and possibilities for identification of the user [Li et al., 2012].

The case building

The aim was to assess the energy saving potential when anticipating on the human influences by sending energy only to those spots where energy is needed to change the thermal conditions. Therefore the building occupant needs to be included in the control loop of building services.



Properties	
meeting room	
open-plan office	
corridor/staircase	
cell office	
Year of completion	2006
Floor surface	ca. 500 m²
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

Figure 1. 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).

This research used a real building and user's behaviour: measurements were performed on the fourth floor of Royal Haskoning, an international engineering consulting company in The Netherlands, Rotterdam (**Figure 1**).

Low-budget wireless sensor networks with portable nodes show high potential for real-time localization and monitoring of building occupants [Feldmeier and Paradiso 2010]. Therefore static wireless sensor nodes were mounted on the floor 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 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 locate in which zone the occupant is. With the nodes a mesh is created consisting of 30 zones.

Figure 2. Occupancy intensity as percentage of the most occupied workplace, showing two hotspots and increased activity around the toilet, coffee machine and printer.

Results

The measurement results were obtained for six weeks during winter period. During this period most of the occupants of the floor (20 employees) wore a node for localization. The average occupancy of the employees was approximately 40%. Occupancy hotspots can be distinguished as shown in **Figure 2**. The amount of time of occupants being present in a zone is summed over the whole period. There are obvious favorite workplaces and higher occupancy intensities around the coffee machine, toilet and printer.

Appliances

The use of electrical appliances is the most influencing variable on building performance. 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. [Parys et al. 2011]

When the averaged profiles for occupancy and use of electrical appliances are looked into, there is a strong correlation between them with a determination coefficient of 0.94. Looking at workplace level there is no clear correlation. This is proved by **Figure 3** with the occupancy and appliance use for two reference days. Connections are visible, but the appliance use does not correlate with the occupancy.

Energy saving potential

Data of the measurements are applied in a simulation to determine the energy savings potential compared to the designed energy demand. Three variations can be distinguished, B. the actual energy demand, C. send energy to spots only when needed (human in the loop) on room level and D. human in the loop on workplace level with individual climate control. The obtained energy saving potential by the profiles for the three situations is shown in **Figure 4**. The measurements were 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. A sensitivity analysis is established by applying the standard deviation of the different profiles to the model, to ground the reliability of the results.

Conclusions

Big steps need to be made to reach future targets regarding energy consumption and comfort level in the built environment. With increasing energy performances, the influence of the occupant becomes significant and should be looked into. In the used case study the human influence is 3-5 times higher than variations in building parameters. With the human in the loop approach energy is only sent to those spots where needed by localizing the building occupant and anticipating on its influences. From measurements of 20 employees during 6 weeks on an office floor it is clear that occupancy hotspots can be distinguished.

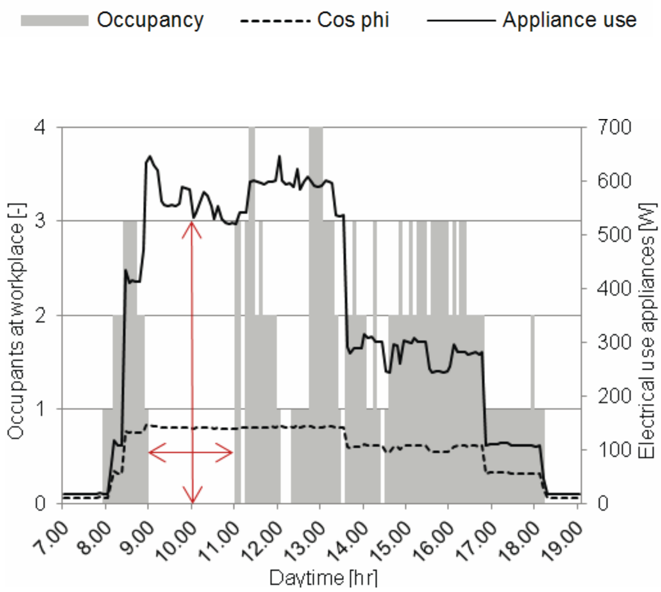
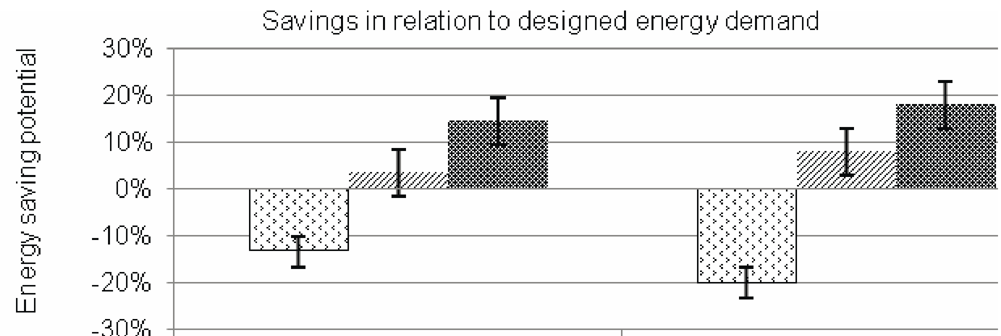


Figure 3. Occupancy for 4 workplaces and total energy demand for those places for a reference day, time step = 5 minutes. The red arrows indicate that energy demand can be reduced when the occupants are not at their workplace.



	Heating demand	Cooling demand
B. Actual energy demand	-13%	-20%
C. Human in the loop - room level	3%	8%
D. Human in the loop - workplace level	14%	18%

Figure 4. Energy savings compared to designed energy demand for actual energy demand (B), energy control on room level (C) and sending energy to the individual on workplace level (D).

A strong correlation between the occupancy and the most important human influence on building performances, use of electrical appliances, is shown on floor level. However, on workplace level a relation can be noticed, but lets a lot of space for decrease of the energy demand / internal heat gains. Further research towards possibilities and advantages is needed.

With the human in the loop approach more than 20% energy savings can be achieved on heating demand and up to 40% energy savings on cooling demand compared with the actual energy demand. 3E