AI AND SENSOR APPLICATIONS IN 'SMART HOMES': CURRENT RESEARCH ACTIVITY AND APPLICATIONS IN DOMESTIC HOMES

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Abstract

This paper introduces the current research in the area of Smart Homes and then introduces a modelling approach for a domestic home. The modelling approach for a domestic home in the second part of this paper investigates the inherent properties of a house, which could facilitate further research into energy flow, timing methods and optimization.

Keywords: domestic, Smart Home, prediction, AI, sensor fusion, smart environment, thermal comfort.

Introduction

The area of Smart Homes was researched in different sub-areas, such as computer science, electronics, and medicine. The idea of Smart Homes was not new, but had been mentioned and researched several times in the past literature, either as pervasive or ubiquitous computing [1], which is the implementation of computer technology into every day life with as little obstruction as possible, aiding the human in daily tasks at home. To give an overview on the variety on research in algorithm applications, sensor use cases and energy management, the following section introduces current research projects. It is followed by the project the authors of this review are currently undertaking.

Current research projects

Research activity has ranged from complete system solutions to the technology and algorithms behind such systems. Recent reviews [2,3] focused on research projects that incorporated complete system solutions, and discussed sub areas in Smart Homes.

Smart Environments. Smart, intelligent environments were built and used in different projects. One of these projects was the Gator Tech Smart House[4] , developed at the University of Florida. The authors introduced a Smart Home using the Open Services Gateway Initiative (OSGi) technology, a framework based on Java. The system consisted of several, so called "hot spots", which represented different appliances in the house, for example Smart Mailbox, Smart Front Door, Smart Plug, and many more.

The DOG Gateway, researched at the Politecnico di Torino [5] in Italy, inter- connected different home automation systems. The researchers simplified the management of the systems by creating a neutral home automation system.

The Easy Living In Kitchen (ELIK) system, developed at the University of Pisa, Italy [6], provided a kitchen with a distributed embedded system. The system supported the user's activities, for example with a recipe database, controlled the actuators, for example the oven and cooking time, helped in safety issues, for example finding gas leaks and reporting/logging them and made the environment smarter with regard to power consumption as well.

Algorithms and data processing. A research project investigating and applying AI methods in Smart Home en- vironments was MavHome (Managing An Intelligent Versatile Home) [7],[8], which was researched at the University of Texas in Arlington, USA. Inside the MavHome, user data was collected and analyzed to train and use prediction algorithms.
Understanding and categorizing the data collected from sensors, for example in a Smart Home, was presented by Diane J Cook [9], at the Washington State University. The author's paper described tools and algorithms that analyzed and processed sensor data.

Energy efficiency and thermal comfort. Research into the energy efficiency of homes was undertaken in various areas. The integration of sensor-fusion into Smart Homes and the application in night saving heating showed an improvement of approximately 30% in energy usage [10].

The placement of radiators in relation to windows was proven to be crucial in heat distribution and airflow in a room; based on computational fluid dynamics simulations[11].

Research into thermal comfort was also undertaken. Thermal comfort was a measurement of satisfaction within an enclosed environment. A project in France observed facial expressions to deduce new methods and models of thermal comfort detection [12].

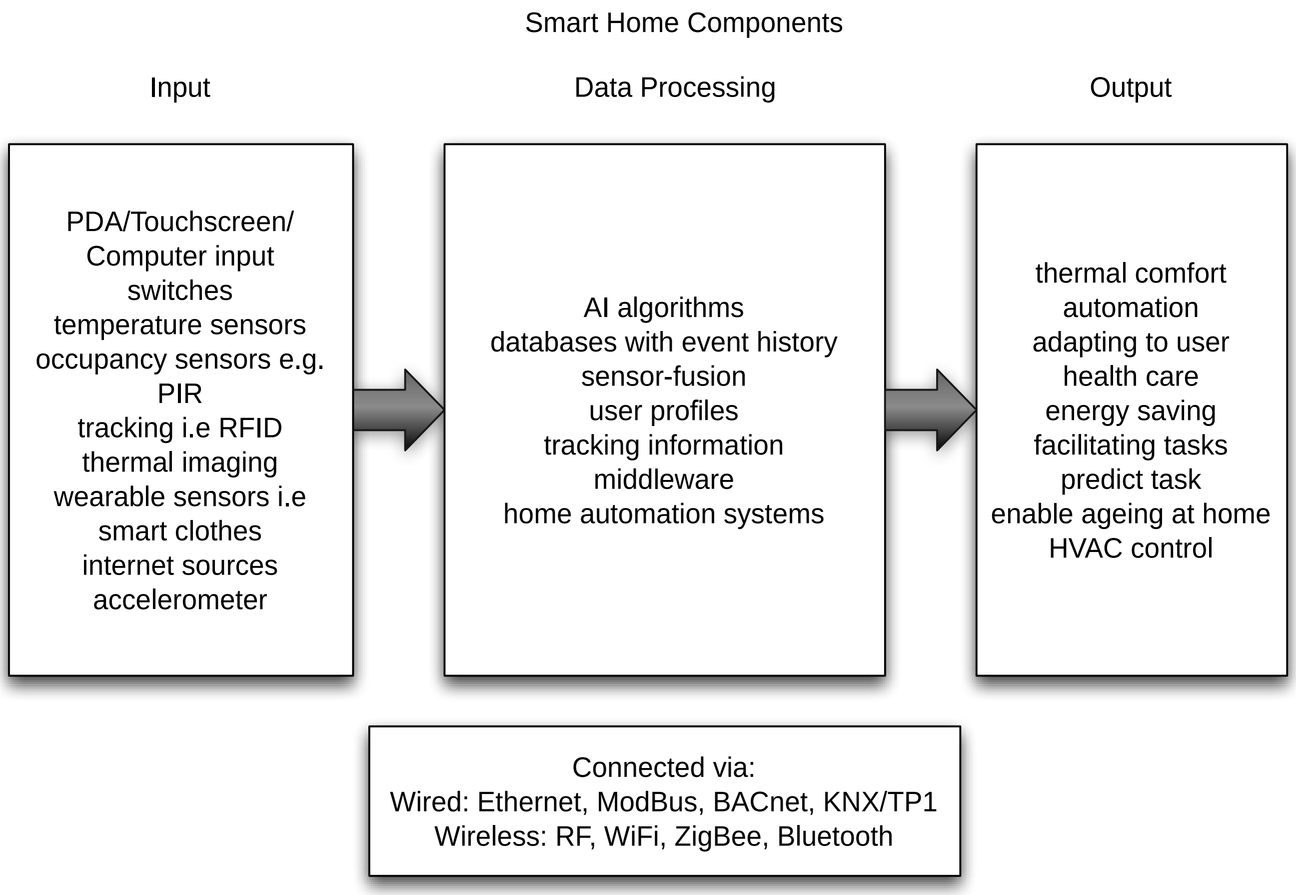
The Bundeswehr University in Munich studied methods to estimate thermal values in a room without disturbing the inhabitants by using thermodynamic models in a closed system environment [13].

In comparison to the research undertaken to improve energy efficiency or the methods of calculations, the standard used in ISO 13790:2008 [14] gave detailed advice on how to arrive at an Energy Performance Certificate (EPC). The methods described in the standard used yearly or static determined data, with variations for seasons.

Discussion

Research into Smart Homes has been active over the last few years, as shown in the literature review. The areas of input, the data processing and the outputs identified during the literature review of Smart Homes are shown in Fig 1. The main focus of the energy efficiency research in Smart Homes has mainly been focused on new technologies and not on the integration into already existing homes. Wireless technologies, for example ZigBee [15] or meshed sensor networks could make a difference. A recent survey showed that the improvements provided with EPCs were not followed [16], and the use of wireless technologies would enable the inhabitants of a domestic home to pay a lower price than running cable based solutions through existing infrastructure. New buildings and developments were able to integrate new technologies in the design phase. It can be concluded that one of the key incentives to attract inhabitants' interest in this sector could be achieved by integrating low cost modifications to housing and approved methods of saving energy.

The methods to determine energy performance in the European Norm (EN) ISO standards were detailed and adequate. One of the standards' weaknesses was the reliance on the use of static data and historic data collected over years for energy performance calculations. A dynamic approach could give a house owner a more accurate view of energy performance from day to day, instead of being based on yearly data or standard years.



Sensor applications in a domestic home

The following approach will use different kinds of sensors to help create and refine a model of a domestic home. A first draft of the model can be seen in Fig 3. The figure and the approach will be described in the following subsections.

The house as a model. A domestic home is subjected to inputs and outputs, for example rain, wind, solar radiation, inhabitants, seasonal change, air temperature, gas, electricity, transferred heat, waste or air temperature in the inside. The inputs and outputs regarding temperature development are mentioned in Fig 2.

Capturing the inputs and outputs could be achieved by measuring elements, such as temperature sensors, pyranometers or gas meters. Using these sensors in calculating accurate energy performance for buildings were methods encouraged by the ISO 13790:2008 and subsequent standards. The measurements with and installation of accurate sensor equipment equipment were advised by the World Meteorological Organization [17] to acquire data accurate enough for the calculations of energy performance certificates. Some of the data was acquired over a longer period of time, sometimes years, if an average estimate was procedures could be enhanced with dynamic approaches.

On this basis, the idea of a model-based approach is introduced. In such a model, a domestic home could be viewed as a system with specific inputs and outputs. The connections between outputs and inputs will be partly formulated and interim results defined. The testing of this model will be carried out in an ongoing experiment as well as system responses of a domestic home.

Use cases for the model could be: optimization of the energy efficiency, the time the heating needs to reach a certain set-point temperature, or the energy required to maintain a certain set-point temperature.

The connections and relations in the interim and actual data could be retrieved by using AI applications, such as ANNs, finding data patterns or classifying and clustering of data, as described in [9] by Diane J. Cook.

An approach to the outputs and interim results used in the data analysis is shown in Fig 3. In addition to the aforementioned inputs, thermal comfort was also considered. It will be an additional target that should be addressed when modeling a domestic dwelling, as the inhabitants' thermal comfort was dependent on the temperatures and temperature developments inside.

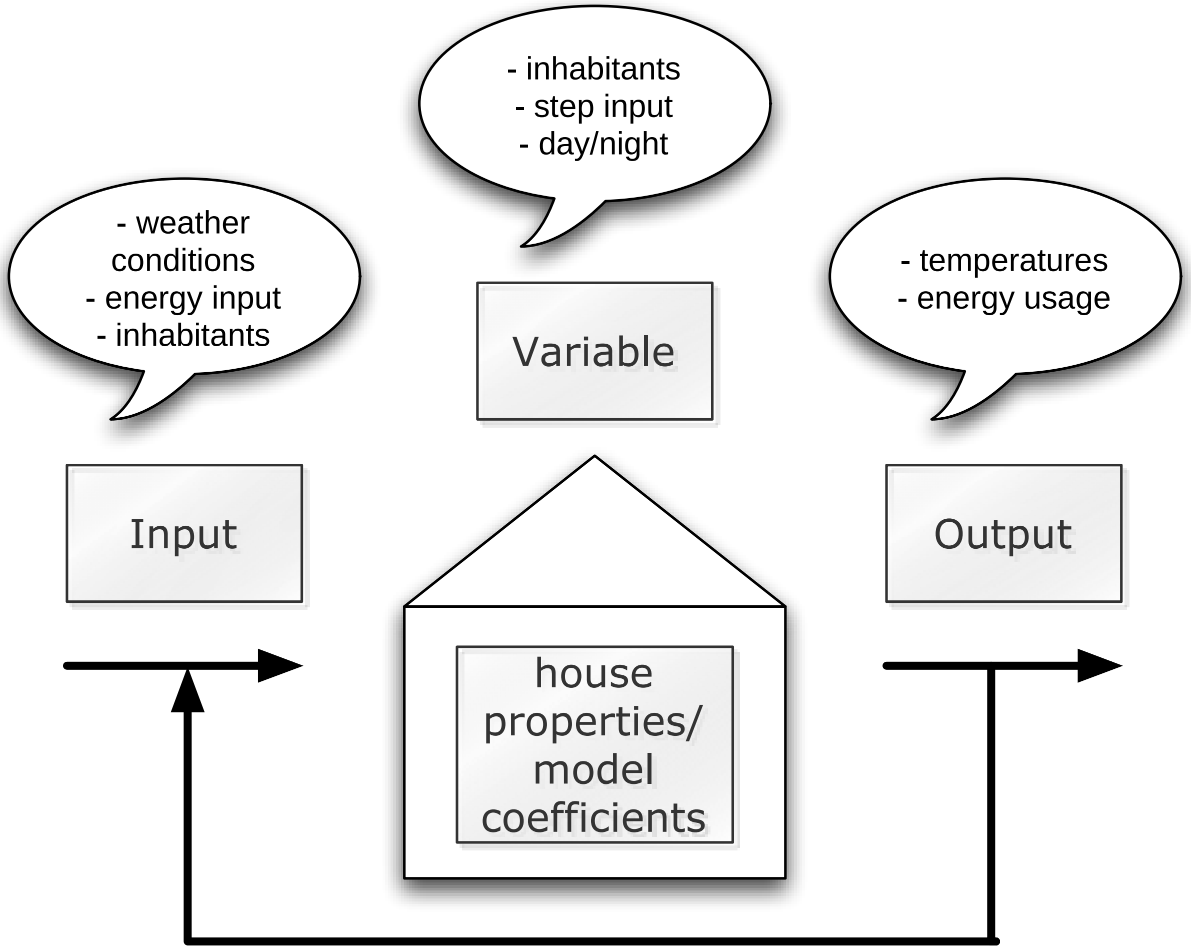


Figure 2: Inputs and outputs to a domestic home

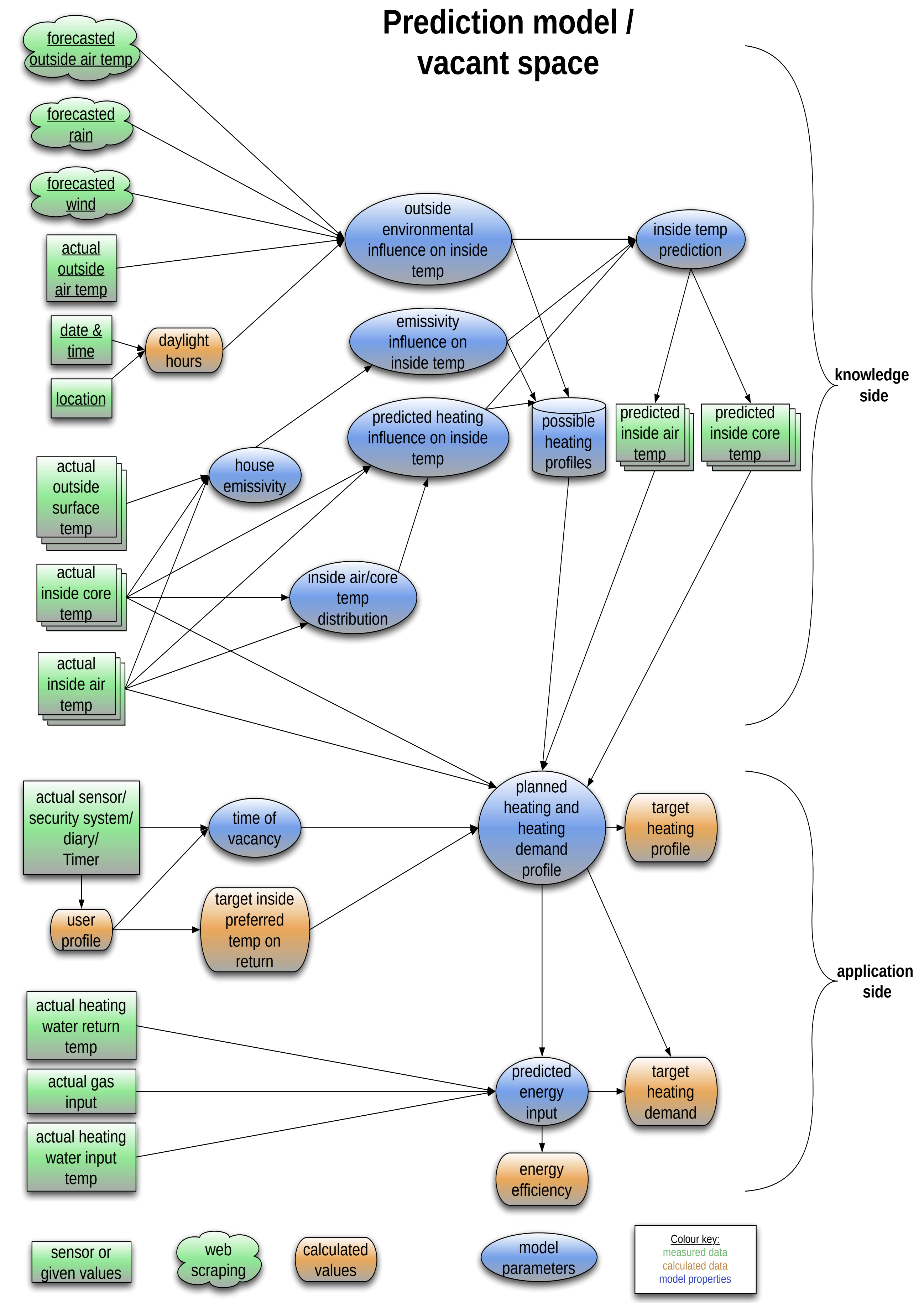


Figure 3: Initial layout of the model for prediction

How to build the model with sensor data. The temperature data will be gathered with sensors placed at different locations inside the domestic home. These sensors will then be probed for temperature readings at a given interval. A specific term was phrased during the initial layout of the model - core temperature. It referred to a wall inside a domestic home which is not an outside wall or connecting to another adjacent house and made out of solid material It was expected, that the rate of change affecting the core temperature would not change as fast as outside temperatures. This phenomenon can be seen in Fig 4, showing a sample recording of temperature data. The other temperatures of interest for the model will be selected dependant on their impact and correlation to this core temperature.

The other sensory data will be scraped from web sites, such as internet forecasts and weather station data close to the location of the domestic home. Together with the inside house data, this data will be analysed and used for following purposes:

1. Create model parameters, which are so far outside impact, house emissivity and heat influence/distribution

2. Aid in heating profiles based on forecasts and aforementioned parameters

3. Build applications that use the parameters and predictions

4. Improve and adjust the current model to reflect the real world To achieve these goals, neural networks (NN) will be used as well as data mining tools.

The domestic home as a system. Apart from collecting sensor data continuously, experiments will be carried out to find a system response. The output of these experiments will be similar to Fig 5. In blue the step input and in red the response over time. Such an experiment would for example be carried out by having a start condition and subject the system to a step input and recording the response over time. These results will give an insight into the heating parameter.

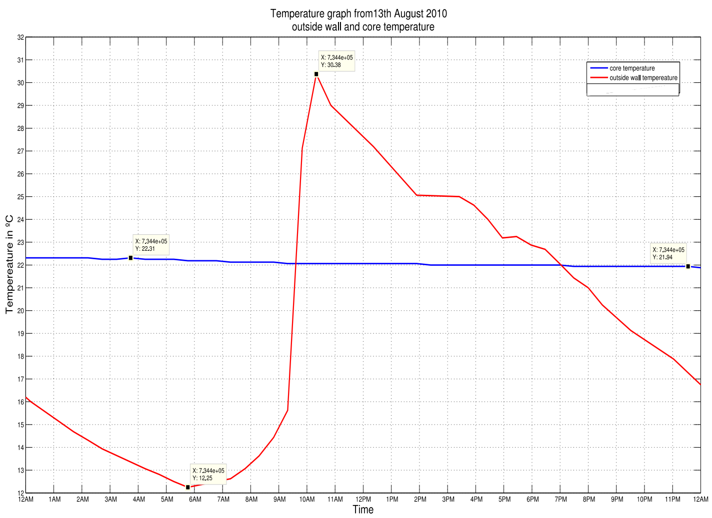


Figure 1: Outside wall (red) and core (blue) temperature over the period of one day

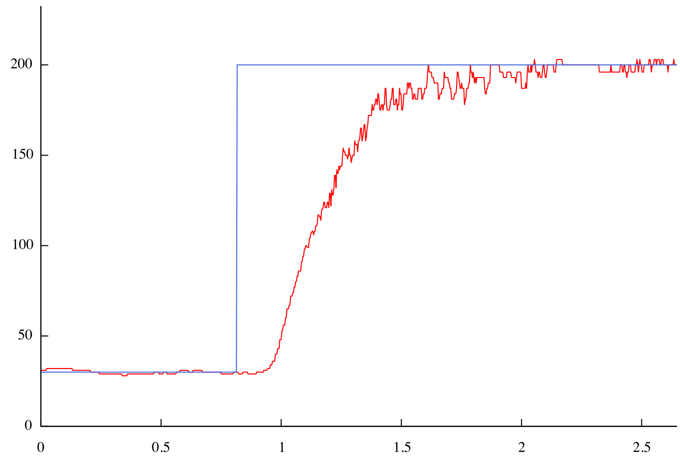


Figure 5 Expected result for model response

The model vs thermal comfort. The model will include thermal comfort in the future. Devices to collect user input are installed and enable the user to input if the temperature felt is too warm, too hot or ok. This data will be used as an opposing goal compared to the optimal energy efficiency. Therefore a balance needs to be found in which both are satisfied, that is the user as well as the optimal energy efficiency. This optimization problem could be addressed with findings on optimal control [18]. In our experiment the user input will be used to build a profiling and it will influence the predicted heat.

Current status. The current model has to be tested and experiments to be undertaken. As soon as the experiments start, the heating parameter can be derived. The outside impact parameter can be derived from existing continuous data and the emissivity parameter can be derived from data collected inside and outside the house.

Conclusions

Selected current research projects were presented and the topic of energy efficiency discussed. The second part of the paper introduced a modelling method for a domestic home as a system with inputs and outputs. The incentives to look into and optimize heating systems were improvements to the existing EPC, representation of a domestic home as a system and also to help improve the two thirds of old heating systems in the UK [19]. As soon as the system response experiments have begun, more results will be published.

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