ECO-NUDGING: INTERACTIVE DIGITAL DESIGN TO SOLICIT IMMEDIATE ENERGY ACTIONS IN THE BUILT SPACE

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Abstract. In the built space, building occupants, their behaviours and control actions are research areas that have gained a lot of attention. This is well justified since energy behaviours can result in differences of up to 25% in building energy consumption. Previous research recommends exploring ways to influence occupants' energy behaviour – through eco-feedback and by directly engaging occupants with building controls. Very little attention has been given to the role digital art and design can play in soliciting and changing human energy-related actions and behaviours in the built space. This paper proposes a new process that combines eco-feedback, gamification, and ecological digital art to trigger occupants to take immediate and precise control actions in the built space. We design, deploy and test this by creating an immersive human-building-interaction apparatus, which we place in a month-long exhibition. This experimental interface was informed by a novel vision for engagement-based human-building interactions deeply rooted in aesthetics, digital art and design. It also uses digital art to mediate between the occupants and energy-performance of spaces by redefining their relationship with and perception of energy – moving from metrics and quantities understanding to one that is art and emotion-based. The analysis reveals that this new type of human-engagement-based interactive building-control mechanism can add a significant layer of influence on energy-related actions – without revoking the individuals' ability to control their environment. It also highlights digital design and art's power in guiding actions and interactions with the built space.

Keywords. *Human building interactions (HBI); occupant behaviour (OA); ecological feedback (eco-feedback); gamification; energy behaviour; immediate actions.*

ملخص. قد وجد أن سلوكيات شاغلي المباني قد ينتج عنها اختلافات تصل الي 25% من استهلاك الطاقة. وقد تم توجيه الاهتمام للبحث في طرق جديدة لتغير سلوك شاغلي المباني لتقليل الاستهلاك و الكثافة الاستخدام. وقد كانت الأبحاث السابقة توصى بإيجاد طرق للتأثير على استهلاك الشاغلين عن طريق إشراكهم في محددات المباني من خلال تفاعلات ذكية. ولم يكن هناك الاهتمام الكافي للدور الذى يقوم به الفن الرقمي لتغيير نمط المستعملين للطاقة. هذه الورقة البحثية تقدم وسيلة جديدة لدمج المعلومات البيئية المستمدة بالتناغم مع التصميم الرقمي للتأثير علي شاغلي المباني لاتخاذ خطوات جادة وسريعة لضبط البيئة المبنية . نصمم وننفذ ونختبر فكرة لربط بين الإنسان والبيئة المبنية من خلال تجربة تم عرضها لمدة شهر .هذه التجربة التي بنيت علي الربط بين التفاعل بين الإنسان والمبنى وربطهما معا بالفن والتصميم الرقمي الجمالي .و أيضا استخدمت الفن الرقمي للتوسط بين السكان وأداء الطاقة في الفراغات بإعادة تحديد العلاقة بينهما وبين مفهوم الطاقة وذلك بالانتقال من القياسات المترية والكمية الى قياسات تعتمد علي الفن وترتكز على التفاعل العاطفي. وقد أظهر تحليل هذه البيانات أن آلية التفاعل بين الإنسان والبيئة المبنية يمكنها إضافة أبعاد جديدة للتأثير في تصرفات المستعملين الخاصة بالطاقة بدون تحجيم قدرتهم علي التحكم في بيئتهم المحيطة. وكذلك تلقى الضوء على قدرة الفن والتصميم الرقمي على توجيه التفاعل مع البيئة المبنية.

الكلمات المفتاحية: *التفاعل البشري مع المباني، سلوكيات شغري المباني، تفاعلات بيئية، تحكم بيئي للمباني*

1. Introduction

In the built space, building occupants, their behaviours and control actions are research areas that have gained much attention. This is well justified since energy behaviours can result in differences of up to 25% in building energy consumption (Stazi *et al.*, 2017). Additionally, building controls are one of the areas that have been rapidly advancing due to the application of new information technologies, such as automation, artificial intelligence and big data (Day *et al.*, 2020). Most of the current work on the topic is focused on predicting occupant behaviour and automating building controls, without intending to change occupants' behaviour nor their modes of interactions with the building and its components (Swaminathan *et al.*, 2018; Tamas *et al.*, 2020). However, these smart building controls' technical, social and ethical challenges are becoming ever more apparent.

On the other hand, eco-feedback, which aims to inform users or actors about the consequences of their actions to reduce negative impacts, has been reported as an effective means for influencing behaviour (Buchanan *et al.*, 2014; Jain *et al.*, 2012; Khosrowpour *et al.*, 2018). Adversely, little attention has been given to studying the design parameters, game-logics, and the logics that can allow feedback technologies to solicit specific behaviours from occupants.

This paper moves beyond the current mainstream building-control automation research and other forms of "smart utopias" (Darby, 2014) to explore a new engagement-based process that combines eco-feedback, gamification, and ecological digital art to trigger occupants to take immediate and precise control actions in the built space. Through this exploration, the paper attempts to answer the following question: *Can real-time artistic eco-feedback be an effective way to trigger targeted indoor environmental control actions?*

2. Background

2.1. CONTROLS AND OCCUPANT BEHAVIOR

Occupants' behaviour and their priorities are influenced by various external factors (Ozcelik et al., 2019; Stazi et al., 2017). Today, many automation and control models, even those proposing what is known as human-in-the-loop controls, assume that discomfort is one of the major drivers for triggering interaction with building controls (Aryal and Becerik-Gerber, 2018; Gupta and Kar, 2018; Park et al., 2019).

While meeting the occupants' comfort expectations appears to be a relevant strategy for smart controls, it might be missing on the potential to direct users to take more environmentally favourable actions. Also, in the context of the global environmental crisis (Jain et al., 2012; Vandevyvere and Heynen, 2014), comfort-focused control approaches disregard many important ecological, ethical (related to prioritizing humans and their over nature or resource consumption), cultural/beliefs and even biological factors (Cole and Brown, 2009). Additionally, many studies have highlighted that occupants willingly accept minor or temporary discomfort – when given the correct, material or psychological, incentive, in the form of rewards or compensations (Deuble and de Dear, 2012; Eichler et al., 2017).

Thus, the question arises, *how can occupants be persuaded to take control actions that are more favourable to the building or the environment?*

2.2. ECOLOGICAL FEEDBACK

Feedback, and ecological feedback in specific, is one of the external parameters known to influence human behaviour in built spaces (2014). Previous work, such as that of Jain *et al*. (2012), has shown that the engagement-character of control interfaces or their interactive-ness is directly linked to possible energy reduction. Other studies have also reported on the success of eco-feedback in raising awareness and possibly creating medium and long-term occupant behaviour changes (Buchanan *et al.*, 2014; Gulbinas and Taylor, 2014; Tiefenbeck *et al.*, 2019).

However, the current work on eco-feedback remains focused on long-term metrics and overall consumption and saving trends. Certainly, the consequences (such as energy savings) are essential to consider in eco-feedback approaches' success. However, little research has attempted to study directly the range of actions that can result from eco-feedback – precisely immediate actions that answer to eco-feedback. Also, very little attention has been given to understanding the role digital art and design can play in the process of soliciting and changing human energy-related actions and behaviours in the built space (Gunay *et al.*, 2014; Orland *et al.*, 2014; Zhuang and Wu, 2019).

While Janda (2011) suggest that we approach eco-feedback in buildings as a form of pedagogy, most published work depends on providing occupants with direct data (such as energy consumption metrics or savings metrics) or messages (such as red indicators for high usage and green indicators for eco-usage, or text information related to comfort or efficiency) (Zhuang and Wu, 2019). This approach is novel and has been barely explored in the built environment – except for the work of (Cucuzzella, 2019; Cucuzzella *et al.*, 2019). Also, little published research have focused on exploring ambient and alternative (i.e. non-technical and non-quantitative) eco-feedback and interfaces – with few exception such as the work of Rodgers and Bartram (2011).

3. Methodology

To answer the proposed research question and to explore the potential of artistic and ambient eco-feedback to trigger targeted, or specific, indoor environmental control actions, we design, deploy and test an immersive human-building-interaction apparatus. We place our experiment in a month-long exhibition. The setup included a living-room-like space, equipped with 3-indoor environment devices (a heater, fan, and 2-lights), and a large screen with a control pad. The large screen allowed for an immersive experience. Each of the 3 devices included a non-invasive AC current sensor. We use electric current information to create real-time artistic visualizations. We design 3 different profiles (sleep, workout and study) with different target levels for the equipment (for example, in the sleep profile, the heater was set to level 1, and the fan and lights are off). The setup can be seen in Figure 1.

Figure 1. Experiment Setup

The logic of the interface was designed to be simple. When the participants first enter the space, they are prompted to reset all devices to the zero (0) level, pick up the control pad, and select one of 3 profiles. Each of the profiles had its specific device target levels. The artistic visuals moved a cross a spectrum of conditions, between *two opposing extremes*: (1) a state of harmony and (2) a state of agitation. As the devices' settings approach the target levels, the visual would progressively approach harmony. We made the difference between the two states very obvious during the design process. Figure 2 shows an example of the workout profile transition from harmony to out of sync.

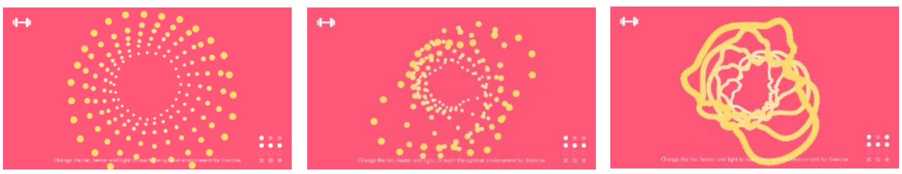

Figure 2. The workout visuals in the harmonious, uneasy (intermediate), irritated states (from left to right)

The interaction's goal was for the participants to arrive to a state of harmony by executing control actions on the 3 devices. We gave the participants the option to use hints along the way (which appeared in the form of text on the screen) – to help them achieve the target. When the users were satisfied with the settings, they were required to press "SUBMIT". Figure 3 presents the overall interaction process.

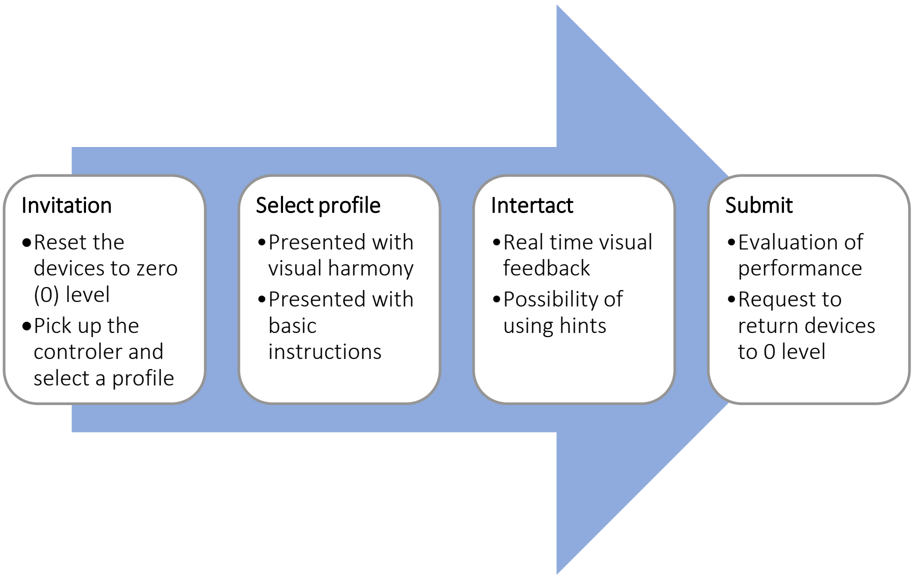

Figure 3. Interaction process

We collect data about the time it took for the users to from the start of the interaction to the moment they submitted, the number of hints used for each interaction, and the 3 devices' levels at the SUBMIT moment. We assess the submitted answer's accuracy, ranging from 3-all correct, 2 or 1 – partially correct, and 0-incorrect. We complemented the quantitative data with informal discussions with the participants.

4. Results and Discussion

4.1. GENERAL RESULTS

We collect 197 data points throughout the month-long setup. The basic data analysis shows that in close to one-third of the cases, the participants were able to arrive at the correct settings for the selected profile. In about 50% of the time, they figured out one or two of the parameters, and in less than 20% of the cases, they were not able to get to any correct parameters. These results are illustrated in Figure 4 (left).

We find that the average number of hints used was 0.7 (median of 0 hints, and a mode of 0 hints), with a standard deviation of 1.4 hints. The distribution shows most participants did not use any hints (about 65% of the cases) and about 20% of the cases 1 hint was used, and in about 15.75% of the cases two or more hints were used. These findings are illustrated in Figure 4 (right).

The engagement time recorded for the cases had an average of 27.6 seconds and a standard deviation of 24.9. Figure 5 presents the Pareto chart of the engagement time, showing close to 50% of the cases below 20s of engagement time.

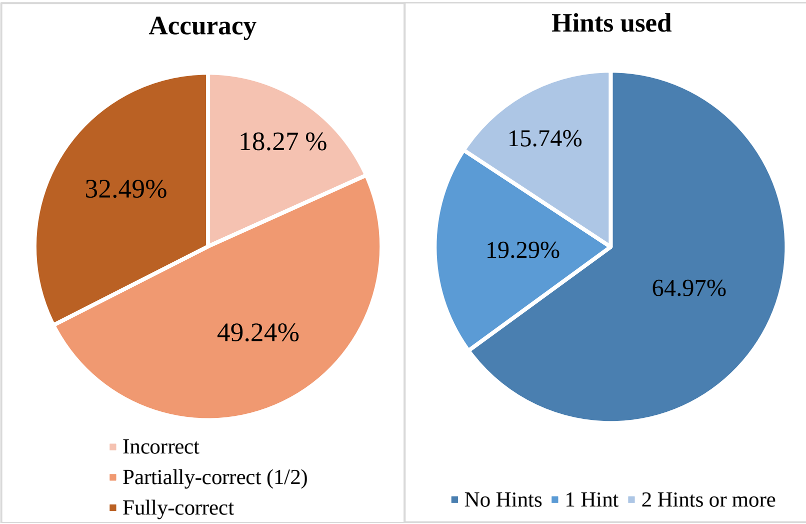

Figure 4. Results – left: accuracy and right: hints used

The results show that the artistic eco-feedback setup we used was able to trigger occupants to take the specific control actions required and reach all or some of the correct parameters in more than 80% of the time. To reach the device levels of the profile required the participants to modify 3 independent devices. It is important to note that the participants did not have earlier knowledge of the required device levels, they did not know how their control actions affect the visuals they saw on the screen, and they had no numerical/quantitative data related to the devices' energy. They also did these control actions with little or no assistance (in the form of hints) and were able to attain outcomes in less than 20 seconds.

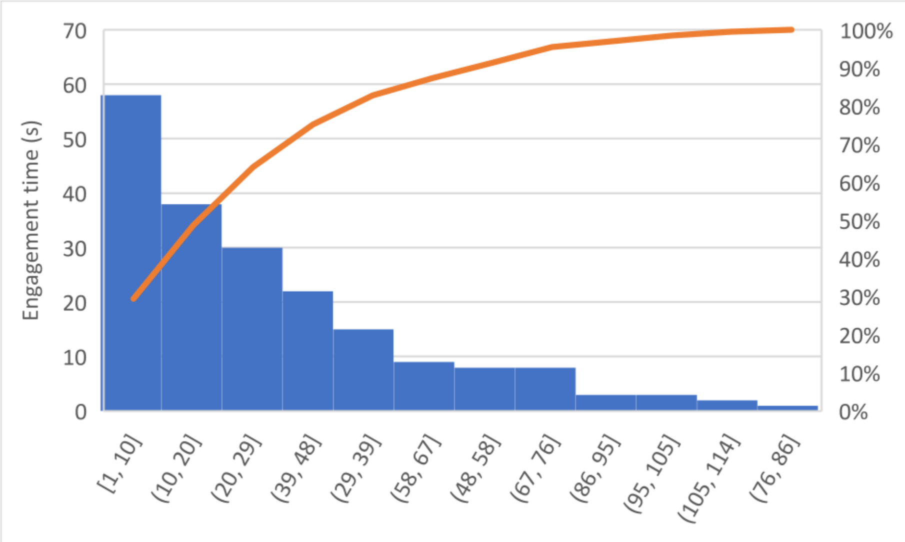

Figure 5. Pareto chart for the engagement time

4.2. CORRELATIONS BETWEEN EXPERIMENT PARAMETERS

Using the Spearman's Rank-Order correlation, we find a highly significant positive correlation between the hints used and the engagement time (i.e. the more hints used the longer the engagement time), a highly significant positive correlation between the hints used and the accuracy (i.e. the more hints used the more accurate the solution), and we find a weak correlation between the engagement time and the accuracy of the solution. These findings are presented in Table 1.

TABLE 1. Correlation between the different variables of the experiment.

		Hints used	**Accuracy**
Engagement time (s)	$\mathbf{R^2}$	0.361	0.169
	***p* -Value**	1.81×10^{-7} ***	0.0177*
Hints used	$\mathbf{R^2}$	-	0.434
	***p* -Value**	-	1.97×10^{-10} ***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.3. INFERENCES AND RELATION TO AVAILABLE KNOWLEDGE

The collected measurements and the occupants' discussion revealed a number of important dimensions that are key for developing new modes of interactions with buildings. These developments have been suggested by Day et al. (2020) and others as an urgent task in the field of smart building controls.

A. Art and design-based interfaces can help users take actions that are not rooted in their need for comfort. Thus we might consider that interactive eco-feedback tools can trigger users to take actions that would be considered illogical or irrational under normal conditions (O'Brien and Gunay, 2014). For example, we find that occupants have turned on both the fan and heater in a very small space – when triggered by the interface to do so (in more than 50% of the cases requiring such action to occur). While most participants indicated that there was no environmental/comfort motive for changing the devices (since the space environment was controlled), that the heater and fan cause discomfort in the small space, and that the equipment (specifically the fan and heater) were significantly overpowered for room size – they still took actions that contradict these comments.
B. We find that the priorities of indoor control actions have shifted to meet the profiles selected' requirements. Previous publications, such as Ozcelik et al. (2019), suggested that lighting or visual comfort actions usually take precedence. Our experiment shows that the visual dominance reported by is replaced by thermal or multimodal action dominance when triggered by the interface to do so.
C. That very little or no "material" rewards (such as monetary or score-based rewards) were needed to trigger participants to take action. Instead, the visual appeal of the art-form acted as a form of psychological incentive mechanism. This is clear since most participants noted that the visual's ambient nature made them appealing to watch.
D. There is a clear potential to explore building controls and interaction as a form of companionship – where the long-term relationship needs to be developed, maintained and fostered. Such an approach has been studied previously in the "Tamagotchi Effect", where owners developed emotional attachments to their virtual pets.
E. Janda's (2011) suggestion to consider HBI and building control interfaces as a form of pedagogy is as relevant today as it was 10 years ago. This places building controls and HBI beyond a "simple" engineering or technical problem – referring to complex problems as defined by (Rittel and Webber, 1973). We find that further explorations in the field of design are needed to study the forms, modes and logics of building controls. We propose that exploring the theoretical underpinnings of human-building interactions is necessary to make the technical engineering developments meaningfully applicable in real-world contexts.

While theoretical in nature, this experiment's findings placed the issue of human behaviour in built spaces at the intersection of the fields of design, art, engineering, and education. The findings suggest that, researchers can move away of depending on occupants' knowledge about their long-term energy consumption or savings to concentrate on providing occupants with prompt positive stimuli regarding their short-term energy-actions (de Dear, 2011) – and on ways to deliver immediate action-reward mechanisms through enticing visuals and interactions. This would transition energy eco-feedback from objective reporting to form of coaching (through step-by-step guidance) – where occupants are presented with options to take immediate and precise control actions that are within their means. This contrasts to other messages that are broad in their focus or that fall beyond the user's capacity. Such an approach would also place energy eco-feedback as a for of modern digital companionship – as explored in the work of (Chen *et al.*, 2012; Floridi, 2008; Kumar *et al.*, 2019; Pfadenhauer, 2015).

5. Conclusion

In this research, we investigate the topic of indoor environment building control from an alternative approach. We find that the current focus of most published work is centred on prediction and automation issues. We find that, while there are calls for more interactive and engaging interfaces to be developed, little attention has been given to studying the content, logic and form of eco-feedback in an indoor environment – including non-metric based feedback methods. Additionally, available work is highly focused on analyzing the long- and medium- term consequences of eco-feedback (such as energy savings). However, no work has focused on studying the immediate occupancy control actions that can result from exposure to eco-feedback.

In the face of these gaps, we, designed and deployed a new system that uses art as an ambient eco-feedback mode, intending to trigger occupants to take specific control actions. During the 1 month experiment, we collected close to 200 data points. We found that, despite the abstract nature of the required actions' feedback and ambiguity, participants were successful in attaining the pre-defined target levels for 3 indoor devices. We also found that participants were very efficient and generally accurate when figuring the devices' required setup – with 1 or more of the 3 devices levels set correctly in an average of about 27 seconds.

While the findings here cannot be directly transferable to real-building situations, they highlight that giving users control (as opposed to revoking control through automation), while guiding them to make decisions can translate to positive and accurate control of indoor parameters. Such interaction and engagement-focused control strategy would also develop the users' awareness of the consequences of their actions and lead occupants to possibly develop meaningful "relationships" with their buildings. The exploration here can help answer the design gaps identified in recent reviews of the topic (Day *et al.*, 2020).

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