Designing an Information System for Residential Heating and Ventilation to Improve Comfort and Save Energy

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Abstract. Large amounts of energy are wasted because heating systems run round-the-clock even though residents are out or occupy only a small part of their home. Major reasons for this behaviour are the non-intuitive heating controls and missing direct feedback about the heating activity or even energy consumption. In addition, bad ventilation behaviour, e.g. tilted windows, may lead to unhealthy room climate as well as significant heat losses. To address these problems, we analysed the requirements for a supporting information system. We present a first prototypical implementation of an individual-room heating and ventilation system which combines automation, an intuitive user interface and supporting feedback. This should empower residents to achieve energy-efficient heating and improved comfort.

1 Introduction

In Germany, 71% of energy consumed by residential buildings is due to space heating [1] distinguishing it as a powerful lever for energy-efficiency measures. Besides weather, thermal properties of the building, and the heating system, user behaviour determines the energy consumption for residential space heating. Concerning the latter point, there are three simple options for saving energy: (1) decreasing setpoint temperatures permanently, (2) turning down the heating when a room/home is not occupied, and (3) correct ventilation behaviour. However, executing on these options might challenge users' comfort and ultimately motivation to preserve energy. More specifically, users have to remember lowering setpoints when leaving, they might have to tolerate unpleasant temperatures and they don't get any direct feedback about the effect of their effort.

In the 70s and 80s, programmable thermostats were developed to overcome some of the aforementioned issues. But most users struggle to program their heating schedule due to the bad usability of such devices [2]. Moreover, it can be quite challenging to define a suitable schedule if residents' daily routines change. These challenges are addressed by a new generation of *connected thermostats* enabling intuitive user interaction via smartphone interfaces and in some cases even providing presence-based heating capabilities. The most known product in this category is the learning thermostat by NEST Labs[3] in the US. Another similar solution for European heating systems was developed by the startup tado[4] in Germany. Both solutions replace the central thermostat, which controls the heating according to the temperature of a single zone in the building. While this approach is cost-efficient it often leads to under- or oversupply of particular rooms and setback strategies can only be applied on the whole dwelling.

Contributing to the recent IS stream of *Energy Informatics* [3], we applied information systems thinking and skills to design a prototype IS helping residents to achieve energy-efficient heating and improved comfort.

2 Requirements Analysis

2.1 Conceptual Approach

In contrast to NEST, tado and several academic implementations [4, e.g.], which are *smart* or *intelligent* central thermostats, we pursue a decentralised, individual-room approach by controlling the hot water flow at each individual radiator. Therefore our system can, in contrast to the former, also be used in multi-family homes with central heating. There are already solutions of controllable radiator valves (CRVs) with additional smartphone- and web-based interfaces. They ease the process of creating a schedule as well as adding the convenience of remote control. However, we wouldn't call them *smart*, since they lack the ability to automatically adapt the schedule to changing user behaviour. For example, NEST tries to learn a schedule and temperature preferences by analysing user interactions with the system and by leveraging a PIR presence detector. Tado utilises the geolocation capabilities of smartphones to infer the distance of residents to their homes and to adjust the setpoints accordingly. To our knowledge, decentralised control approaches with such capabilities do not exist so far.

Moreover, as shown by Frontczak et al. [5], humidity and air quality are important factors influencing residents' comfort. Therefore it is necessary to make people aware of poor room climate and to foster optimal ventilation. Of course, most people have their own ventilation habits to overcome bad climate conditions, but due to feedback information, ventilation is often suboptimal in terms of energy efficiency and even comfort gains. For example, many people keep their windows tilted in winter, which leads to minor air exchange but tremendous heat loss. Similarly, people try to overcome dry air in winter by opening a window which often leads to the opposite effect since the outside air may contain even less humidity.

2.2 Fundamental Requirements

On the basis of our conceptual approach we can formulate key requirements for a heating and ventilation information system:

[3] https://nest.com/thermostat/
[4] https://tado.com

- **Comprehensible individual-room heating control**: The heating system is generally slow in response to user interaction. As a result, residents tend to set the heating to maximum when they feel cold, thereby often wasting energy. Thus, we require the IS to give immediate feedback in form of an estimated heat-up time to the desired temperature. Furthermore, it should be visible when the system is active, i.e. heating up. CRVs often have built-in room temperature sensors. However, due to the proximity of the CRVs to the radiator this can lead to deviations of several degrees to the actual room temperature. Therefore, we require an independent temperature sensor per room.
- **Presence-based automatic scheduling**: Similar to NEST's and tado's approach, the system should be capable of scheduling the room temperature automatically such that on the one hand the user's comfort temperature should always be reached when a room is occupied, and on the other hand the temperature should be maximally decreased when a room is empty. This *smart* feature is not trivial to implement, because it has to strike balance between energy savings and comfort. Furthermore, privacy and automation complexity have to be considered from a user perspective. (cf.[6])
- **Easy-to-use manual scheduling**: Since automatic scheduling may not be the optimal solution in every case, we require an easy-to-use manual schedule which can be edited remotely. Thus, the user should be able to adjust the schedule as soon as unexpected changes in his daily routine occur.
- **Room climate assistant**: The system should analyse temperature, humidity and air quality of a room to provide actionable information for optimising the room climate.

3 Design of the Artifact

In the following, we give a brief technical overview of our system. Afterwards, we show how the requirements have been implemented.

3.1 System Implementation

- **Connected room climate sensors**: Off-the-shelf wireless sensors (Netatmo[5] weather station) provide temperature, humidity and air quality (CO_2 concentration) measurement data in 5min resolution which is accessible through a cloud-based API.
- **Controllable radiator valves (CRV)**: Commercial motorised valves (eQ-3 Homematic[6]) allow to control setpoints remotely and can be installed by residents in minutes.
- **Home controller**: A low-cost, embedded computer (BeagleBone Black) relays data and control signals between the local CRVs and our backend server.

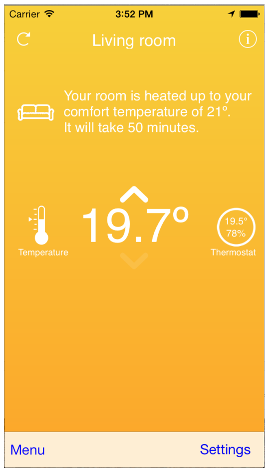
[5] http://www.netatmo.com
[6] http://www.eq-3.de/homematic-197.html

– **Backend**: Besides the storage of measurement and user interaction data, it provides the platform to implement *intelligent* features.
– **Smartphone app**: The main user interface is an iOS smartphone app that gives users control of their heating and feedback about their room climate.

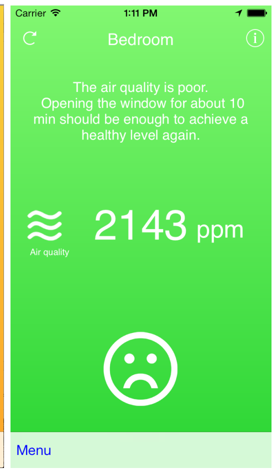
3.2 Feature Implementation

In the following, we present how we have implemented the requirements and how an user can interact with our system.
After choosing a room via a list menu in the app a temperature view will be displayed (see Fig. 1a). In the centre of the screen, the current room temperature is shown. The up/down arrows illustrate if the room is currently heating up or cooling down. On the right, the CRVs temperature measurement and valve opening are shown. The status message on the top explains what the systems is doing. During heating it entails an estimated heat-up time to the desired temperature which is calculated by taking previous heat-up procedures into account. Furthermore, the room temperatures and setpoints for the day can be visualised by turning the app to landscape view (see Fig.1d).
In Fig. 1c, a heating schedule for a week, divided in two schedules, one for workdays and one for the weekend can be seen. The schedule allows to set time intervals for typical heating modes: comfort-mode (indicated by a "couch" icon), sleep-mode (indicated by a "Zzz"-icon) and away-mode (indicated by a "walking man" icon). Each heating mode has a selectable temperature setpoint associated with it. The user can simply change the schedule by moving one of the knobs to the left or right. Compared to any user interface of a radiator thermostat, we claim that this is a strong usability improvement.
Presence-based automatic scheduling is implemented similarly to tado's approach by leveraging the smartphone location services. Temperature setpoints are lowered depending on the distance of the resident to his home. But, in contrast to tado, the user can choose which room (instead of the whole dwelling) should be controlled by this feature. Hence, our approach offers more flexibility and convenience, especially if some residents are not smartphone users or do not want to share their location for privacy reasons.

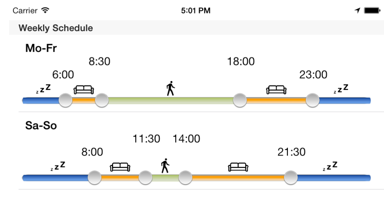
The air quality screen (see Fig.1b) shows the current CO_2-Level in ppm (parts per million), an informative feedback text and a smiley icon which empowers the user to judge the air quality at a quick glance. If ventilation is appropriate, the feedback text entails a reasonable ventilation time, which is estimated based on the current CO_2-Level and previous ventilation procedures.
Similarly to the air quality screen, a humidity screen is available. There, the user is warned about moldiness risk if the humidity is higher than 70%. If the indoor humidity is too low (<30%), the system recommends opening a window only if the humidity levels outside are high enough.



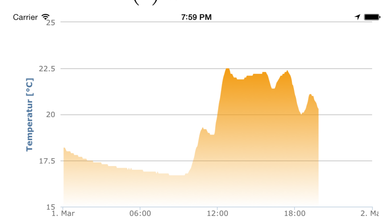
(a) Temperature



(b) Air quality



(c) Schedule



(d) Temperature history

4 Forthcoming Evaluation of the Artifact

Currently our system is running in five dwellings with friendly users in order to achieve a stable system from a technological point of view. For the next heating season, we plan to equip additional 10-20 comparable dwellings in multi-family homes in order to evaluate energy savings, influence on ventilation behaviour, user satisfaction, and the general usability of the system. Energy savings and influence on ventilation behaviour can be measured (approximately) using the room climate sensor measurements. User satisfaction and usability will be evaluated by interviews.

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