IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

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To cite this article: M Monsberger *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **323** 012123

IOP Conf. Series: Earth and Environmental Science **323** (2019) 012123 doi:10.1088/1755-1315/323/1/012123

An innovative user feedback system for sustainable buildings

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Abstract. A lot of research is currently focused on studying user behavior indirectly by analyzing sensor data. However, only little attention has been given to the systematic acquisition of immediate user feedback to study user behavior in buildings. In this paper, we present a novel user feedback system which allows building users to provide feedback on the perceived sense of personal comfort in a room. To this end, a dedicated easy-to-use mobile app has been developed; it is complemented by a supporting infrastructure, including a web page for an at-a-glance overview. The obtained user feedback is compared with sensor data to assess whether building services (e.g., heating, ventilation and air-conditioning systems) are operated in accordance with user requirements. This serves as a basis to develop algorithms capable of optimizing building operation by providing recommendations to facility management staff or by automatic adjustment of operating points of building services. In this paper, we present the basic concept of the novel feedback system for building users and first results from an initial test phase. The results show that building users utilize the developed app to provide both, positive and negative feedback on room conditions. They also show that it is possible to identify rooms with non-ideal operating conditions and that reasonable measures to improve building operation can be derived from the gathered information. The results highlight the potential of the proposed system.

1. Introduction

Energy efficiency plays an important role in the building sector. Aspects such as user behavior [1] or optimal operation of heating, ventilation and air-conditioning (HVAC) systems [2] have a significant impact on the energy consumption of buildings. Moreover, achieving a high level of user satisfaction is an important goal of building operation. Although standardized comfort models (e.g., Fanger [3]) provide a basic framework for the operation of HVAC systems, meeting the specific needs of building users is often a tedious and time-consuming process. In many cases, user dissatisfaction goes hand in hand with inefficient operation of building services, for example, if HVAC system set points or control strategies are wrong. In such cases, it is beneficial to determine optimum system settings in order to achieve both, a high degree of user satisfaction and energy-efficient operation. While many research activities focus on the analysis of sensor data to optimize building operation, so far only limited attention has been given to the immediate capture of user perceptions by means of individual user feedback and the use of such feedback for optimizing building operation. Field studies of mood-tracking applications have shown that techniques for reporting mood feedback are well accepted and can improve performance if the application is well integrated into the work processes [4]. For this reason, the research project FEELings (User Feedback for Energy Efficiency in Buildings) aims to develop an integrated user feedback system which allows building users to report their mood and personal perception of room conditions via a mobile app. In this paper, we will introduce the basic concept of the novel user feedback system and the design of the developed user feedback app. We also present initial results obtained from a first test period (roll-out phase), which show that the system provides the necessary functionalities to capture user feedback and to deliver relevant information to improve building operation.

2. Description of the integrated user feedback system

2.1. Overall system design

Figure 1 shows the overall concept and structure of the investigated user feedback system. The main system components are a mobile app representing the interface to building users and a database for storing the feedback along with measurement data.

Users are able to give feedback on room conditions via the app by specifying their mood and comfort level. Each feedback is tied to a specific location or room in the building. Users can set a default location such as their own office. If users want to give feedback on other rooms or buildings, they can enter a different location manually or semi-automatically via a QR code. In the future, localization may be done automatically by means of indoor positioning.

The user information is stored in a database together with measurement data (temperature, humidity, CO_2 concentration, light intensity etc.) and building service system data (HVAC operation parameters) of the corresponding room. Data analysis methods are subsequently used to identify room and operating conditions which are perceived as pleasant. In a first step, favorable conditions are reported to facility management staff who can manually adjust settings of building services systems for the rooms. In an advanced stage, the adjustment should be done automatically. This would lead to building services systems adjusting themselves according to the user feedback, meaning that system operation matches the user needs.

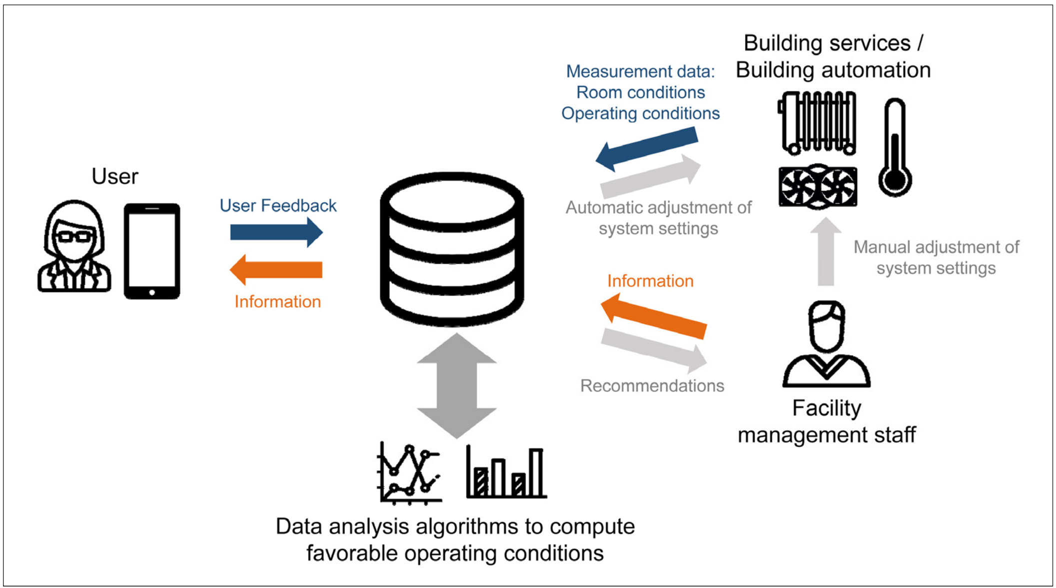

Figure 1. Concept of the user feedback system connecting building users, building services and facility management staff by means of data analysis.

Besides mood and comfort reporting, the app also provides additional functionalities in order to motivate people to use it. Users can report issues such as damages or failures of technical equipment to facility management staff (e.g., power or water failure, broken heating or air-conditioning etc.). In addition, the app can be used by facility managers to communicate with the building users, for example, to announce maintenance works. Finally, users can access statistical information based on the obtained feedback (e.g., frequency of feedback, building rating based on the feedback etc.). This information is very important to keep people interested in the app and consequently keep them as active users.

So far, the mobile app, a web portal and the database for storing user feedback and measurement data have been implemented and evaluated in an initial test phase. The development of data analysis algorithms to automatically detect preferable operating states has not yet started and is subject of the second phase of the FEELings project.

2.2. Design of the user feedback app

The developed user feedback app was implemented using the Ionic HTML5-based cross-platform framework [5]. Ionic was selected to cover Android, iOS and the desktop browser with one code base, drastically reducing development effort of the app.

After installing the app on a smartphone (or after opening the app in a desktop browser), users register with their e-mail address and select a default location by choosing the building and the room from a pull-down list or by scanning a QR code at the room entrance. Once registered, users can submit mood and comfort ratings and report issues.

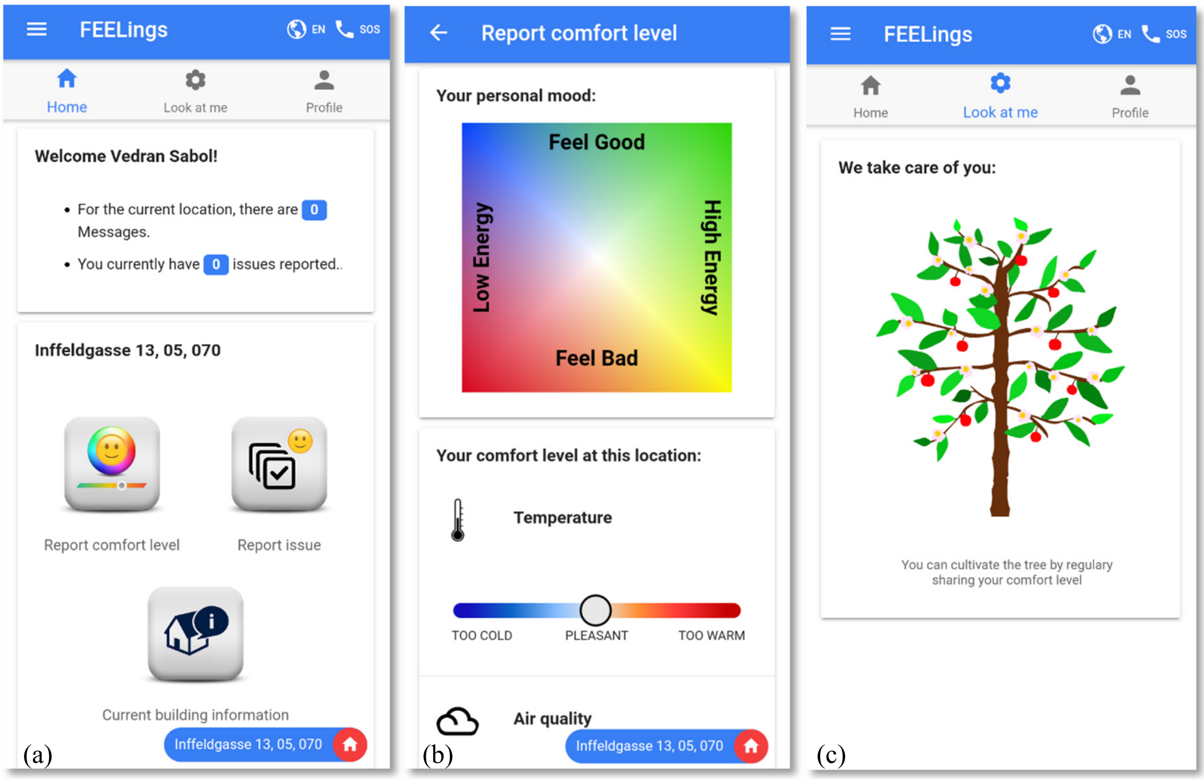

Figure 2. Design of the app: (a) home screen for navigating the app; (b) mood map and sliders for reporting user's comfort level; (c) a motivational widget which responds to the user's activities of submitting feedback.

Figure 2a shows the home screen displaying the user's name, the location, the number of reported issues and the number of messages from facility management related to the user's building. From here, users can select one of the three major functionality blocks of the app: (1) submit the current mood and comfort level; (2) report an issue specific to the room, building or environment; (3) obtain information on reported issues concerning the user's building.

IOP Conf. Series: Earth and Environmental Science **323** (2019) 012123 doi:10.1088/1755-1315/323/1/012123

Figure 2b illustrates the screen for submitting the personal mood using a mood map. The mood map is a rectangular area where the y-axis corresponds to how the user currently feels (*bottom – feel bad, top – feel good*), while the x-axis represents the user's energy level (*left – low energy, right – high energy*). By simply touching (or clicking) a specific position in the mood map, users can express their mood along these two dimensions. Furthermore, the comfort level can be specified more precisely using sliders representing temperature (*too cold – pleasant – too warm*), air quality (*fresh – ok – bad*), noise level (*quiet – lively – noisy*), light intensity (*too dark – pleasant – too bright*) and the type of activity (*sitting, standing or moving*). Optionally, users can submit a short message of up to 300 characters.

Figure 2c shows a motivational widget in the form of a tree: if a user submits feedback frequently, the tree will grow green; otherwise the tree starts losing leaves until the branches remain naked. We believe that using a natural metaphor, such as a growing tree, could motivate users to nourish the tree by reporting their mood and comfort level more frequently. Moreover, users may opt to receive bi-weekly or daily reminders to submit feedback.

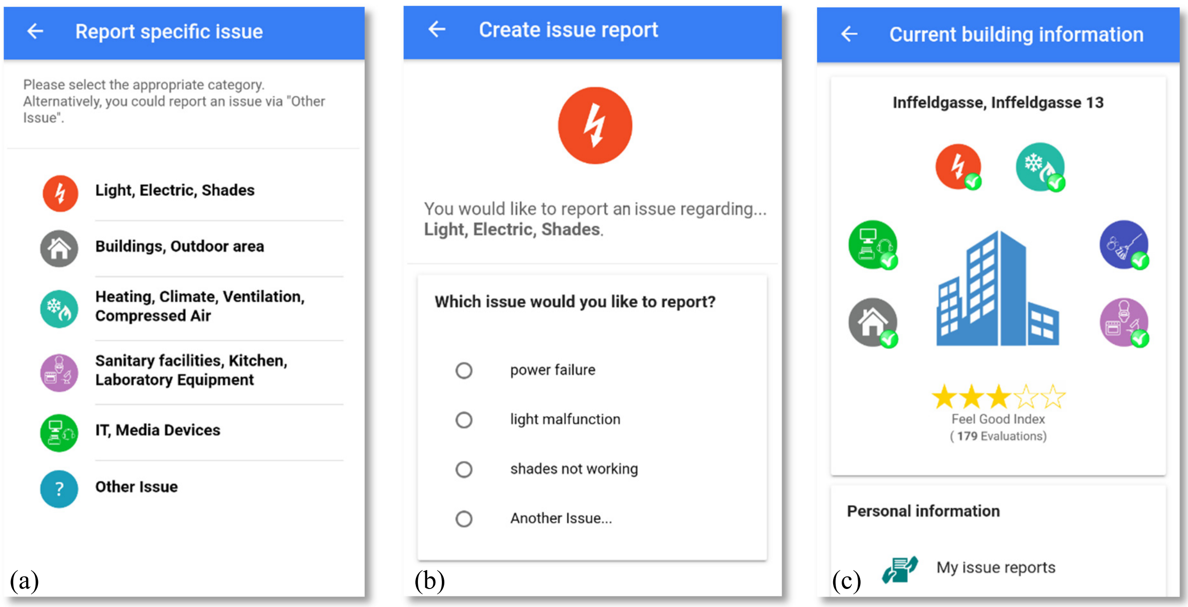

Figure 3. Mechanism for reporting issues: (a) selection of issue category; (b) more detailed specification of the problem; (c) overview of the state of a building in six categories.

Figure 3 shows the possibilities to report and monitor issues related to the room, the building or the outside environment. After selecting an issue category (figure 3a), users can choose from a list of predefined options to specify the issue in more detail (figure 3b). If no option describes the issue well enough, users can select the option "Another issue…" where it is possible to provide a textual description and to upload a photo of the problem. For later reference, users have access to all issues they reported. A reported issue is immediately sent to the maintenance service per e-mail, including a link to a web page containing all information submitted for that particular issue. The maintenance team can take action or, if necessary, request further information from the user.

Finally, figure 3c shows a status overview of the user's building for each of the six issue categories and a star rating calculated based on the submitted mood and comfort ratings.

3. Initial test results

3.1. Description of the first use case

The novel user feedback system is evaluated over a period of one year in four different use cases. A use case represents a monitored building in which users are asked to use the app. The use of the app, and therefore participation in the project, is voluntary. A building at the campus of Graz University of

Technology was selected as first use case. The seven-story building was put in operation in 2012 and accommodates offices, laboratories and seminar rooms. About 250 people currently work in this building. The building is equipped with a floor heating system operating in heating mode in winter and in cooling mode in summer. The temperature is controlled via four zones on each floor (i.e., no single room control). While a central ventilation system is available in all laboratories and seminar rooms, the ventilation of office rooms takes place manually by means of window ventilation.

The roll-out of the user feedback system for this first use case took place in December 2018 with an information event for the building users. The first two and a half months of operation are used as trial phase in order to test the basic functionality of the system, to get user feedback to improve the app and to eliminate bugs. After successful completion of this initial test phase, the system will be rolled out to the other use cases. The following results were obtained from this initial test phase which lasted from December 10, 2018 until February 28, 2019. A total of 55 users, i.e., about 20% of all building users, participated in this initial test phase.

3.2. *Frequency of comfort ratings*

Figure 4 shows the accumulated number of comfort ratings over time; sections with a high growth indicate an active use of the app, while constant sections correspond with no use (e.g., Christmas break with no app usage at all). Sharp increases correspond with information events (e.g., during roll-out) and e-mail reminders (e.g., on January 24, 2019) or with times with poor room comfort.

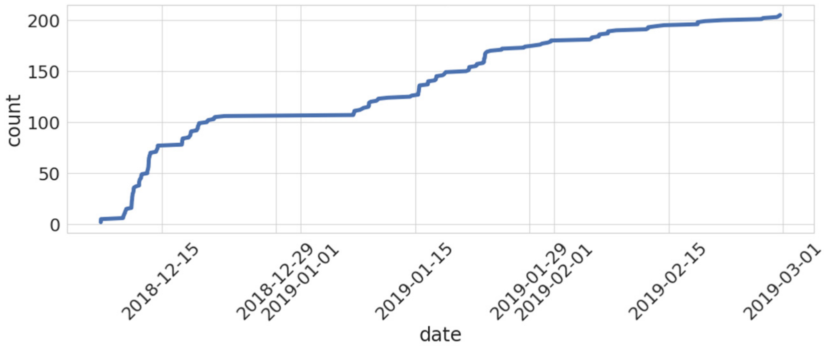

Figure 4. Accumulated number of comfort ratings over time.

The total of 205 app ratings can be broken down into specific feedback categories as shown in table 1. Part of the feedback was sent with default values preset by the app. There are two possible explanations for this. First, the default value matches the user's perception, or, second, the user did not want to provide feedback in a specific category and simply kept the default value. The number of default values varies significantly between the different categories. Table 1 shows that the mood map most often has a value different to the default setting, followed by air quality, temperature, noise, light and the work profile.

Table 1. Number of non-default feedback values per input category. Percentages relate to the total of 205 comfort ratings.

	Mood	Air Quality	Temperature	Noise	Light	Work Profile
Count	167	148	111	106	57	39
Percentage	81%	72%	54%	52%	28%	19%

3.3. *Distribution of mood ratings*

The feedback from the mood map (figure 2b) provides a first indication about the well-being of building users. Figure 5 shows the result (i.e., non-default feedback values) obtained for the selected use case building during the initial test period. The two-dimensional mood map was divided into nine areas of equal size in order to categorize and compare the user ratings. The overall mood feedback for the use case building is positive. A total of 114 mood ratings have at least a rating of *FEEL OK* and *ENERGY OK,* which corresponds to 68% of the overall number of non-default ratings. Moreover, 61 ratings belong to the *FEEL GOOD* and *HIGH ENERGY* group (upper right corner). On the other hand, 15 reported mood ratings fall into the *FEEL BAD* and *LOW ENERGY* category (lower left corner). A more detailed look at the data shows that the poor mood ratings come from eight specific rooms. An obvious conclusion from this result is that people generally feel comfortable in the building except certain rooms. The user feedback from these rooms was thus analyzed in more detail. First results for one particular room are presented in the next section.

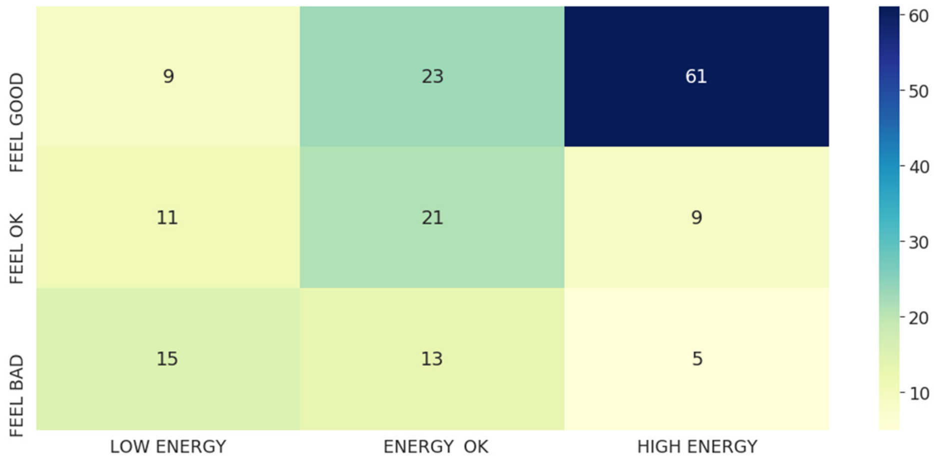

Figure 5. Heatmap encoding the number of ratings for nine mood groups of equal size.

3.4. *User feedback on room temperature for an office room*

Figure 6 shows the measured room temperature and the reported room temperature feedback over the initial test period for an office room with 14 occupants. The mood map feedback for this room was poor (FEEL BAD and ENERGY LOW) in comparison with other rooms. The room is equipped with two sensors (brand Tinkerforge, type Temperature Bricklet v1.1) positioned in the longitudinal axis of the room at one-third points at a height of approximately 1.4 m. The upper part of figure 6 shows the temperature profile measured by one of the sensors. Temperature values are recorded every five minutes. User feedback is illustrated in the lower part of figure 6. Each point corresponds with a reported temperature feedback using the temperature slider of the app (see figure 2b). The points' vertical positions in figure 6 coincide with the slider positions, covering the range *too cold – pleasant – too warm*. Five of the 14 room occupants participated in the test and provided feedback. One user only submitted one rating; the other users gave multiple ratings over the test period.

The average room temperature is around 26 °C as apparent from the temperature profile. This is a comparatively high value in winter months. The profile has downward spikes showing significant temperature decreases for short times. These spikes are caused by manual room ventilation. People who work in the office regularly open the windows when they arrive in the morning. This explains the absence of spikes during the Christmas break from December 22, 2018 until January 6, 2019 when the office was not occupied.

The amount of feedback of the four users is declining over time as figure 6 shows. While 25 room temperature ratings were received between December 10 and 22, 2018, only 15 ratings were received between January 6 and February 28, 2019. One possible reason is that people lost interest in the app, potentially because no action was taken to improve the temperature level in the room.

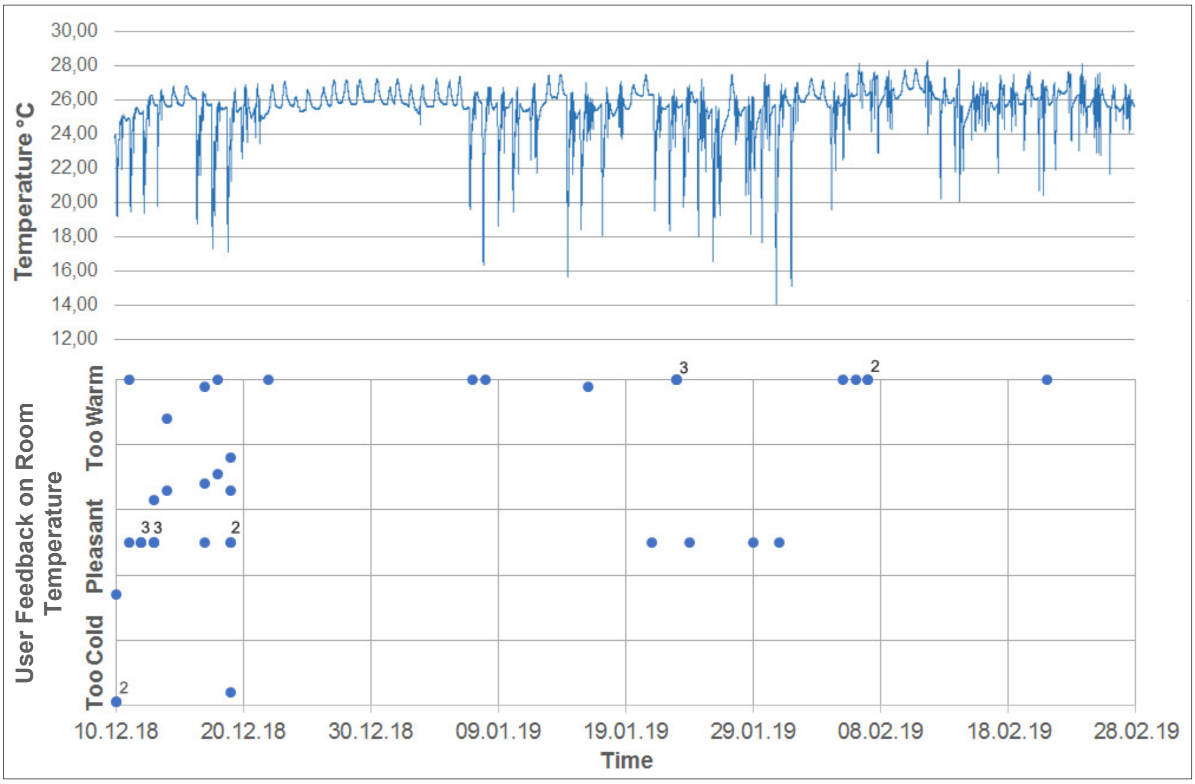

Figure 6. Measured room temperature and reported feedback on the temperature for an office room.

Figure 7 shows the temperature ratings against the measured room temperatures at which these ratings were submitted. Temperatures above 26 °C are rated as *too warm*. Ratings submitted between 25 °C and 26 °C vary between *pleasant* and *too warm.* The majority of ratings in the temperature range between 20 °C and 25 °C is *pleasant*.

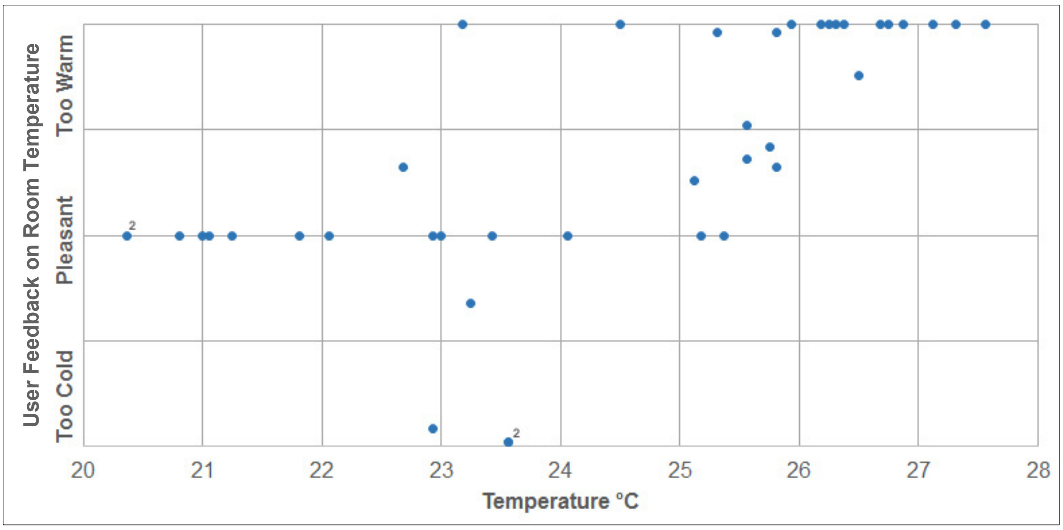

Figure 7. Feedback on the room temperature vs. measured room temperature for an office room (data from the test period between December 10, 2018 and February 28, 2019).

The results presented in figure 6 and figure 7 indicate that the average room temperature of around 26 °C is too high. A reasonable measure would hence be to adjust the set point of the heating system in order to reduce the temperature of this room. Such an adjustment would also reduce energy consumption for room heating. The practical implementation of this measure will be evaluated with the facility management staff. The impact of this step on the personal sense of users' comfort can in turn be monitored with the app. These initial results already highlight the potential for identifying non-ideal room conditions by using the proposed user feedback approach.

4. Conclusion and outlook

In this paper, we introduced a novel feedback system for building users and presented results of its initial test phase. The principal idea is to capture perceptions of building users about room conditions with an app and to compare the obtained user ratings with measurement data. The immediate user feedback makes it possible to determine whether given room conditions correspond with user requirements. The generated information is used to optimize the operation of the building with respect to both, user satisfaction and efficiency. In a first phase, the overall system was designed, set up and evaluated in an initial two-and-a-half-month test in order to prove the basic functionality. The results of this initial test have shown that users utilize the app to report both, positive and negative feedback. Based on this feedback, it was possible to identify rooms with non-ideal room conditions. In one example, users rated room temperatures during winter months as too high. This is an indication for facility managers to reduce the room temperature by adjusting the heating system. This example shows that the generated information can support decision making of facility managers. It can be concluded from the initial test results that the system provides the basic functionalities for capturing user feedback and delivering relevant information to improve building operation. In a next step, data analysis methods will be developed in order to automatically detect non-ideal room conditions. Information about such conditions will be provided to facility managers so they can optimize system settings. In an advanced stage, this optimization process should be done automatically by computing set points based on data analyses and by directly applying them to building automation systems. The proposed approach should help to increase the efficiency of building operation and the quality of building use.

Acknowledgements

The project FEELings (FFG Grant No. 861684) is funded in the framework of the program 'Stadt der Zukunft', which is a research and technology program of the Austrian Federal Ministry of Transport, Innovation and Technology. 'Stadt der Zukunft' is managed by the Austrian Research Promotion Agency (FFG) together with Austria Wirtschaftsservice Gesellschaft mbH and the Austrian Society for Environment and Technology (ÖGUT). Know-Center is funded within the Austrian COMET Program – Competence Centers for Excellent Technologies – under the auspices of the Austrian Federal Ministry of Transport, Innovation and Technology, the Austrian Federal Ministry of Economy, Family and Youth and by the State of Styria. COMET is managed by the Austrian Research Promotion Agency FFG.

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