SPELL: Affecting Thermal Comfort Through Perceptive Techniques

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Abstract
Thermostats allow people to set the temperature they desire, even if personal thermal comfort perception is tied to a number of external stimuli [9]. Here we investigate dependability of people's thermal comfort, from the multi-sensory features of environment (light colors). We want to prototype a system that influences people's thermal comfort through other stimuli instead of temperature changing. The preliminary Spell research envisions a smart system for heating control that proactively compensates temperature variations using light color variations, accomplishing both the objectives: to satisfy user request for thermal comfort, while optimizing energy consumption. Two preliminary experiments were made: one demonstrates that people's perceived temperature is different from the actual temperature in a space; the second one shows how lights color affects the temperature perceived by people. As a result we derived preliminary guidelines for the prototyping the Spell system. [1]

Author Keywords
Temperature, Perception, Smart Buildings

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ACM Classification Keywords
H.1.2 [User/Machine Systems]: Human factors.

Introduction and Goals
In last years, the interest of scientific community for an improvement of buildings energy efficiency is increasing. Pursuing this goal is encouraged also by different governments like the European Union with the Horizon2020 program [2]. In this scenario, the so called *smart buildings* - a complex system where the building environment is smartly managed by ICT - have been identified as a solution to increase the energy efficiency of such spaces [12]. In a smart building, thanks to the presence of the so called *smart technologies* (smart meters, smart thermostats, smart lights, smart appliances, etc..), it is possible to explore new paradigms of interaction between people and proactive smart energy systems, improving the quality of user experience [10]. Spell explores the potentialities offered by smart technologies to innovate the traditional approach toward thermostat and smart heating systems. We focus our attention on the perception of thermal comfort, which could be influenced by different external stimuli [6, 5]. As consequence, we need to rethink the way users interact with a thermostat, changing the current approach to temperature setting. How a smart proactive system for heating control can optimize energy consumption, while satisfying people's thermal comfort? We investigate how perceptive techniques can be used by the smart system to affect temperature perception and to provide a warmer or colder sensation to people, optimizing energy consumption for heating system. As first step we studied the use of light color as perceptive attribute.

Background and relevant work
In past years, the invisibility of energy was the main issue to solve, while attempting to create a users awareness around energy consumption. An increasing number of literatures [7, 8] demonstrated the psychological importance of receiving display feedback about energy consumption to guide users attention towards energy saving behaviors. Today innovative solutions are emerging, for example the smart learning thermostat Nest [4]: it aims to optimize energy consumption, learning from user's temperature setting and redesigning the interactive processes between people and the heating system. Previous researches investigated the relationship between light color and perception or associated meaning. Relevant for us was the research by Winzern and Albers who in [13] conducted some laboratory experiments to evaluate the influence of colored light on thermal comfort in aircraft cabin. The results showed that room temperature was perceived warmer with yellow light than in one with blue light. Furthermore, a number of studies were focused on the effect of multi-sensory embodied perception on people's thermal sensations [9] or ideas and thoughts [11]. As a result, we decided to use these conditions to innovate the approach to energy saving system design. Spell differs from contemporary thermostat because instead of annoying users with temperature setting and messages about energy consumption, it takes care of people's thermal comfort through light color changing and perceptive techniques, while optimizing energy consumption.

Experimental setup and results
In this preliminary phase of the Spell Project, we aim at observing on the one hand the difference between the real temperature and the felt one, while on the other the existence of the influence of the light color on the

Figure 1 The experiment was conducted for two days (the chart shows only the results of the first day). The chart shows the real temperature and the answers of the occupants of our lab, when they were asked to guess about the room temperature without knowing the actual value.

Figure 2 In the chart users perceived temperature is showed in parallel with the respective color of light (yellow and blue area). Yellow lights were used to create a warmer feeling, while blue lights for colder one. Dotted lines indicate absence of data. In day 2 from 13:00 to 13-45 we employ neutral light without collecting data

temperature perception. With these two goals in mind, we set two different experiments. Both the experiments were carried out at the JOL S-Cube Lab in Milan involving our colleagues in different surveys.

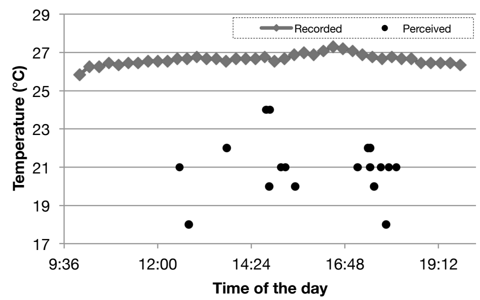

Figure 1: Results of the first experiment

First Experiment. The first experiment was to record the temperature of our lab through a sensor and to ask to the seventeen occupants which was the felt temperature (the users were asked to reply a survey sent by e-mail every two hours).

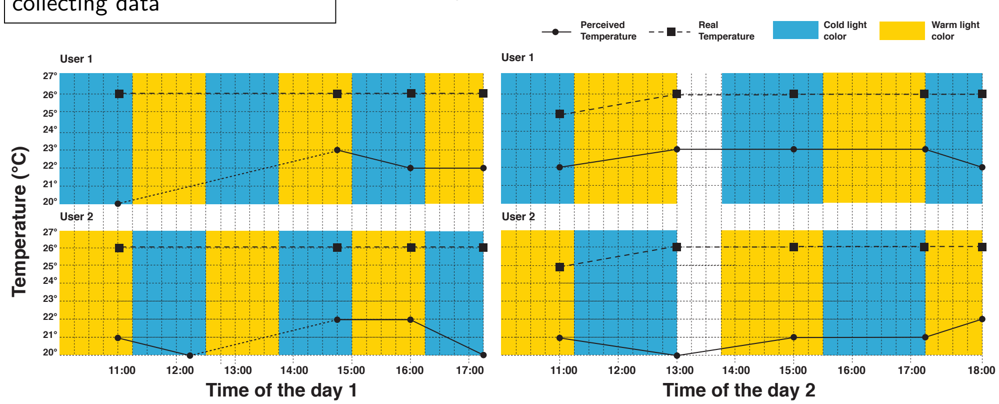

Figure 2: Results of the second experiment

The experiment was ran for two days (Fig. 1 shows the data of the first day). The experimental results showed that in the 100% of the cases, the users were wrong in guessing the temperature value: indeed, the difference between the real temperature and the felt one was about 2.76^{o}C in the best case, 8.66^{o}C in the worst and 5.73^{o}C in average. Thanks to the first experiment we demonstrated that people are not able to associate the number in ^{o}C to the real temperature in a space.

Second Experiment. During the second experiment, two desks were equipped with a Philips Hue Lamp each [3], so we could change the color of the light. We asked to people occupying those desks to use only the Philips Hue lamp. For two days during the working hours, we modified the color of the light (from cold to warm and viceversa) at specific time interval asking users, by e-mail, which was the perceived temperature after a while. The second experiment demonstrated that the perceived temperature has the tendency to be tied to the color of the light.

Envisioned system

According to these results, we outline two fundamental guidelines: **1.** Showing the temperature on a thermostat is not convenient since that numeric value does not directly reflects each user' subjective perception. Therefore a new interface has to be based on people expressing their feeling regarding their thermal comfort. **2.** A smart system for temperature control has to act not only on the HVAC (Heating, Ventilation and Air Conditioning) system, but also on other possible actuators (like the lights) able to modify the user's perception while being less energy expensive. Acting on the temperature perception instead of acting on the real temperature, let us to avoid the use of the HVAC system and consequently to save energy.

Example of user interaction

Let us suppose a user who's feeling cold. When he taps *I feel cold*, the red part starts to expand, providing users a first perceptive feedback.

Following these guidelines, we envisioned a new smart system for temperature control called Spell that we will explore and prototype in future researches: users will interact with Spell through an interface which allows them to express if they feel warm or cold in that moment. Since we think it is important to give the user a first feedback to start influencing the perceived temperature, the interface will start expanding the blue color by tapping on *I feel warm*, and viceversa the interface will expand the red color by tapping on *I feel cold* (see the figures on the left). According to the users input, in a first moment, Spell will raise or decrease temperature using the HVAC system. Then it will turn off the HVAC system, decreasing the energy consumption, but it will change the color of the environmental lights to compensate temperature variations. In this way, it is possible to save energy decreasing the usage of the HVAC system, and compensating the perceived temperature acting on perceptive elements (like lights color). Obviously, we expect the perceptive elements to be effective at the most for one or two degree with respect to the felt temperature; anyway this results is still important since, as confirmed by energy providers [1], every one degree difference on the temperature adds around 10% to the HVAC running costs.

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