# Human-Building Interaction in the Smart Living Lab

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## Abstract
This paper briefly introduces how we approach the domain of Human-Building Interaction (HBI) and describes a set of related ongoing projects in the framework of the Smart Living Lab in Fribourg, Switzerland. While each of these projects investigates a different aspect of Human Building Interaction (e.g. comfort, performance, awareness), they all share the HCI perspective with particular emphasis on long-term user experience at the individual as well as societal levels.

## Author Keywords
Human-Building Interaction, HCI, interactive technologies, comfort

## Introduction
The *smartlivinglab (.ch)* is a center of competence on the built environment of the future. Its goal is to envision the living spaces of the future, addressing environmental issues, and at the same time favoring occupants' well-being. It leverages the combined skills of three Swiss academic institutions in the areas of sustainable architecture, building engineering, law and human sciences. In this context, the *Human-IST (Human Centered Interaction Science and Technology)* research center is in charge of developing and evaluating interactive technologies to improve human-building interaction along several dimensions including hu-

man comfort, energy awareness and user understanding of building functioning. This particular approach considers three different types of building use with increasing remoteness: *a*) users directly experiencing the building, *b*) users observing its appropriate functioning (such as facility managers), *c*) and designers aiming to take use questions into account at an early design stage .

This article is a teaser; it is not meant to be exhaustive. It briefly introduces several ongoing projects carried out by our team along these lines.

## Human-Building Interaction

Human-Building Interaction (HBI) has been the subject of several recent research papers. On one side, computational researchers aim to create algorithms and frameworks that are able to better understand building occupants' behavior in order to build automatic systems that improve energy consumption and comfort [3, 4]. On the other side, HCI researchers have developed systems to improve occupants' awareness (about the energy consumption of the built environment) and have sought to impact their behavior for instance through visualizations, either ambient [8] or on-screen [2].

Starting with the observation that buildings are becoming more and more automated with increasing sensor and actuation capabilities, we adopt an HCI approach to study the specific case in which users inhabit the automated building itself, while directly experiencing the influence of their behavior on the building. In this sense, Human-Building Interaction aims at studying human behavior and interactions in and with buildings, and at developing and evaluating interactive artifacts, with the overarching aim to improve human comfort. The major dimensions of comfort should be analyzed using an interdisciplinary approach so that additional factors such as physical comfort of residents, their happiness, reduction in energy consumption and ways to improve social and energy awareness can be studied.

Currently, modern-day home automation systems tend to favor automatic control to achieve a definition of objective comfort that is meant to please an average inhabitant, and ensure lower energy consumption. However, when specific comfort needs are not met, the lack of user involvement in automation solutions often generates frustration. The approach presented here postulates that HBI should allow a certain level of mutual understanding to instantiate a *conversational* interaction between user and building.

## The Comfort Box

The Comfort Box uses HCI techniques to improve an occupant's personal comfort using sensing and interactive techniques. The Comfort Box, like a companion, is an interactive and empathetic personal device situated in the work or living space of an occupant, and is responsible for reflecting her or his personal comfort.

The first goal of the project is to understand and acquire user's comfort data. For that purpose we designed a sensor-system that collects data to measure the parameters that influence thermal, visual, acoustic and respiratory comfort. Further, the sensor-system has been designed so that it can reflect the user's comfort conditions back to them.

Consistent with the existing study on the crisis of discomfort [6], we have observed in a preliminary study [10] that there is a considerable time lag between the environmental sensors displaying that the inhabitant had left their thermal comfort zone, and the time when they take appropriate action (such as opening the window). For the case that is illustrated in Figure 1 this time-lag is about 30 minutes.

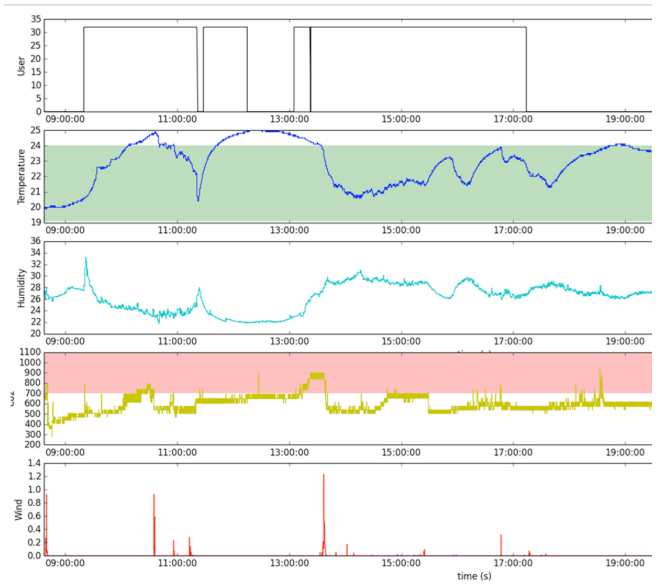


**Figure 1:** User comfort as observed by our Comfort Box. The second row shows that the user stayed approximately 30 minutes above the thermal comfort zone before taking action. Even worse, the 4th row concerns the $CO_2$ level; here again the user stayed in an unhealthy zone without noticing it fast enough.

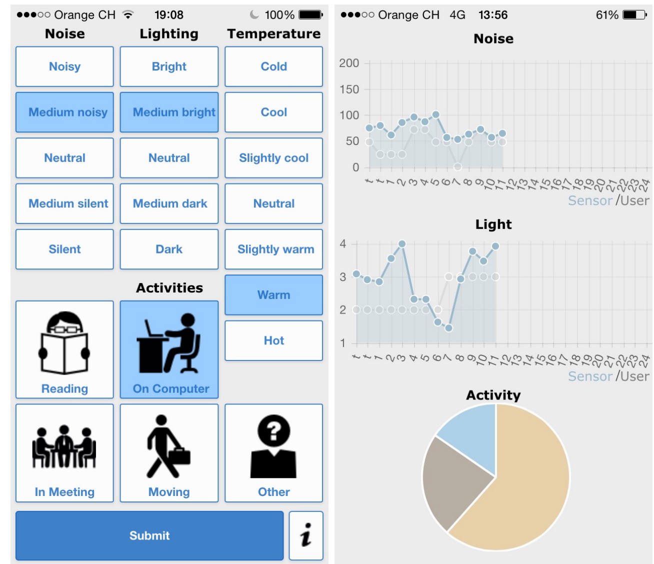


**Figure 2:** Smartphone application form to acquire perceived comfort (left) and the representation of the data recorded compared with objective data from sensors (right)

In a related project, we have developed a smart-phone application to acquire perceived comfort (thermal, lighting conditions, noise) through simple questionnaires in order to relate it to the environmental comfort measured with on-board sensors [7] (Figure 2). The newest version of the Comfort Box will mix the two approaches, personalizing the feedback — either ambient or through messages — for each user, so as to reflect not only environmental comfort data but also adapt the reflective interface to their comfort profile.

## Analyzing Human Indoor Interactions

We have developed a system that passively monitors participants' indoor locations within the context of social-networking events and provides an offline analysis of participants' networking behavior [9]. Throughout this project we created a functional indoor localization system based on RFID technology, capable of identifying the zones of individuals with decent precision. Such a system enabled us to leverage the principles of context-aware computing in the analysis of participants' interests and networking requirements during conferences and workshops. The system has been tested in an ecologically valid setting, and in addition to locating individuals, we were able to visualize the live interaction data

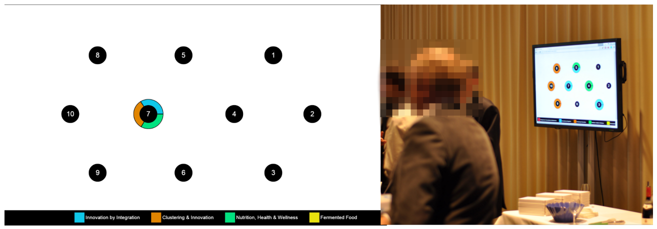

**Figure 3:** Live visualizations of tracking to support networking during social events.

between participants via a web service (Figure 3).

At the time of writing, we are developing a similar technology to track occupants in the Smart Living Lab in a non-intrusive manner, which is based on Bluetooth technology and iBeacons. We believe that such a technology will enable us to understand and analyze spatio-temporal interactions between inhabitants and the living environment, including artifacts. Furthermore, such an analysis can reveal the living behaviors of inhabitants (which differ from one individual to another), mitigating communication breakdowns between a human and the living environment, and render buildings more comfortable for their inhabitants.

## Building Data Visualization

To address the needs of experts to assess the adequacy of building automation systems, one of our Master's project aimed at using visual analytic techniques to take advantage of recorded sensor data. The goal was to develop an interactive visual tool to ease exploration of 3 years worth of data such as meteorological, space temperature, window blind control and HVAC data.

By linking a parallel coordinates plot with a circular heatmap and allowing users to easily control the display of vari-

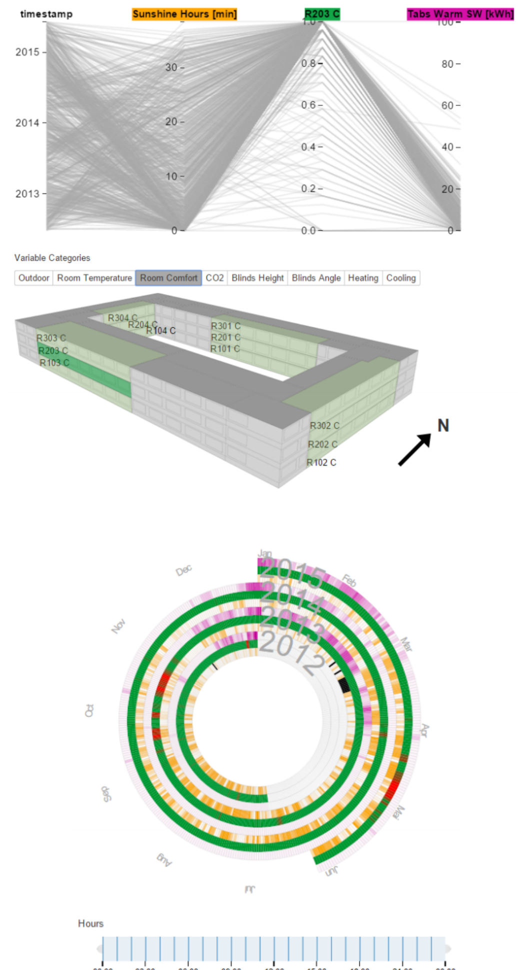


**Figure 4:** Interactive visualizations of real building data. A parallel coordinates plot (above) is linked with a circular heat map (below). A 3D model (middle) allows to intuitively select variables that are displayed in the above graphs.

ables through a 3D model of the building (Figure 4) [1], experts were able to make sense of spatial relationships that are difficult to spot in the raw data, and observe various building behaviors. For instance, they observed relationships between parameters such as high indoor temperatures were found to be correlated to the outdoor temperature, but not always in a specific room, thus suggesting the need to investigate room usage. They also observed outliers such as abnormally high temperatures in spring and autumn, which were found to be related to deliberate seasonal cooling deactivation. The HVAC used in the building could only be switched manually between the heating and the cooling settings. After initial qualitative testing, the project was well accepted by the experts overall, which encourages further development in this direction.

## Energy Awareness and Design Tools

Two other projects are also currently being pursued on the topic of HBI in our group. One develops interactive visualizations for a pre-design tool that enables to study relationship between the embedded $CO_2$ equivalent with the operating $CO_2$. Here, the aim is to empower designers to choose, early in the design process, strategies that present good total $CO_2$ performance for a specific building project [5]. The other looks at increasing user energy awareness to trigger behaviour change. The aim is to encourage users to shift their usage of appliances at a time when the $CO_2$ content of electricity is low, for example when the sun shines on the photo-voltaic panels, by proposing appropriate user interfaces.

## Conclusion

Human-Building Interaction is a novel research domain whose goal is to study humans' interactions within buildings, and to develop and evaluate interactive technologies to improve human-building collaboration towards energy efficiency, comfort, collaboration, etc. This article briefly introduces this domain and illustrates it with several research projects within the Smart Living Lab.

## Acknowledgments

The projects briefly introduced in this paper would not have been possible without the hard work of Master's students: Thomas Rouvinez, Leonard Stalder, Roman Baeriswyl, Moreno Colombo and Roman Kuepper. Their Master's thesis reports are available on the Human-IST website.

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