A Learning Approach for Energy Efficiency Optimization by Occupancy Detection

Vitor Mansur[1(✉)], Paulo Carreira[1,2], and Artur Arsenio[3,4]

[1] Department of Computer Science and Engineering, Universidade de Lisboa, Lisbon, Portugal
{vitor.mansur, paulo.carreira}@ist.utl.pt
[2] INESC-ID Lisboa, Lisbon, Portugal
[3] Department of Computer Science, Universidade da Beira Interior, Covilhã, Portugal
arsenio@alum.mit.edu
[4] YDreams Robotics, Lisbon, Portugal

Abstract. Building Automation Systems control HVAC systems aiming at optimizing energy efficiency and comfort. However, these systems use pre-set configurations, which usually do not correspond to occupants' preferences. Although existing systems take into account the number of occupants and the energy consumption, individual occupant preferences are disregarded. Indeed, there is no way for occupants to specify their preferences to HVAC system. This paper proposes an innovation in the management of HVAC systems: a system that tracks the occupants preferences, and manages automatically the ventilation and heating levels accordingly to their preferences, allowing the system to pool its resources to saving energy while maintaining user comfort levels. A prototype solution implementation is described and evaluated by simulation using occupants' votes. Our findings indicate that one of the algorithms is able to successfully maintain the appropriate comfort levels while also reducing energy consumption by comparing with a standard scenario.

Keywords: Energy savings · Users preferences · Occupancy detection · HVAC system · Thermal comfort

1 Introduction

Heating, Ventilation and Air Conditioning (HVAC) systems account for up to 60 % of the total energy consumption of commercial buildings [1]. In modern buildings, HVAC system settings are configured centrally on the management console of the Building Automation System (BAS). Despite the fact that BASs aim at saving energy while maintaining occupant comfort [2], HVAC settings are only reviewed seasonly to account for large climate and occupancy variations. Indeed, settings are not adjusted in real-time to take into account fast dynamics of occupant preferences leading to overcooling or overheating. In practice, since occupants cannot control the HVAC thermal settings, they may experience discomfort while the system is probably cooling or heating above what is required and wasting energy. If occupants were given the

R. Giaffreda et al. (Eds.): IoT360 2014, Part I, LNICST 150, pp. 9–15, 2015.
DOI: 10.1007/978-3-319-19656-5_2

opportunity to control the system, situations of excessive service delivery that energy expenditure would be less frequent.

Energy management systems (EMS) are concerned with finding sources of waste and acting to improve energy savings. EMSs corrective action also typically targets HVAC systems in order to reduce energy waste. However, if occupants are not in the loop, these improvements are under-optimal. An intelligent climate control solution that takes into account occupant opinions regarding comfort is potentially capable of minimizing the energy consumption while maintaining the occupants comfort.

Studies show that the use of occupancy detection techniques with light and HVAC systems is beneficial to energy optimization, reaching savings values from 10 % up to 50 % [3–5]. However occupancy detection does not always have an acceptable accuracy rate. A promising approach is to use Radio Frequency Identification (RFID) systems to detect occupants with reliable accuracy, and retrieve occupants' information such as their comfort preferences. This can lead to a higher occupancy detection accuracy and energy management control.

Maximizing occupant comfort from individual preferences is challenging because preferences can be contradictory. Even if possible for occupants to change HVAC system settings, it still may difficult to reach a consensual set-point value so that every single occupant feel comfortable. To date, there is no platform that maximizes comfort by collecting information on the occupant preferences and (i) compute a setpoint which will control the temperature based on their feedback, (ii) encourage occupants to save energy by presenting them information on the other occupant votes, (iii) takes into account occupants preference history to improve decision making, and (iv) makes automatic decisions to configure the HVAC subsystem automatically.

This paper describes an approach that enables occupants of a given room to give their opinion on HVAC system configuration. A machine learning algorithm calculates a setpoint temperature that best fits their suggestions and find the most appropriate actuation to minimize energy consumption while at the same time maximize comfort. The proposed system incorporates dynamic user feedback control loops in order to optimize the energy/comfort trade-off.

2 Solution Architecture

The proposed solution tracks occupant through RFID card-reading, interacts with occupants on a web-front displayed on their mobile devices, computes set-points and sends commands to the HVAC sub-system through an OPC gateway. The system architecture is depicted in Fig. 1. The system consists of the following modules [6]:

RFID Module that retrieves the users information from the RFID tag on a student card. RFID card readers were mounted and two doors entrances and wired to two Arduino systems (Arduino Board plus RFID and LCD shields), coupled to another system, a Raspberry Pi, to aggregate the information of these systems and send it to the Storage Module. An entrance acknowledge feedback is presented to the user on the (LCD) screen (it could also be sent to a smartphone).

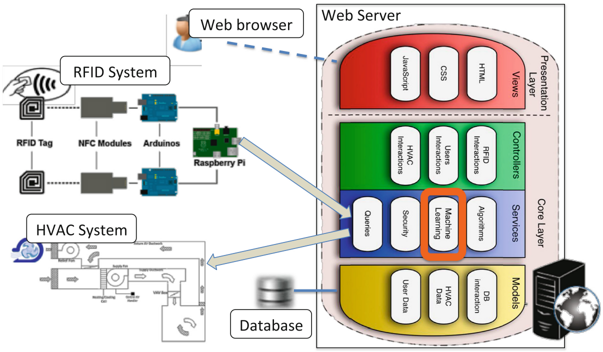

Fig. 1. Solution architecture and modules. On the left, the occupancy detection and HVAC modules (the peripheral modules) on the right, the application core modules.

Backend Application Interface consists of the presentation layer running on the web server to abstract the access to the database.

Storage Module uses a PostgreSQL Database to store and manage user information.

Application Core acts as the brain of the system, performing all computation including the simulation and the learning algorithm. Some of the main functions are:

- Occupancy detection: Knowing and deciding if a user is on the room or not, based on information received from the RFID System.
- User voting & feedback handling: Collecting user's votes and send users feedback regarding ambient variables.
- Setpoint calculation: Collecting the occupant's votes, validate them and calculate a new setpoint which minimizes discomfort.
- Learning algorithm: Learn information about occupant's behaviour and predict a best decision to make [7].
- Interaction with HVAC System: Send information about the new set-point and receive information about the ambient variables.

2.1 Occupancy Detection Using RFID

In order to adjust automatically to occupant preferences, the system must know the identities of the occupants. The main algorithm works in three stages: the first one is to detect the RFID tag (or student card), the second one is to route this information through a Raspberry Pi and add a simple security layer to the information. Finally, in the last stage, receives the information through a web service, adds a presence flag on the user database, saves the date, time and hour that the user entered the room and return the response to the Arduino's LCD and the entrance. Figure 2 depicts the flow of interactions that are triggered when a tag is read.

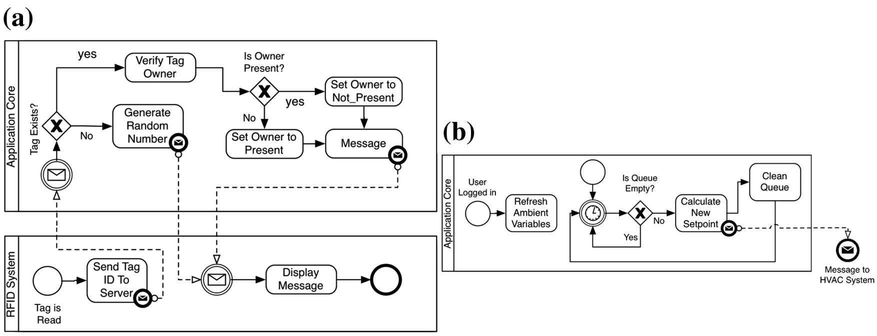

Fig. 2. (a) RFID System's interaction with the Main Application. It starts by sending the read tag ID to the Core, which verifies if the owner exists and defines it as present or absent. (b) Main functions of the Application Core: Refresh ambient variables, calculates the setpoint periodically and cleans queue.

2.2 Setpoint Calculation

The setpoint calculation algorithm is responsible for gathering the occupants' votes and calculating a setpoint, which tries to minimize the probability of negative voting, thus maximizing overall comfort for users in the room.

After a user votes, the Application Core starts by verifying if the user is in the room; if not, the process ends with an error message. Next, it verifies if the user has already voted; if so, it automatically overwrites the last request, adds it to a queue and stores it on the database with all the relevant information of the status of the room.

The system verifies the voting queue at specific intervals. If the queue is not empty, it calculates the new setpoint, cleans the queued requests and sends the new setpoint to the HVAC system. Then, it returns to waiting on the queue. Figure 2b illustrates the process. Setpoint computations are based always on the direction of the majority of votes. Therefore, the temperature settings will converge to an average value where most occupants feel comfortable. This algorithm assumes that a vote is correlated with the dissatisfaction of the occupant regarding current temperature settings, so the occupant wants to change it by voting to increase or decrease the temperature. The vote calculation starts by collecting all the queued votes and calculating the number of people in the room. It compares the percentage of votes relatively to the number of people in the room. The difference between the votes to increase and decrease the temperature should be greater than 10 %; if its not the case, the algorithm only cleans the queue and does not change the setpoint. The calculation decides if the setpoint should increase or decrease the temperature considering the majority of the votes changing it from 1°C.

2.3 Learning Algorithm

By having users configuring the HVAC System with votes, the overall performance can be improved enabling the system to automatically configure itself. First it is necessary to gather all the votes, identify patterns into it and learn them to take decisions in the future. Many learning algorithms are able to identify patterns on input data with a large number of examples. In this particular case, the system will not have a large amount of data to identify patterns. The analysed input consists of a stream of users votes who want to raise, maintain, or decrease the temperature. After collecting these votes, a learning algorithm is applied to separate this data into clusters according to data similarity. This way, it becomes possible à-posteriori the auto configuration of the room's setpoint without further needing the occupants to vote.

We employ an unsupervised learning algorithm to configure the setpoint according to a prediction based on the actual status of the room. The application core achieves this by loading the information about the room and comparing it to a set of previously calculated scenarios. Then it decides which setpoint is most appropriate. The algorithm retrieves the information on each vote made and saves it on the database during the submission of a user request. The users vote will not interfere with the set-point estimation, it is solely used for the purpose of training the Learning Algorithm. The k-means algorithm [8] used is a method of cluster analysis that divides into k clusters a set of n observations, each cluster S being associated with a centroid C. Each observation should belong to the cluster with the nearest mean. First, the algorithm starts by mapping the clusters by choosing k random values and define them as the new centroids, then it iterates and calculate a new centroid [9]. Each centroid is related to a system decision. The algorithm calculates once per day the new centroids, updating all the new requests and labeling each one of them, based on all previous votes, and new ones made on the previous day. This method makes it possible to calculate the setpoint, and simultaneously using data to train the algorithm to achieve better results. Once the system has the clusters calculated, it takes the information on current variables such as the indoor temperature, hour of day, number of occupants and calculates the cluster that fits better these variables. Then verifies which is the decision (for temperature setpoint definition) associated with the cluster.

3 Experimental Evaluation

The proposed algorithms were evaluated on a simulation of a real life environment using EnergyPlus package. The simulation environment consists of a room where occupants are able to cast a vote with the intent of setting the temperature, which best fits their comfort [6]. The system computes the new setpoint and adjusts the HVAC system accordingly. The data collected in order to evaluate the system corresponds to the overall daily comfort value, the daily mean energy consumption in KWh and the mean daily setpoint. Two scenarios were considered.

In the baseline scenario, the temperature within the room did not vary throughout the day, independently on the occupant's votes. Simulations were made using fixed setpoints from 20-22°C. According to Fig. 3a and Table 1, the mean energy consumption is 67,89 KWh, standard deviation of 9,37 KWh, and the mean confort value is 75,7 with standard deviation of 1,58.

In the other scenario, the system adjusts the room temperature based on the learning algorithm and occupants votes. The Learning Algorithm scenario was tested in two experiments, one using k-means algorithm during 10 days of simulations to train it employing 9 centroids (k = 9), and the other employing 3 centroids (k = 3). It is shown that a larger number of clusters decrease energy consumption at a cost of a smaller confort level. Such trade-off is also seen in both learning experiments compared to the baseline scenario, as shown in Table 1 and Fig. 3b.

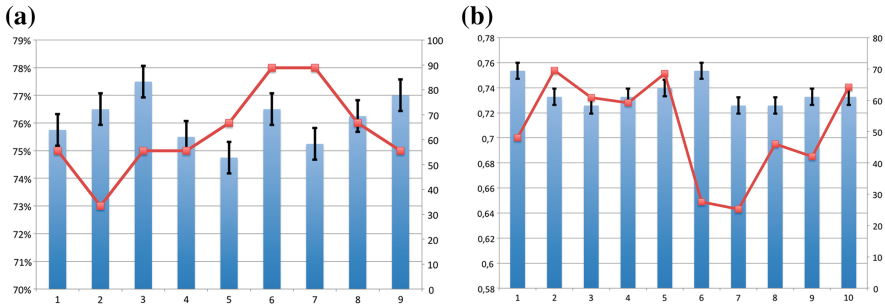

Fig. 3. The red line shows the percentage of the computed comfort (left axis scale), and the blue bars shows the energy consumption in KWh of each simulation (right axis scale); (a) Baseline simulations results; (b) k-means simulation results, with k = 3.

Table 1. Simulations experimental results (Energy Use in KWh, Comfort in %, and Setpoint in °C).

	Baseline Scenario		k = 9 and Days = 10			k = 3, Days = 10		
	Energy Use	Comfort	Energy Use	Comfort	Setpoint	Energy Use	Comfort	Setpoint
Mean	67,89	75,67	52,49	66,44	20,24	62,22	70,78	21,67
Std Deviation	9,37	1,58	39,74	2,38	4,45	4,18	4,01	0,41
Superior CV	74,25	76,7	77,12	67,91	22,99	64,81	73,26	21,93
Inferior CV	61,54	64,96	27,85	64,96	17,48	59,63	68,29	64,96

4 Conclusions

The use of BAS and EMS systems is becoming evermore common and sophisticated and seeking to promote energy savings by integrating new sources of data, such as user preferences, in real-time. Our hypothesis was that developing a learning system based on occupants input could allow controlling a HVAC system, to minimize the energy consumption while maximizing average user comfort. The results using the k-means algorithm suggest that it is possible to allow a room to configure the HVAC system based on a machine learning technique. Despite the comfort rate, which is approximately 5 % lower than the baseline, the energy consumption had a decrease of 5–KWh on the mean consume. This suggests there was a reduction on the energy consumption while abstaining from a higher occupant comfort rate.

Acknowledgments. Work developed in the scope of SMARTCAMPUS Project and supported by EU funds (http://greensmartcampus.eu). P. Carreira was supported by Fundação para a Ciência e a Tecnologia, under project PEst-OE/EEI/LA0021/2013.

References

1. Yang, R., Wang, L.: Development of multi-agent system for building energy and comfort management based on occupant behaviors. Energy Build. **56**, 1–7 (2013)
2. Soucek, S., Zucker, G.: Current developments and challenges in building automation. e & i Elektrotech. und Informationstechnik **129**(4), 278–285 (2012)
3. Boman, M., Davidsson, P.: Energy saving and added customer value in intelligent buildings. In: International Conference on the Practical Application of Intelligent Agents and Multi-Agent Technology, vol. 1, pp. 505–516 (1998)
4. Klein, L., Kwak, J., Kavulya, G., Jazizadeh, F., Becerik-Gerber, B., Varakantham, P., Tambe, M.: Coordinating occupant behavior for building energy and comfort management using multi-agent systems. Autom. Constr. **22**, 525–536 (2012)
5. Padmanabh, K., Adi Malikarjuna, V.: iSense: a wireless sensor network based conference room management system. In: Proceedings of the First ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings, pp. 37–42 (2009)
6. Mansur, V.: Energy Efficiency Optimization Through Occupancy Detection and User Preferences. Instituto Superior Tecnico, MsC Thesis (2014)
7. Arsenio, A.: Development of neural mechanisms for machine learning. Int. J. Neural Syst. **15** (1–2), 41–54 (2011)
8. MacKay, D.: Information Theory, Inference and Learning Algorithms, pp. 316–322. Cambridge University Press, New York (2003)
9. Sun, Z., Wun, Y.: Multispectral image compression based on fractal and K-Means clustering. In: 1st International Conference on Information Science and Engineering, (1), pp. 1341–1344 (2009)