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"Our Inherent Desire for Control": a Case Study of Automation's Impact on the Perception of Comfort

Arianna Brambilla[a,b]*, Hamed Alavi[c], Verma Himanshu[c], Denis Lalanne[c], Thomas Jusselme[a], Maryline Andersen[a]

[a] *EPFL Fribourg - Building 2050 research group, Blue Hall, Passage du Cardinal 13B, Fribourg 1700, Switzerland*
[b] *School of Architecture, Design and Planning, University of Sydney, Wilkinson Building G04, NSW 2006, Australia*
[c] *Human-IST research centre – University of Fribourg, Avenue de l'Europe 20, Fribourg 1700, Switzerland*

Abstract

To investigate the relationship between occupants' perception of control over building elements and their comfort, we conducted a study where two prototype office rooms were compared: while the first room allowed occupants to open or close the window and configure the shading, the second one was fully automated. The quantitative analysis of collected data *a)* supports the existing results in the literature reporting higher satisfaction where manual control is maintained, and *b)* uncovers a new impact of highly automated systems**:** lower control over building elements can increase the occupant's consciousness of the environmental factors and the saliency of comfort parameters.

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1. Introduction

The trend towards highly energy efficient buildings, minimizing energy needs to provide comfortable indoor conditions, has motivated the development of Building Automation Systems (BAS). These systems typically employ

* Corresponding author. Tel.: +61-8627-6074
E-mail address: ing.ariannabrambilla@gmail.com

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human-instructed rules and intelligent algorithms to keep indoor environmental variables (temperature, lighting, etc.) within the standard comfort ranges. BASs have been widely studied and have demonstrated a significant energy-saving potential in many situations [1-3]. Nevertheless, advances in BAS technologies have typically been focused primarily on optimizing the tradeoff between energy use and objective comfort [4-6], overlooking the importance of the occupants' interactive experience with their environment. This has led to the current situation where maximum efficiency has been directly translated to minimum agency for the occupants. The problem has been underlined by recent studies showing that a lack of control over building or façade elements can induce a sense of frustration and discomfort [7-10]. An interesting study [11] highlighted the necessity of introducing a machine learning system to create a users-adapted BAS; however, the latest market trends are not oriented toward these types of solutions.

A multidimensional understanding of a building occupant's perception of control over the built environment is therefore of great importance, not only to improve user satisfaction but also to maximize the BAS energy saving potentials. The few studies that have addressed this concern so far tend to deal with one specific environmental parameter at a time (e.g. the impact of venetian blind control on visual comfort), decontextualizing the control question from the overall experienced situation. The present study investigates the relationship between user satisfaction and perception of control, while emphasizing the combined effect of selected comfort parameters. In the following sections, we first describe the prototype office spaces that provide the experimental conditions, the hypotheses and data collection methods. The last section draws conclusions and shows possible directions for future works.

2. Test Environment: The Rooms

Experiments were conducted in a 1:1 scale prototype, comprised of two office rooms (6x3x3m each) divided by an anteroom (1.5 m large), which was used also as technical room. The two rooms were geometrically identical and the internal disposition and furniture were also identical. The walls facing south were almost fully glazed, with the last 0.7m at a side openable as a single hopper. Windows integrated both an external louvre shading for solar control and an internal fabric roller shading for glare control (3% of light transmission). The external shading and the windows opening could be controlled both manually and by BAS. The rooms were independently heated and cooled by a ceiling radiant system and had the disposition for mechanical ventilation. Although the rooms were built identically, one room was kept fully automated, with mechanical ventilation (hygienic air-flow rate 50 m3/hr), shading system controlled by BAS, and no possibility of opening the windows or overriding the system; this scenario is called the "High-tech" condition. The other was manually operated and no mechanical ventilation was applied, and created the "Low-tech" condition.

3. Hypotheses

To build up a multidimensional understanding about the influence of perceived control over the environment, we compared the High-tech and Low-tech conditions in terms of visual, thermal, and general satisfactions. In particular, the following hypotheses were tested:

- **H1**: Overall satisfaction of the indoor environment is higher in the LT condition than in the HT condition.
- **H2**: Thermal satisfaction is higher in the Low-tech condition than in the High-tech condition.
- **H3**: Visual satisfaction is higher in the Low-tech condition than in the High-tech condition
- **H4**: The preference for the Low-Tech condition is influenced by psychological components (i.e. even when no physical difference or tangible change is observed, the occupants report less satisfaction in the High-tech condition). Such effect has been found in similar studies [12, 13].

4. Experimental Design

4.1. Participants

The experiment followed a within-subjects design, that is, the same group of participants was tested under both the scenarios. To control for the order effect, we used a counterbalanced design in which the subjects were divided into two different groups, testing the rooms in reversed order. In total 19 (32% women) adults participate to the experiment.

The average age was 29, ranging from 23 to 47 years old. Despite the high number of researchers among the test subjects (9 on 19), only 16% regarded themselves as an expert in the domains of comfort and energy efficiency. The participants were asked to perform a regular standardized office task during the experiment in both conditions. The participants were recruited among the smart living lab partners and were compensated for their participation with chocolates.

4.2. Experimental procedure

Two scenarios were tested: BAS controlled room (High-Tech) and manually-operated room (Low-Tech). The whole procedure took around 150 minutes, during which participants were exposed to: 15 minutes of initial trial, one hour with the first condition, 15 minutes of break, and finally another hour with the second condition. This time was enough to accomplish the acclimatization process without triggering the learning effect, based on which testers could get used to a space. The experiments took place at the same time of the day, starting at 1:15pm, in order to recreate the same boundary scenarios. The procedure followed in each session was the same and standard instruction were given to the subjects. An explanation of the procedure and the rooms were given during the initial trial, after which subjects were left alone to get used to the environment and start the experiment. In each condition, the participants were asked to fill-in a questionnaire (printed on paper), which was divided into two parts corresponding to preliminary- and post-assessment of comfort variables. In either condition, the participants were requested to complete the first part of the questionnaire (10 - 15 minutes) followed by a task to read and summarize an article displayed over a computer screen (30 minutes). Finally the participants were asked to complete the second part (post-assessment) of the questionnaire (10 - 15 minutes). The participants could choose the articles from a collection of articles; each participant picked two different articles for the two conditions.

4.3. Data Collection

We collected two types of data - objective environmental conditions and subjective (perceived) assessments. Environmental parameters included indoor and outdoor air temperatures, relative humidity, luminance level and carbon dioxide concentration for both rooms. The monitored data were used to track the indoor environment and assure that no significant deviation between High-Tech and Low-Tech indoor conditions occurred. The sensors were placed in the two rooms in identical position. The rooms were equipped with a VAISALA GMW93R transmitter (humidity, temperature and CO2 detector), which was placed at the center of the internal wall at 150cm height. Moreover, a horizontal luminance sensor (DeltaOhm -VPHOT03BLAK) was placed on the desk, in the middle position between the computer screen and the window. In this way, the environmental data corresponds to the three main dimensions ascribed to indoor environment quality - temperature, humidity, CO2 concentration, and luminance. The questionnaire was organized in five different sections. The first section mainly collected demographical data about the subject, such as age, gender, profession, self-appraisal of sensitivity on environmental conditions (cold, hot, noise, etc.). The second section inquired about the environment and was asked to be filled at the beginning, before the office task in the first condition. The survey included questions about thermal sensation vote, thermal satisfaction grade, general environment assessment, lighting and glare vote, visual comfort assessment, and reasons to the answers. The third section was exactly like the second section, but was filled after the office task, giving the possibility to notice the acclimatization process. The sections aimed at collecting data about the perceived comfort were repeated for both the High-Tech and Low-Tech conditions. The fifth section collected general impressions on the importance of having control over the façade in relation to the completed experiment.

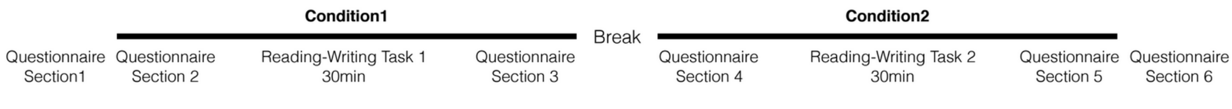

Fig. 1. Schematic illustration of the experiment's procedure. During the time spent in the two conditions participants had to fill a preliminary section with environmental perceptions rates, compile with assigned task (reading an article and writing a summary) and then fill the successive questionnaire section, which was asking again to rate the environment. This procedure is repeated for both High-tech and Low-tech conditions.

The thermal vote adopted a seven points scale, ranging from hot to cold with the possibility to choose the option neutral. For the satisfaction assessments, instead, the scale used was a six points scale, without any neutral or unclear option, obliging participants to think about their perception and to assign a value, whether as slightly (un)comfortable or very (un)comfortable.

5. Data Analysis and Results

In this section, we first report the results of the statistical tests that we ran to validate the aforementioned hypotheses using ANOVA (Analysis of Variance) and T-Test. Next, we present the result of our attempt to extract the most influential parameters that construct the overall perception of environment. This is accomplished through applying Principle Component Analysis (PCA) on the questionnaire data. Before conducting analyses, the questionnaire data was normalized to accommodate the different scales for different kinds of questions. All the values were normalized in the range of [0, 1].

Table 1: A table displaying the mean and standard deviation of different comfort variables before and after the exposure to the room. The F-value, Df, and p-value correspond to the statistical difference amongst the conditions using ANOVA. The higher values corresponding to different variables are stated in blue color

Variable Name	*Assessment*	**Low-Tech room**		**High-Tech room**		**F-Value**	**Df**	**p-value**
		M_{LT}	**SD_{LT}**	**M_{HT}**	**SD_{HT}**			
Overall Environment Assessment	*Pre*	0.58	0.16	0.61	0.21	0.11	34.10	.74
	Post	0.64	0.20	0.55	0.27	1.25	31.35	.2
Visual Comfort	*Pre*	0.60	0.24	0.63	0.24	0.16	35.90	.68
	Post	0.64	0.18	0.61	0.24	0.22	33.64	.64
Thermal Comfort	*Pre*	0.62	0.21	0.58	0.22	0.19	35.80	.66
	Post	0.64	0.25	0.56	0.26	0.81	34.97	.37

H1: *Overall satisfaction with the indoor environment is higher in the Low-Tech condition.*

As shown in Table 1, participants in the Low-Tech condition perceived higher comfort as compared to the High-Tech condition in their post-task assessment i.e. after spending time in the rooms (MLT = 0.64, MHT = 0.55). However, this difference was not statistically significant. On the other hand, in their pre-task assessment, participants reported higher overall comfort in the High-Tech condition as compared to the Low-Tech condition (MLT = 0.58, MHT = 0.61). However, this difference was also not significant.

H2: *Thermal comfort is perceived higher in the Low-Tech condition.*

The mean value of perceived visual comfort was observed to be slightly higher in the Low-Tech condition (MLT = 0.64, MHT = 0.56) than the High-Tech condition after performing task in the rooms, as shown in Table 1. Furthermore, their initial perceptions demonstrate a similar trend where thermal comfort was perceived to be higher in the Low-Tech condition (MLT = 0.62, MHT = 0.58). However, both these differences were not statistically significant, therefore we cannot consider the validity of H2.

H3: *Visual comfort is perceived higher in the Low-Tech condition.*

The participants reported higher visual comfort in the Low-Tech condition, in their final assessment (MLT = 0.64, MHT = 0.61). However, this difference was not found to be statistically significant. Furthermore, the preliminary perception of participants' visual comfort demonstrates a reversed trend, where visual comfort was perceived to be higher in the High-Tech condition (MLT = 0.60, MHT = 0.63). Again, this difference was not found to be significant.

H4: *The preference for the Low-Tech condition is influenced by psychological components*

- Out of the 7 participants who reported higher satisfaction, visual comfort, or thermal comfort, only 3 manipulated the window in Low-Tech condition.
- In none of the experimental sessions that conducted in High-Tech condition, the automated shading or ventilation activated, rejecting the conjecture that the malfunctioning of automation system gave comparative advantage to the Low-Tech condition.
- No significant variation in High-Tech and Low-Tech lighting and thermal environment was detected by the sensor network to justify any difference in the participant's' ratings.

- Table 2 shows the change in the perception of comfort before and after spending time in the two conditions. The direction of change in the Low-Tech condition is positive, indicating improved underestimation of comfort. The effect is opposite in the High-Tech condition suggesting that the participants overestimated the provided comfort by the automation system.

Table 2: A table summarizing the change in participant's perception before and after treatment. ΔLT, ΔHT correspond to the mean value of the difference in the preliminary- and final-assessment of the comfort variables. The t-value, Df, and p-value correspond to the t-tests performed to assess the difference in the mean change in perception.

Variable Name	Δ_{LT}(mean)	Δ_{HT}(mean)	t-value	Df	p-value
Overall Environment Assessment	0.055	-0.044	1.307	32.22	.20
Visual Comfort	0.044	-0.021	1.299	33.09	.20
Thermal Comfort	0.011	-0.021	0.637	34.89	0.528

These four aforementioned findings indicate that there exists a strong psychological component that drives the perception of comfort in relation to the degree of control. In the next section, through the analysis of principal components, we further explore this aspect by identifying the cluster of variables that collectively explain the user experience in the built environments.

5.1. Principal Component Analysis (PCA)

All the perception variables in the questionnaire corresponding to the thermal, visual, and overall comfort, from the pre- and post-assessment in the two conditions, were used as input to the PCA. The first five principal components (PCs) were observed to collectively explain 82.95% of variance in the data, and the first two PCs accounted for 62.47% of variance. We observed that the first PC was significantly correlated with the visual, thermal, and the overall perceived comfort parameters, suggesting that it corresponds to the overall satisfaction with the environment, and these contributing parameters can be replaced by this PC. Furthermore, the variables recording the perceived glare and the disturbances caused by it while performing the task were found to be significantly correlated to the second PC, indicating visual discomfort while performing the task. Furthermore, the variables representing visual comfort and satisfaction with the light level were found to be negatively correlated to the second PC. The interesting observation that came out of the PCA, however, was the dispersion of the individual's comfort perception in the reduced dimensional space, which was found to be remarkably higher for the High-Tech condition as compared to Low-Tech condition, along the first PC. As the first PC is strongly correlated to the perceived comfort, one can imply that the spectrum of participants' comfort perception was higher in the High-Tech condition. This higher variability in perceived comfort might signify to a sense of attention or consciousness that is induced as a result of loss of control due to automation.

6. Summary and interpretation of results

The quantitative analysis for this pilot study revealed the three following points, two of which support the existing research literature while the third sheds light on a new aspect of the "building control" question:

- Reinforcing the previous studies' results, our findings showed that the perception of control is positively correlated with the perceived comfort and overall satisfaction.
- The general preferences for low-tech condition seem to have psychological reasons, since only few participants who reported higher satisfaction in low-tech condition exercised their choice to change the configuration of window or shading.
- Interestingly, the observed spectrum of (reported) satisfaction level was found to be more dispersed in the high-tech condition as compared to the low-tech condition. One possible explanation for this expansive range of responses can be attributed to the heightened consciousness of participants about environmental factors when the control is taken away from them. This may lead to a situation where the occupants are more attentive to their indoor experience, which when coupled with personal preferences may result into highly varied responses.

7. Conclusions

The results showed that comfort sensation is related to physical environment, but also to more hidden psychological components such as the perception of control over our surroundings. The participants in our study pointed out higher satisfaction in the manually operated room, without really operating the façade. One can conclude that the mere idea of maintaining control and the possibility of modifying the environment if necessary is powerful enough to act as a placebo for comfort sensation. The effect is more visible in the test-group that first tried the manually-operated scenario: even if the majority didn't operate the façade, when control's possibility is taken away; they responded to the cognition of reduced control arising the expectation about the indoor environment and the comfort's thresholds. It is noticeable that some general comments made by participants pointed out the preference of having a manual tilt-and-turn windows more than a motorized casement, despite any of the testers considered the system difficult or not-straightforward to use. Despite the variable range of population used as testers, few participants described themselves as scientists with research interest in energy and/or built environment, when asked about their profession. It is expected that this could lead to a slight bias, in that some might want to adapt their answers to fit their perception of what constitutes a comfortable environment, rather than rate what they actually felt in the different conditions. This paper presents a pilot study, which highlights the necessity of a deeper and more comprehensive investigation on the relation between the psychological desire of control and comfort perception. Future works should also study how these interactions could change in an open-office, where different personal requirements must be negotiated.

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