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Development of a comfort platform for user feedback: the experience of the KTH Live-In Lab

Rolando Davide[1*], Molinari Marco[1]

[1]KTH, Royal Institute of Technology, Stockholm, Sweden

ABSTRACT

This paper presents the comfort platform created within a research project carried out at KTH Live-In Lab in Stockholm, Sweden. The KTH Live-In Lab is a platform of buildings to test and promote innovation into the built environment. The Live-In Lab includes several buildings with state-of-the-art and expandable sensor infrastructure.

The comfort platform has been created to manage user feedbacks in buildings. The comfort platform includes a user-friendly web application and a cost-efficient sensor device that allow to exchange feedbacks with the building users.

The comfort platform is proposed as a possible solution to bridge the gap between modern smart buildings and existing buildings with limited sensor capability.

This paper describes the comfort platform and the environment where it has been tested. The paper also summarizes the preliminary findings and the potential large-scale implementation.

Keywords: energy efficiency in buildings, buildings digitalization, user feedback in buildings, smart buildings.

1. INTRODUCTION

Smart buildings and cities are considered to have a key role to foster energy efficiency and reduce the environmental footprint in the built environment and at the same time provide improved indoor and living conditions.

However, there are several challenges and risks associated to the development of smart buildings. Demonstrators and experimental buildings can be the key enablers for smart buildings, to demonstrate and upscale the validity of the smart building concept, foster innovation and mitigate the risks.

The KTH live-In Lab (LIL) [1] is a platform of buildings with the goal of testing and demonstrating innovative technologies to improve energy efficiency and indoor air quality in buildings, ultimately adding to sustainability in the built environment. A key role in the Live-In Lab is played by Information and Communication Technology (ICT) to understand behavior; this paper describes the experimental setup of the LIL and a cost-efficient tool that has been developed to tackle the following question: how do we map comfort and energy performance in buildings with no sensors?

2. KTH LIVE-IN LAB: TESTBEDS

2.1 KTH Live-In Lab buildings

The experimental buildings in the Live-In Lab are grouped into three categories: the core lab, i.e. the Testbed KTH, extended labs, i.e. the Testbed Akademiska Hus and Testbed Einar Mattsson, and trusted buildings.

The Testbed KTH and the Testbed Einar Mattsson are residential buildings for students, all sited in the KTH main campus in Stockholm.

Heating to the buildings is provided by ground-source heat pumps connected to 12 boreholes with a total length of 3600m; the temperature in 6 boreholes is monitored via fiber optics measurements. The heating distribution system of the apartments consists in thermally activated building slabs that provide ventilation and heat at the same time. Electricity is generated locally, with 1150 m^2 photovoltaic panels installed on the flat roof with the possibility to install storage systems, in particular batteries for electricity. Heat from domestic hot water is recovered by means of 64 wastewater heat recovery exchangers.

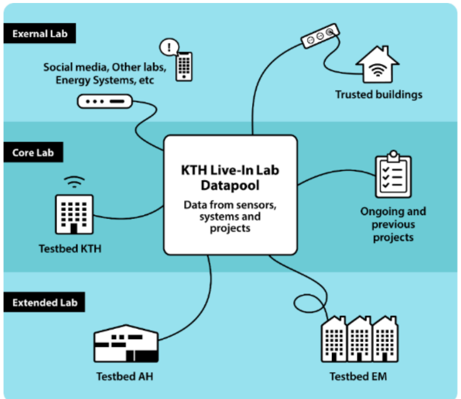

Fig. 1: Live-In Lab experimental setup

2.1.1 Core Lab: Testbed KTH

The **Testbed KTH** constitutes the core lab in the Live-In Lab as it has the highest degree of reconfiguration and flexibility for researchers. The physical premises account for a total of 305 m^2 distributed on approximately 120 m^2 living space, 150 m^2 service space and a project office of about 20 m^2.

The Testbed KTH is extremely flexible in terms of geometry and installations. The buildings have load-bearing exterior walls, while interior walls in all apartments are constructed of light materials; this allows an easy reconfiguration of indoor spaces to ease the research, for instance, on the interaction of building occupants with the environment.

The testbed is extensively equipped with sensors to monitor temperature, carbon dioxide, relative humidity, air pressure, energy consumption, tap water and window opening.

2.1.2 Trusted buildings

Alongside core and extended labs are trusted buildings, which may be regular buildings with limited or no sensor capability. Within a National project funded by the Swedish Energy Agency [2], a set of 6 buildings with 243 single-room apartments for student accommodation are included as trusted buildings in the Live-In Lab platform. These buildings have only a few temperature sensors installed for fault detection purposed in a limited number of apartments. No measurement is available for monitoring the indoor comfort conditions.

The smartness capacity of the Live-In Lab testbeds and trusted buildings varies considerably, from the Testbed KTH, with the highest degree of sensor capacity and configurability to trusted building that may have no sensor capacity at all. To promote energy efficiency it is imperative to enable interaction with the users and to upgrade the sensor capability of older buildings.

To this aim, a cost-effective platform to increase building smartness has been developed, with functionalities that can be adopted in both regular and smart buildings. This paper illustrates its development and application to a preliminary feedback campaign to map perceived comfort and energy efficiency in buildings. The paper also draws preliminary conclusions from the ongoing campaign.

3. MATERIAL AND METHODS: COMFORT PLATFORM

In this chapter, the comfort platform is described: the platform consists of hardware and software designed to gather and provide feedbacks to and from the building users.

3.1 *Software – the comfort app*

A web application, called here Comfort App, has been developed to allow the users in the Live-In Lab to provide feedbacks about their perceived comfort. The app is designed to be user friendly, informative and to provide a non-invasive user experience. Figure 1 shows examples of the panels implemented in the web application. The homepage of the web app consists in a minimal interface with only a few buttons corresponding to comfort perceptions (e.g. "Too cold", "Too dry", "Poor air quality"). By tapping one of the buttons, a second panel invites the user to provide a short comment on the choice. Providing the comment is not mandatory. All the feedbacks are collected anonymously into a database. Secondary panels show the user a few metrics of the feedbacks provided and some aggregated metrics to compare (anonymously) the feedbacks from other users in the same building or in the same measurement campaign. The app provides also additional features for researchers and building managers, including the possibility to leave notifications to group of users.

3.2 Hardware – the comfort box

The hardware component of the comfort platform utilizes the ESP12 as core prototyping module. The ESP12 module is a wireless module based on the low cost and low power System on a Chip (SOC) microcontroller ESP8266. The main features of the module include a 80MHz CPU, 4Mb of flash memory, 802.11 b/g/n WiFi, serial connection up to 921600bps, 9 General Purpose Input/Output (GPIO) pins and 1 Analogue/Digital converter (ADC). The supported communication protocols include I2C and SPI.

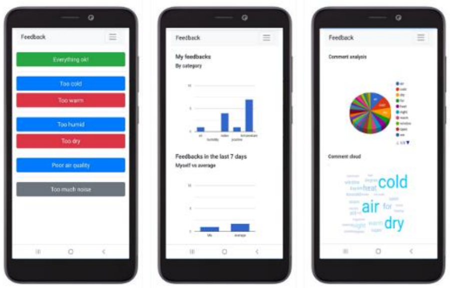

Figure 1 Example of panels implemented in the Comfort App

In the prototype, called here Comfort Box, the ESP12 module is to a prototyped electronic board where several low cost sensors are mounted. The first version of the prototype (shown in Figure 2) includes sensors for monitoring temperature, relative humidity, CO_2, equivalent CO_2 (eCO_2), Total Volatile Organic Component (TVOC) and light intensity. Worth noticing, the temperature measurement is redundant and performed by two separate sensors. The measurement of CO_2 is also redundant, but obtained through distinct approaches. A dedicated low-cost CO_2 sensor performs one measurement of CO_2, while a second value (eCO_2) is derived by the measurement of TVOC.

The Comfort Box prototype is powered with 5V DC current provided by an external power supply. Common 5V 1A power supplies are suitable for powering the device.

3.3 Communication and data management

Compared to other examples available in literature based on similar hardware [3][4][5], the proposed Comfort Box stores no measurements locally but directly transfers all the measurements to a remote server. This approach has the clear disadvantage of not providing a local backup of the measurements. On the other hand, this design choice also brings numerous advantages in terms of prototype costs, data management and scalability of the solution.

First, the local storage of the measurements requires two main additional components mounted onboard: the physical storage and a Real Time Clock (RTC). While these requirements are obvious, their implications are often overlooked. Low cost prototyping boards like Arduino (www.arduino.cc) can store data to an SD card through dedicated modules that are widely available. Not least, recording measurements requires the tracking of the measurement time in order to be meaningful.

Figure 2 First prototype of the Comfort Box

In addition, in this case, dedicated modules for Arduino are available and can be connected to the prototyping boards. It is worth to notice that each additional module has an impact on the cost, design, manufacturing and operation of the entire prototype. Moreover, examples of unpredictable malfunctioning of low cost RTC modules are available also in research literature [4]. One of the most common problem of RTC is to have time drifts adding up over measurement campaigns of only few days.

The local storage of the measurements requires also the data to be physically collected and the reset or maintenance of the storage itself. Also, leaving the data on the device opens to privacy issues quite difficult to control.

All the problems related to the local storage and the RTC modules can only be detected by regular and physical inspection of the device. This implies clear disadvantages for relatively long measurement campaigns with multiple devices.

The wireless communication of the measurement solves all the above-mentioned issues. The remote server automatically assigns the time of the measurement upon receiving the data. Algorithms on the remote server can also detect in real time any anomaly on the communication or the data related to any device.

For these reasons, a server side API has been developed for the communication and data management.

The API handles the authentication and authorization of each Comfort App user and each Comfort Box device. Worth noticing, the information coming from the Comfort Box and the Comfort App are secured via public key cryptography techniques.

The API also handles the connection between the data transferred through the Comfort App and Comfort Boxes and the relational database where the data model of the Comfort App is implemented. The Comfort Platform utilizes MySQL as database engine.

A web interface helps the administration of the Comfort Platform. Users, devices, buildings, building rooms and campaigns can be created and edited. Also, measurement campaigns can be monitored in real time and operation parameters of individual Comfort Box can be set. As an example, the measurement interval of each Comfort Box can be individually assigned remotely.

An important aspect of any measurement is the calibration the sensors. Within the Comfort Platform, the calibration parameters for each sensor of each Comfort Box are stored on server side. The calibrated value are calculated upon receiving the data and stored along the raw values.

Finally, Figure 3 shows the basic communication layout of the Comfort Platform. The current implementation of the platform allows buildings with limited or not available sensor capability to have the monitoring of the indoor environment and interactive feedback features through a low cost and flexible solution.

Worth noticing, in case of buildings with no wireless networks available, dedicated networks have been easily implemented through the installation of common 4G routers.

4. EXAMPLE OF RESULTS

Figure 4 and Figure 5 show examples of the results obtained through the Comfort App. One of the purposes of the App is to be informative for the users and Figure 4 shows examples of the feedback metrics that are available. Along the summary of the feedbacks from the user, the App provides also aggregated metrics about the user feedbacks compared to the feedbacks sent by the users of the same building. These metrics have the purpose of engaging the users through gamification techniques [6] and the insights of the results will be presented in future works when more data will be available. Figure 5 shows an example of feedbacks metrics available to the building managers. For a given selected period, visual representations of the user perceived comfort are elaborated in real time.

5. DISCUSSION AND CONCLUSIONS

The proposed first version of the Comfort Platform represent a low-cost solution to provide monitoring and communication capabilities to buildings with sensor network limited or not available.

Monitoring the indoor comfort conditions and allowing the user to easily communicate the perceived comfort enables the mapping and identification of critical issues in building energy systems that potentially enables improvement in the building system settings, energy saving behaviors and awareness.

The proposed solution is low-cost, flexible, scalable and contributes to create a bridge between the built environment and new and modern buildings where much relatively costly ICT solutions are included at design stage.

The future works will include additional features and a thorough analysis and evaluation of the collected data.

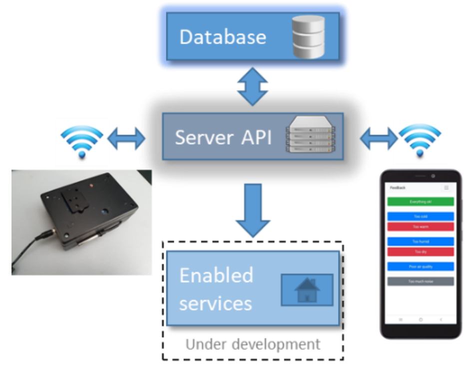

Figure 3 Comfort Platform: basic communication layout

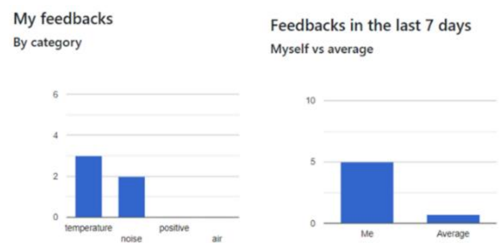

Figure 4 Example of results: comparative feedback from the users

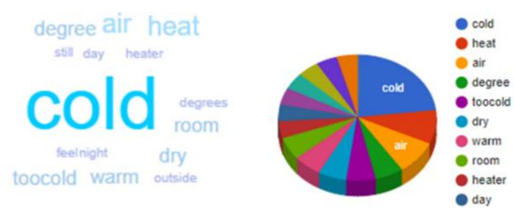

Figure 5 Example of results: word cloud automatically generated by the feedback provided by the students living in the Testbed KTH apartments

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