Energy Saving by Context Aware Heating

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Abstract: A significant part of the overall energy consumption of office buildings and households in Europe is consumed for heating. Today's standard is that heaters are controlled by thermostats so that the desired temperatures are maintained for set periods. We now present ConAH (Context Aware Heating) that controls heaters so that heating periods are minimized while keeping the comfort of the occupants. ConAH utilizes information about future presences of occupants in the rooms, called location context of the occupants. To minimize the heating periods and save energy, heaters are switched on just sufficiently before and during usage times of the room and are switched off in all other cases. To calculate the moments to switch heaters on (heat up) or off (cool down), ConAH needs: 1. the future occupancies of the room. Future room occupancies are obtained via the prediction of the occupant's context, here in terms of location. 2. the time that the room needs to heat up or to cool down between two reference temperatures. This is called the room's heating and cooling profile and is determined by experiments in a real meeting room, as well as by simulations. We present the potential energy savings of ConAH compared to a standard controller with a thermostat and explain the effects that are responsible for these results.

1 Introduction

In recent years the importance of efficient energy usage is growing. The European Union aims at reducing the overall consumption of energy by 20% till 2020 [EEC11]. Since Germany has set a goal to exclusively use renewable energy sources by 2050, then of course energy efficiency is crucial to achieving this goal. In Europe a large portion of the overall energy is consumed by heating. In the planning phase of buildings, the right expertise can help to reduce the demand of heating. E.g. the orientation to the sun and the insulation of external surfaces are important factors. In Germany around 90% of the buildings are not, or just barely, thermally insulated [EOB07]. For these and even for efficiently constructed and well-insulated buildings there are options for improvement in energy efficient operation. Thermostats are today's standard for controlling heating. They maintain the desired room temperatures by controlling the heaters.

To control the heaters, the presence of the occupants can also be useful. Here in the paper we call this type of information "context". An example of context is the current occupancy of the room. To reduce the energy demand, the heater is only switched on when persons are in the room. It is easy to detect this context, e.g. via motion sensors.

However, changing the temperature is a slow process. Thus, starting the heating just when persons enter the room might be too late and causes physical discomfort due to too low room temperature. The desired temperature has to be reached before occupants enter the room; the heating has to start in time before they do. In this paper we present our idea to utilize "Context Aware Heating", called ConAH. ConAH aims at minimizing the operation periods of heaters to the ones really needed. It also assures the occupants' comfort by heating rooms early enough to avoid physical discomfort. To do so, the following data is essential: 1. the future occupancies of the room. Future room occupancies we obtain via the prediction of the occupants' contexts, here in terms of location. 2. the time that the room needs to heat up or to cool down[1] between two reference temperatures. This is called the room's heating and cooling profile and was measured for our test room (the meeting room at the Chair for Communication Technology (ComTec), Kassel University). We will show that ConAH can achieve energy savings compared to a standard controller with a thermostat in scenarios where rooms are sometimes not occupied. In principle, similar ideas can be used for air conditioning.

This paper is organized as follows: Section 2 gives an overview of the different approaches of energy efficient heating systems. In Section 3 ConAH is explained. Section 4 presents the experiments done to determine the heating and cooling profiles of the ComTec meeting room and the heating energy consumptions. In Section 5 we present the resulting energy savings of ConAH and explain the responsible effects. The conclusion is given in Sections 6.

2 State of the art

Looking at heating systems with respect to energy efficient control, there are solutions like the RWE Smart Home [RWE13] and Aprilaire [AP13]. These solutions support interfaces to allow occupants to configure e.g. the thermostat for their individual preferences themselves. As a result of studies with the intelligent environment *inHaus* [FI13], the authors of [RZN06] present how to simplify interfaces for environment control. There are projects like the Aware Home [KOA99] from the Georgia Institute of Technology, Atlanta, United States, and the Duke Smart Home [T09] from the Duke University, Durham, United States. These projects are living environment laboratories for research in ubiquitous computing for everyday activities. They allow analyzing occupants' behaviors and testing new approaches in energy efficient management and comfort. The Adaptive House is an initiative by the University of Colorado, United States [M05]. It focuses on the improvement of the occupants' comfort and on decreasing the need of interactions with the home management system. The idea was that the house should be able to program itself. For this reason the switches and controllers to control heating, lights, etc. were replaced by interfaces which are able to log the actions (e.g. switching on) from the occupants. Further, there are sensors to observe the occupancy of the rooms. The logged actions and occupancy information are then used to manage the actuators and to predict future states of the house, which is

[1] Cooling is done by switching off heaters

useful to control heating or air conditioning. After some time of observation there should be no more need to interact with the interfaces (e.g. thermostats). Even if something goes wrong, the occupants just have to indicate their preferences via the interfaces to adapt the management system. Different to ConAH, it does not focus on reaching the comfort temperature before occupants enter the room. The MavHome is a joint research project from the Washington State University and the University of Texas, Arlington, United States [SC05]. It has similar goals and methods as the Adaptive House. A difference is that the MavHome uses the observed sensor data to create context profiles of the users. After some time of observation these profiles are used to control the devices. This project focuses on minimizing maintenance costs, manual interactions and energy utilization. Similar to the Adaptive House, it is unclear how to control the slow heat up process so that a desired temperature is reached just in time of the beginning of the occupancy. Another approach for a context aware heating system is given by the Department of Informatics, Fribourg, Switzerland. They assume that energy can be saved through kinetic awareness [PBH08]. Kinetic aware systems can detect the location of occupants and recognize their activities. The idea is, that when occupants are doing sports, the room temperature does not have to be as high as when they are watching TV. The desired temperature can then be decreased which saves energy. To detect positions and activities, infrared sensors and indoor positioning sensors are used. We think that kinetic awareness might not be helpful in some cases, e.g. in scenarios of daily life in office buildings where most activities are sitting and walking.

3 ConAH - Context Aware Heating

ConAH aims to save energy by minimizing the operation periods of heaters. The basic idea is simple: if no occupants are in the room, no heating is required - but start heating just when occupants enter the room might be too late and causes physical discomfort. Obviously the minimal possible operation period with respect to the occupants comfort consists of two durations: 1. the time needed to heat up the room to the desired temperature till an event starts (an event is a future occupancy of the room and has a start time and a duration) and 2. the time the temperature is maintained during the event. This is illustrated in Fig. 1. The room temperature at 1:00 p.m. is 21°C.There is no event in the next 2.5 hours, so ConAH switches off the heater. The room is cooling down, because heat is transmitted to the colder outside through the external surfaces. The room’s cooling profile is now used to conclude that the room temperature will decrease to 19°C in the next 90 minutes. The room’s heating profile contains the information that the heater needs one hour to increase the room temperature from 19°C back to 21°C. Thus, ConAH calculates that the point to switch on the heater is at 2:30 p.m. (operation period start). The desired temperature is then reached just before the event starts. During the event the temperature is maintained at 21°C. At 5:00 p.m. the heater is switched off again because there is no predicted event in the future (operation period end). The minimal operation period consists of the heating up period from 2:30 p.m. to 3:30 p.m. plus the maintaining period from 3:30 p.m. to 5:00 p.m. (2.5 hours at all). Compared to this, a standard controller with a thermostat would heat during the whole observation period, i.e. from 1:00 p.m. to 6:30 p.m (5.5 hours).

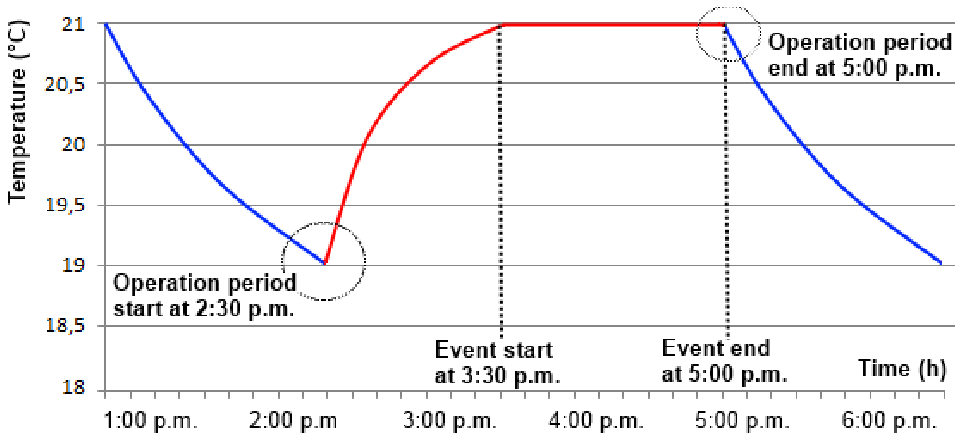

Figure 1: Example of cooling, heating and maintaining periods of context aware heating (ConAH)

The architecture of ConAH is shown in Fig. 2. Each room applying ConAH contains one or more temperature sensors. Temperature sensor readings, information about the occupancy of a room, and a room's heating and cooling profiles are the input for the Operation Period Calculator. The Operation period calculator calculates when to start heating so that a room reaches comfort temperature right before the next occupancy. It also calculates when to stop heating so that comfort temperature is maintained until the end of the next occupancy. The Timer then waits for start and stop times to control the heater.

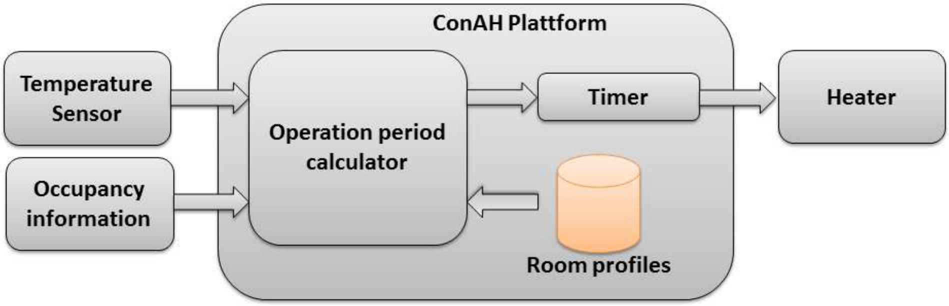

Figure 2: Achritecture of context aware heating (ConAH)

4 Experiments

In this section we present the experiments and their set up for determining the heating and cooling profiles of our test room. We also measure heating energy consumptions for heating up periods and periods where the temperature is maintained.

4.1 Experiment set up - The ComTec meeting room

To measure a room's cooling and heating profiles and to calculate energy savings, we use a meeting room at ComTec. The meeting room has the dimensions of 6.2 x 8.3 x 3.4 meters and a resulting volume of 175 m^3. It has two doors, one exterior wall with large double-glazed windows, and it is surrounded by offices and a hallway. To measure the energy consumption of a heater in kilowatt-hours (kWh), the installed heaters were switched off. Instead we use an electrical heater with a specified maximum consumption of two kWh. In the experiments the heater always heats with maximum power in heating up periods. An ammeter between the socket outlet and the heater determines the consumption. We are going to compare the heating energy consumption if heating is controlled by ConAH and by a conventional thermostat. To detect the consumption of the heater controlled by the standard thermostat, we combine a thermostat with the switch of the electrical heater.

4.2 Experiment conditions

There is more than one temperature zone in a room. E.g. the air temperature above a working heater is higher than the rest of the air temperature of the room. We neglect these zones and use just one sensor placed in the middle of the room. The desired comfort temperature is assumed to be 20.9°C. The lowest acceptable temperature is assumed to be 17.55°C. The surrounding temperatures are as follows. Kitchen: 23.5°C to 24.5°C, neighboring office: 25.5°C to 25.9°C and outside temperature: 1°C to 4°C. The sensor measures in °C +/- 0.5°C and recognizes temperatures in steps of 0.22°C.

4.3 Heating and cooling profiles and heating energy consumptions

Now the cooling and heating profiles of the meeting room and the heating energy consumptions are presented. They are valid for the experiment conditions listed in subsection 4.2. Fig. 3 shows the cooling profile of the meeting room measured from 20.9°C to 17.55°C. The room temperature decreases exponentially with time. In the limit of increasing time it approaches the lowest surrounding temperature, which is actually the outside temperature. Each point in the figure marks a moment at which a detectable change of temperature was measured.

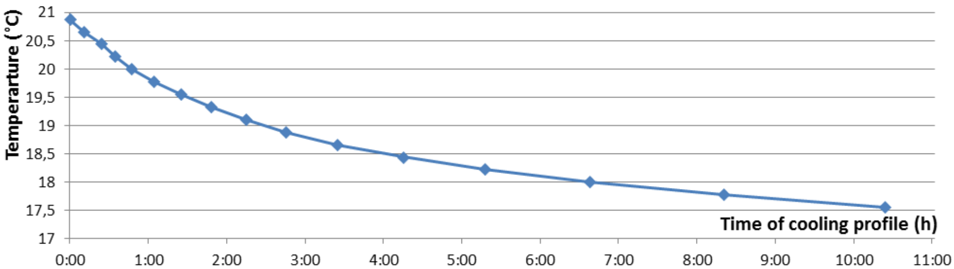

Figure 3: Cooling profile of the ComTec meeting room

Fig. 4 presents the heating profile of the meeting room from 17.55°C to 20.9°C. The room temperature rises exponentially with time. When the electrical heater heats up the room at maximum power, we measure a mean consumption of 1.8 kWh.

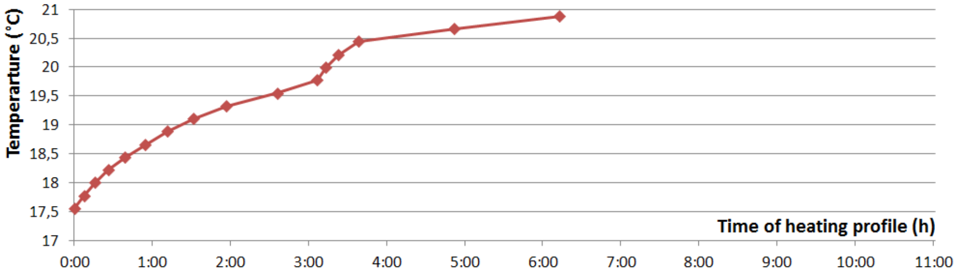

Figure 4: Heating profile of the ComTec meeting room

By now we have obtained the heating and cooling profiles and also the heating energy consumption for heating up periods. A third measurement determines the mean heating energy consumption when the desired comfort temperature is maintained. This is whenever a room is occupied. In these periods the heater has a mean energy consumption of 1.4 kWh to maintain 20.9°C.

5 Results

5.1 Energy savings depend on the time between two occupancies

ConAH aims at saving energy by minimizing the operation periods of heaters with respect to event schedules and the occupant's physical comfort. This means, energy savings can only occur when there are also periods without occupancy. Thus, it makes sense to present the energy savings of ConAH compared to the standard thermostat depending on the time between two occupancies - in other words: How much energy can ConAH save between the end of an event and the start of the next event. This is presented in Fig. 5.

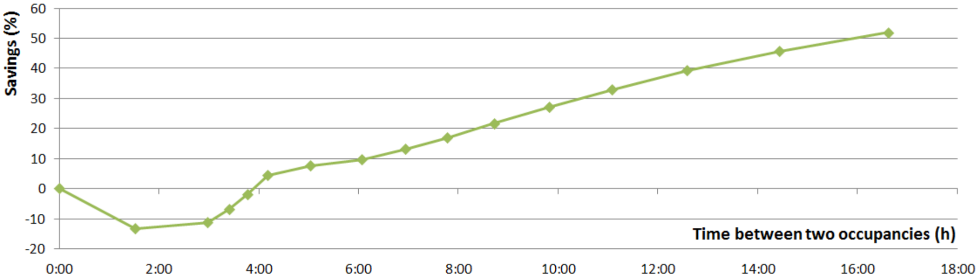

Figure 5: Energy consumption comparison of the context aware heating and a standard thermostat

One thing to notice is the potential to save energy for periods of more than four hours between two occupancies. There is an energy saving of 10 % if the room is not occupied for nearly 6 hours and nearly 30 % after 10 hours without any occupation. An unexpected result, having negative energy savings, takes place if the time between two occupancies is less than four hours. Subsection 5.2 and 5.3 will explain the reasons for positive and negative energy savings.

5.2 Where do the positive energy savings come from

Fig. 3 shows that the room temperature decreases exponentially with time when the heater is switched off. This is caused by the properties of heat transmission. Generally, heat transmission is directly proportional to the temperature difference between room temperature and the surroundings [LL12, D08]. Thus, the larger the temperature difference between the warmer room and the colder outside is, the faster the room temperature decreases. The heating curve in Fig. 4 follows this property, too. At the beginning of the heating up period, the difference between the room temperature and the outside temperature is smaller. Thus, less heat is transmitted to the outside and the heater heats up the room faster. The larger the difference between room and outside temperature becomes, the more heat is transmitted to the outside and the more time is needed to further increase the room temperature. ConAH switches off the heater, if possible. While cooling, the room temperature decreases due to the heat loss through the building outside walls. The same amount of heat has to be returned to reheat the room. Energy savings are achieved because the standard controller always maintains the comfort temperature and thus, always equates the higher heat transmission to the outside. ConAH does not need to equate this heat transmission in cooling periods.

5.3 Where do the negative energy savings come from

In order to explain reasons for the negative energy savings, the influences of heater controllers with different tolerance bands are investigated through various simulation studies. The TRNSYS simulation program [TSS13] is used to investigate the dynamic property of the room temperature. The simulations are based on a room model with a 36 m² floor area. A heater model with a maximum heating power of 2.7 kW is used. The room model has the following ideal conditions in order to reduce influences on the dynamic of room air temperature: There is no heat transmission between the reference room and its neighbor rooms. Heat is only transmitted through the outside wall of the room. The outside temperature is constantly 0°C and there are no solar and internal heat gains excepting the heaters heat. The most common method is the control via a thermostat with the tolerance band of ±1 K (Kelvin) or ±2 K [R12]. For the simulation we implement it with a ±1 K tolerance band. Fig. 6 shows the dynamic property of the room air temperature for a period where the heater is switched off for 2 hours. It is assumed that the room air temperature is about 21°C at the beginning. We start the timing at one hours, which could be 7:00 a.m. From this moment on, the heater is switched off for two hours. In this time, the room air temperature decreases to 19.24°C. By hour three, the heating starts. Because of the tolerance band the heater is not switched off at exactly 21°C but at 22°C and thus, heats up longer than required. This effect predominates for a short time between two occupancies and results in additional expenditure of energy. We simulate again with the same setting but replace the controller by an ideal controller. The ideal controller does not have any tolerance band and stops heating just after reaching 21°C. For this set up, there is no additional expenditure of energy.

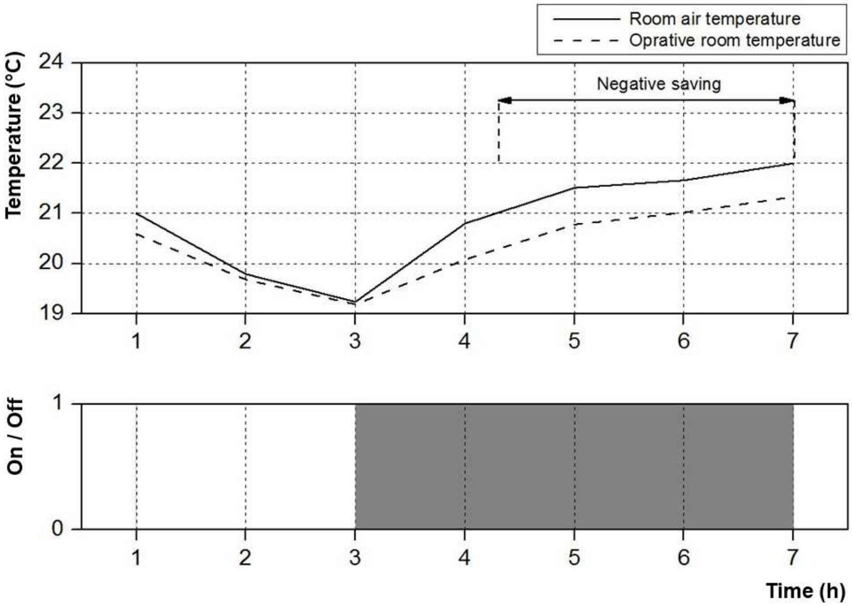

Figure 6: Temperatur dynamics of the room air temperature with a tolerance band of ±1 K

5.3 Energy savings for explicit scenarios

In Fig. 5 the energy savings depend on the time between two occupancies – in other words: How much energy can ConAH save between the end of an event and the start of the next event. To calculate the energy savings during a day, further specific information is needed. It is important to define the observation period and the amount, start times and durations of the events. We will now use the following examples to show how to calculate the energy savings with the extended conditions below:

- Observation period: 7:00 a.m. to 5:30 p.m. We assume that the standard thermostat and ConAH both have a night set back and behave the same way at night.

- To simplify the comparison, the room temperature is assumed to be 20.9°C at the beginning for both, the standard controller and ConAH.

- The overall heating energy consumption with the standard controller with an thermostat is 14.7 kWh for the 10.5 hours of observation.

Scenario - No event in the observation period: This scenario matches e.g. to meeting rooms which are sometimes not occupied for a whole day. A standard controller with a thermostat maintains the temperature for the whole observation period. ConAH immediately switches off the heater at 7:00 a.m. so the room temperature starts to decrease. No event is predicted - the system avoids switching on the heater and the temperature sinks to 17.55°C in the next 10.5 hours (see Fig. 3). In effect, it consumes no energy at all and the energy saving for this scenario is 100 % (14.7 kWh) for the observation period.

Scenario - One event in the observation period: This time an event is predicted. The event takes place at 2:50 p.m. and has a duration of one hour. ConAH calculates how long the room can cool down to a temperature which can be reheated to the comfort temperature until the event starts. The different heating, cooling and maintaining periods and also the energy consumptions are shown in Table 1. The overall energy consumption in the observation period is 10.4 kWh. The standard controller consumes 14.7 kWh in the observation period so ConAH saves 29 % (4.3 kWh).

Process	From – To	From – To	Consumption
Cooling	7:00 a.m. – 9:50 a.m.	20.9°C - 18.9°C	-
Heating	9:50 a.m. – 2:50 p.m	18.9°C - 20.9°C	5 h x 1.8 kW = 9 kWh
Maintaining	2:50 p.m. – 3:50 p.m.	20.9°C - 20.9°C	1 h x 1.4 kW = 1.4 kWh
Cooling	3:50 p.m. – 5:30 p.m.	20.9°C - 19.3°C	-

Table 1: Cooling, heating and maintaining periods for the scenario

6 Conclusion

This paper presents ConAH (Context Aware Heating), our idea to utilize context aware heating to minimize heater operation periods with respect to the comfort of room occupants. The minimal operation period is the time that is needed to heat up a room to a desired comfort temperature until the occupancy starts plus the duration of the occupancy. ConAH is aware of contexts (the future occupancy of the rooms) and needs heating and cooling profiles of the rooms. We measured the heating and cooling profiles of a real meeting room. We showed that minimizing the heating periods can result in energy savings compared to standard controllers with thermostats, if the observed rooms are sometimes not occupied. The energy savings increase with the time between two occupancies - the longer a room is not occupied, the more energy can be saved. Simulations illustrated that negative energy savings for a time period between two occupancies of less than four hours are caused by the controllers' tolerance band. With an ideal controller without any tolerance band, no negative energy savings occur. If there is one event with a duration of one hour, the energy saving with the controller used in our experiments is still 29 % (4.3 kWh) for an observation period of 10.5 hours.

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