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THERMO-SMART: smart thermostat for smart cities

Executive summary

Unlike private houses - where the idea of the thermostat is efficiently applied - environments or buildings open to the public do not provide specific solutions for comfort management in accordance with users' needs. In many cases, the indoor comfort parameters are not appropriately controlled thus generating discrepancies between the needs of the users and the actions taken to meet them. In addition, this also leads to excessive energy consumptions that could be avoided through a specific optimization. Homify project has the aim to provide feasible solutions for the control and monitoring of the comfort level in the academic environment, a public space where the problem of indoor comfort is particularly important.

This is done through the creation of correlations of subjective and objective data, related respectively to the personal comfort sensation of the users and to the physical parameters of the environment. Subjective data are gathered from the users through a dedicated interface, while objective data are collected from an electronic board equipped with temperature, humidity, light, carbon dioxide and particulate sensors. Through the application of data analysis techniques performed in a Cloud server on the obtained data, the Homify concept provides customized control of the actuators of the HVAC system, specific suggestions to the users and complete reports to the management personnel. To verify the feasibility of this project, two prototypes were installed in Politecnico di Milano.

In this way, the Homify project provides not only the opportunity to control the objective parameters of an indoor environment to optimize the average global comfort of the users, but supplies also an efficient solution for the management of public spaces and for the reduction of the energetic consumption.

Key Words

Thermostat, comfort, public buildings, feedback, smart management

Figure 1. Homify Team in Loano (March 2019)

Figure 2. Homify main advantages.

Project description written by the Principal Academic Tutor

With the increasing interest in smart spaces and infrastructures, modern homes and private environments more in general are being equipped with autonomous systems that enhance residents' comfort and liveability. In particular, infrastructures able to govern and control specific comfort parameters and power consumption are fundamental for this purpose. These systems are designed to improve comfort while minimizing the energy consumed for heating and cooling. On the other hand, there are not similar solutions for public buildings where typically control systems tend not to be tailored to the needs and comfort perception of people using shared spaces. This can become a problem for people that tend to spend a lot of their time in public spaces, such as offices or universities, while it is not actually an issue in places where they spend short time periods. There is then a growing need to realize smart infrastructures on a city level preserving comfort conditions for users, while controlling costs for changing indoor parameters. In particular, university presents a great problem in terms of indoor comfort. This led the Homify team to design such a complex system in an academic environment: from sensors to actuators, from user interface to data analysis. The team developed a prototype employing off the shelf sensors, so as to reduce initial costs. The chosen sensors are: temperature, humidity, light, carbon dioxide and particulate. In order to address all the different users, the team chose a very simple method: asking them directly specific information to estimate their comfort level. Specifically, the system can test the whole comfort level of indoor space through a short questionnaire submitted to the users. Therefore, a suitable user interface is designed: a mobile app that interacts with the users. It is simple and intuitive to use and it allows users to monitor all the relevant parameters, to receive customized suggestions, to understand the energy-saving profile proposed by the system and to react appropriately. Moreover, the objective data coming from the selected sensors are used in combination with the subjective comfort evaluations to control the buildings actuators and to implement complex decision-making algorithms, in order to optimize the global comfort of the users. The data collected and elaborated are also at the basis of a web app that allows the system owner to optimize the management, control and maintenance of the building rooms, through fault detection, predictive maintenance and continuous improvement. As proof of concept, the Homify team developed a first application of this system in the university environment. In the Emilio Gatti conference room in Politecnico di Milano, a simple prototype, embedding temperature, humidity, light, CO2 and particulate sensor, was installed. In parallel with the gathering of sensors measures, users' comfort evaluation were collected through simple questionnaires accessible from QR codes that can be found on stickers applied on each desk inside the room. These data were analyzed obtaining correlations between the sensors themselves, in order to optimize device costs, and between subjective and objective results, that are those used to generate control signals for actuators and personal suggestions.

Team description by skill

Riccardo Baccetti
He deepened the issue of the practical applicability of the project concept into real public spaces dealing with feasibility and cost optimization. He coordinated the group work leading to a successful cooperation.

Luisa Cavallaro
She contributed to the definition of the project solution leading the analysis of the users' requirements. Luisa also developed the app interfaces and took care of the graphic design aspect.

Andrea Comino
He deepened the data science aspect of the project addressing preliminary data analysis and machine learning techniques. Moreover, he studied the possible optimization of the prototype.

Simone Dartizio
He worked at the creation of the control system and actuators model, helping also in the prototype building. He studied further evolutions of the project in the smart city context.

Francesca Madonini
She coordinated the building of the prototype dealing with the choice of sensors, the welding of cable connections and installation issues. She also followed its practical implementation.

Tommaso Alessandro Negretti
He studied the subjective comfort evaluation creating an effective tool to collect them. Moreover, he organized the implementation of the prototype at Politecnico di Milano.

Dejan Pejovski
He focused on the definition of the state-of-the-art allowing the team to develop an innovative own concept solution. Dejan also followed the analysis of needs and requirements and helped in building and installing the prototype.

Goal

The increasing number of smart technologies implemented in modern buildings generates numerous problems in their connection and management. This new trend is a consequence of the complexity of our contemporary societies, where conflicting needs and constraints of various natures require unconventional solutions.

As a main project goal stands creating a concept of a smart thermostat which is primarily aimed at optimizing the comfort level of the people present in the specific indoor environment, i.e., the users. To identify the actual situation of the user's well-being, which is defined by the temperature, humidity, air quality and lighting of the space occupied, two major information are necessary: what are the present values of all these parameters and how they are actually perceived by the users. Therefore, creating a model and a prototype of a sensor unit able to collect data on indoor parameters (temperature, humidity, CO_2, noise, lighting) is essential. By leveraging the existing user technologies (for example, the social media) personal comfort level sensation should be estimated. To do so, innovative ways of interaction with the existing widespread technologies are required in obtaining information about the users in a non-invasive way. The integration of data from various types and sources should enable mapping of the physical buildings, modelling of the heating and cooling systems, control of the energy consumption and improving personal comfort. All of the above is to be scaled on a smart city level.

Understanding the problem

A smart programmable thermostat can communicate with the Inter-/Intranet via a wired/wireless network [1]. Commercially available devices can exchange and store data and they can integrate with the existing Heating, Ventilation and Air Conditioning systems. Some of their most common features are: presetting desired temperature schedule, activation based on motion and voice detection, geolocation, energy-saving reports, etc. [2], [3]. These devices, although quite expensive, perform well in individual households. When it comes to public spaces, occupied by large number of people with various comfort preferences and numerous system operating conditions, such as universities, hospitals, offices, etc., a complete, all-inclusive solution does not exist. Issues such as accessibility, user interface choice, identification of "globally shared" comfort level are open for discussion. Network security and authorization are concerned as well, since no standards for this particular technology exist [4]. Installing such smart devices in public buildings with hundreds of rooms is a costly investment, especially if it comes as part of a renovation plan. The solution for all the above-listed problems makes sense only if it can interact with the users: obtaining subjective information which would be used to define control system outputs and giving feedback to the user in terms of suggestions and notifications.

Figure 3. The first prototype of the thermostat installed in Emilio Gatti Conference room.

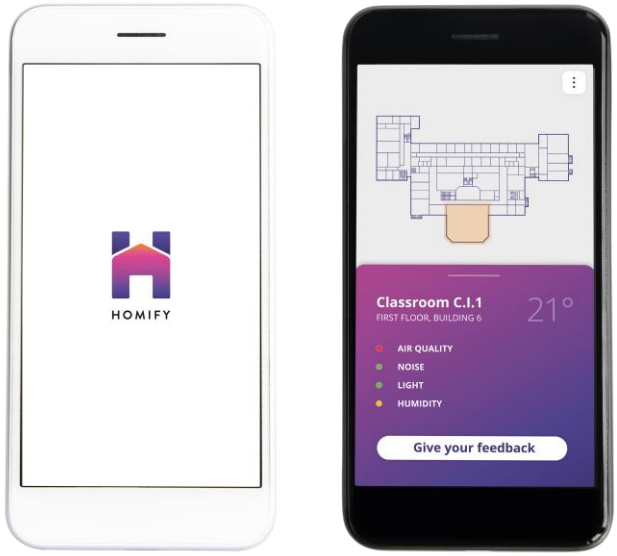

Figure 4. Homepage of Homify mobile app.

Exploring the opportunities

Each of the questionable aspects when a smart thermostat is to be implemented in a public environment can be solved in several ways. Collecting data about personal comfort is possible through filling in a short questionnaire which opens after scanning a QR code or which comes as part of a mobile application. Another option for user's interface is placing a touch screen at the entrance of each room, so that people are allowed to give their feedback. Instead of buying expensive thermostats, it is recommended to build a unit with embedded sensor which can measure all the relevant parameters and send the data wirelessly to a storage memory. Estimating the number of people present in a room can be done by implementing a presence sensor, or by asking the people in the questionnaire to report the number of occupants. Once the data are gathered and processed, some actions need to be taken in order to improve the user's well-being. A completely automated control can be implemented, or semi-automated in collaboration with the users, who can open/close the windows, turn off/on the lights, etc. Having a detailed picture of the situation in all the available rooms in the building in advance is for sure very useful for the person in order to help him choose the most suitable environment.

Generating a solution

Homify is a complex system able to take into account users' feedback in order to adjust their comfort level inside the building monitored. It concerns all the aspects related to personal comfort sensation, such as temperature, air quality, lighting and noise, in creating a complete well-being of the occupants.

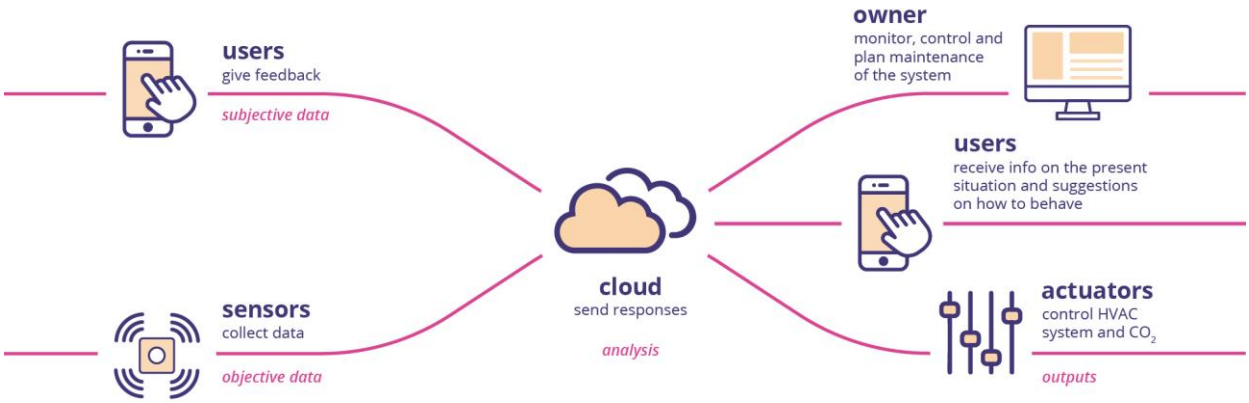

Figure 5. Homify's system concept.

The basic operation principle of the entire Homify solution relies on the collection of two data sets: objective and subjective. The former one is created by smart sensors integrated on a single unit placed inside the environment under observation, including air temperature, relative humidity, CO_2 concentration and light intensity sensors. The latter data series is generated by the users: each person present in the room fills in a simple questionnaire via a mobile application, answering questions related to his own sensation about the same parameters. All the data collected are sent and stored on the Cloud, where their processing occurs through a series of statistical analyses. The final processing aim is identifying corrective measures to be undertaken on the control systems to improve general personal comfort. Homify provides outputs to three different clusters of receivers:

- Technical systems and equipment;
- End-users (room's occupants);
- Maintenance and cleaning personnel.

All the equipment connected to the control unit receives signals sent to their actuators aimed at adjusting the indoor comfort. Most of these control signals are applied to the HVAC system for thermal conditioning and the Air Handling Unit. Stand-by function is available as well.

Homify prepares a set of information to be displayed on the smartphone on each end-user. With the dedicated mobile application, building's occupants have on disposal information about the present conditions of the environment. This solution generates suggestions to the users related to their personalized comfort, which are obtained through a comparison between user's answers on the questionnaire and the global comfort level. Extra information is given through real-time noise and occupancy level maps, lessons schedule, etc.

Malfunctioning signalization and average room occupancy are sent to a web application to improve maintenance and room cleaning strategies. Energy saving reports are generated on certain time intervals.

Homify is capable of improving user's comfort, reducing energy consumption and upgrading the concept of ordinary maintenance. The main concept value lies in its real-time analysis and response, based on data collected from various sources and direct interaction with the users. Homify can be installed in semi-private and public environments which proves the solution's scalability.

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