7th International Building Physics Conference

IBPC2018

Proceedings

SYRACUSE, NY, USA

September 23 - 26, 2018

Healthy, Intelligent and Resilient Buildings and Urban Environments

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Towards a New Way of Capturing Occupant Well-being

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ABSTRACT
Occupant well-being is undergoing a surge of interest in both the research community and industry, as the potential benefits of increased levels of well-being become better quantified and understood. Well-being science itself is also constantly evolving, moving from the traditional negative view of depression and mental disorders as markers of well-being, towards the more positive notion of flourishing, which is feeling good and functioning well. This paper first sets out the key elements of well-being, as found in psychology literature. Surveys and interviews are the main methods used to capture the well-being of individuals and populations, yet completion rates can be low, occupants distracted or irritated by requests to complete surveys and the data infrequent or irregular. Instead, cameras emerge as a potential economic way to gain information about occupants. Their comfort, health and well-being can be monitored with a high frequency, low intrusion and low cost through the use of facial emotions and movements. To this end, a small pilot study is carried out to examine the effectiveness and practicality of data capture by cameras. Data from a new naturally ventilated office building in Cambridge, United Kingdom, is inspected alongside more traditional well-being assessment techniques. It finds that occupants quickly forget that they are being monitored by the cameras and are very engaged with the research, keen to see if it can help improve their workspace. The results and experience from this pilot study form the basis of a more extensive programme of investigations that are described at the end of this paper. The aspiration is to develop this method so that it can be deployed as part of a wider toolkit to holistically capture high quality information about the comfort, health, and well-being levels of building occupants.

KEYWORDS
well-being, occupant satisfaction, smart buildings, comfort, smart sensing

INTRODUCTION
Levels of depression, stress, and anxiety have risen drastically since 2012, with 50% more incidents being reported in workplaces worldwide (Weiner, 2015). Further, the number of people living and working in urban areas is increasing significantly, a further 2.5 billion from today's figure by 2050 (United Nations, Department of Economic and Social Affairs, 2014). With urban areas becoming more dense and green spaces disappearing (CPRE, 2017), the health and well-being of people living in these areas could suffer (Maller *et al.*, 2006). However, people are beginning to take a greater interest in their own health and well-being, with the global wellness market now being three times larger than the pharmaceutical industry (Yeung and Johnston, 2014). This is mirrored in the current explosion of interest in health and well-being in the built environment, with companies such as WELL and Fitwell creating standards to promote good design and improved building control strategies. Further, through creativity and productivity improvements, research is starting to understand and put a value on the effect of increased levels of comfort, health, and well-being on businesses. While historically the construction sector has focused a lot on reducing the energy use of buildings, around 90% of a typical businesses expenditure can be attributed to people, as opposed to only 1% to end-use

energy costs (WGBC, 2014). This reinforces the need to focus on people when designing, controlling or refurbishing buildings, particularly as energy gets cheaper and cleaner, as renewables take over from fossil fuels (Renewable Energy Agency, 2017).

Health and well-being have many definitions (Dodge *et al.*, 2012) but perhaps the most commonly used is that enshrined in the constitution of the World Health Organisation (WHO) which states: '[health is] a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' (WHO, 1948). This positive focus is also mirrored in new well-being research , where flourishing, (a high level of well-being) is defined by Huppert & So (2013) as '(...) the experience of life going well. It is a combination of feeling good and functioning effectively'. The extent of the built environments contribution (or lack thereof) to an occupant's level of well-being, and how this interrelates with the nature of work and interactions at work is complex.

This paper sets out the background and initial work done on the development of a new type of sensor, which may be able to provide high quality data on the comfort, health, and well-being of building occupants. This sensor could be stand alone or form part of a wider toolkit to holistically monitor occupants, helping us better our understanding in this area. The name 'well-being sensor' is purposely optimistic, particularly considering that experts in psychology cannot agree as to exactly how well-being should be measured or defined (Huppert, 2014). The initial idea is therefore to ascertain what information can be gathered about occupants' interaction with the environment from their facial expressions and movements. This moves away from the more traditional Fanger (1973) type approach, which measures environmental characteristics with average levels of activity and clothing levels and infers occupant comfort from those metrics (Figure 1). There exist several sensors for measuring the individual environmental characteristics (temperature, CO_2, etc.), however, the underlying research question in this study is: could a sensor be developed to measure 'well-being' from people directly?

AFFECTIVE COMPUTING

Affective computing is 'computing that relates to, arises from, or influences emotions' (Picard, 1995). This study takes advantage of recent improvements in this area of research, specifically emotion and action unit recognition software, such as OpenFace (Baltrusaitis *et al*, 2016), to establish whether and how they could be used to gauge elements of the comfort, health, and well-being of building occupants. These softwares are quite prevalent now and, with the incorporation of artificial intelligence and machine learning, some can even recognise emotions better than humans (Bartlett *et al.*, 2014). Further, OpenFace, which uses non-verbal facial behaviours, has been shown to identify differences between suicidal and non-suicidal groups (Laksana *et al.*, 2017). Using these programs to gauge occupant comfort, health, and well-being could enable the Building Management System (BMS) to proactively change environmental conditions within a building (such as temperature or air quality) with the objective of maximising occupant comfort, health and well-being.

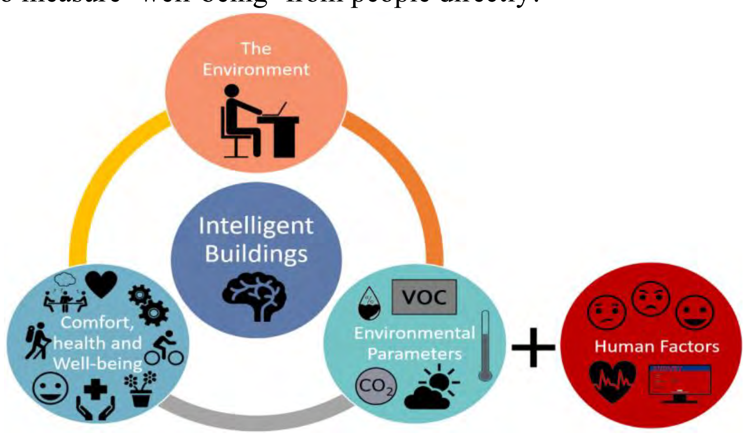

Figure 1 – Intelligent buildings need to include human factors in order maximise occupant comfort, health and well-being.

WELL-BEING

There exists an ongoing, lively debate as to what elements make up overall levels of well-being and on the relative contribution of each individual element. For this study, the Warwick-Edinburgh Mental Well-being Scale (WEMWBS) was chosen as the survey to measure mental well-being as it is one of the most popular and proven scale available. It is generally used to track levels of well-being in populations, but it is suitable for tracking well-being on an individual level, thus making it appropriate for studies and interventions at a local scale (Stewart-Brown *et al.*, 2011). THE WEMWBS survey used for this study consists of fourteen statements, asking the participant to describe on a scale of 1 to 5 how often they have experienced those thoughts or feelings over the last 2 weeks. The questions are as follows: • I've been feeling optimistic about the future • I've been feeling useful • I've been feeling relaxed • I've been feeling interested in other people • I've had energy to spare • I've been dealing with problems well • I've been thinking clearly • I've been feeling good about myself • I've been feeling close to other people • I've been feeling confident • I've been able to make up my own mind about things • I've been feeling loved • I've been interested in new things • I've been feeling cheerful. Similar to populations, there exists a distribution of levels of well-being in buildings as set out in Figure 2. If these levels can be measured more frequently, we can fine tune the design and control of buildings to shift this entire distribution to the right. Improving well-being levels, which may bring productivity and creativity benefits as by-products.

OBJECTIVES

The key objectives of this research are:

a) Review and understand well-being from a 'Psychology' perspective and how this relates to buildings.
b) Review existing well-being capture methods and the current state of the art.
c) Develop a method to continuously capture elements of occupant well-being from video data.
d) Deploy this in several offices to test using a mixed-methods approach.
e) Consider future applications.

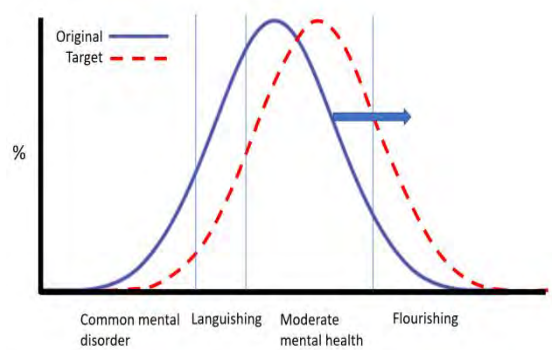

Figure 2 – The well-being distribution in a population and target to shift this further right.

METHOD

The methodology used for this study is similar to that used by the Cambridge Computer Lab in their studies using OpenFace (Baltrusaitis *et al,* 2016). Their method is as follows:

• First, they discuss with a psychologist how they might go about diagnosing a particular condition, e.g. psychosis.

• They then use their software on twos group of people, one with and one without psychosis.

• When analysing their data, they see if there are any statistically significant differences between the two groups, enabling a 'diagnosis' from their software.

This research will take a similar approach. By combining the established method of occupant surveys with cameras and Microsoft's Emotion software, it will be possible to analyse the data and find correlations which infer the same result from survey and camera data sets. Further, from the literature it is clear that there is not a vast body of knowledge about this topic in engineering journals. Rather, most publications tend to be found in computer science, medical and psychology journals. This is a challenge, as the methodologies used by different disciplines can differ substantially. This research will attempt to move towards a methodology more suited to the study of wellbeing (Giddings, 2012). Known as a 'mixed-methods' approach, it is an 'intellectual and practical synthesis based on qualitative and quantitative research' (Johnson *et al,* 2007). This approach was also used by Anderson *et al.*, (2016) with surveys and observations complimenting each other in a natural experiment on well-being in a public space.

Two distinct types of experiment will be undertaken. The first set, referred to as 'natural experiments', include monitoring people in their offices as they go about their daily routine. This will then go on to observe how their 'well-being' changes as the environment changes significantly, such as when an office is refurbished or hydroponic plants are introduced. The second type of experiment will look at shorter term changes and will take place in an 'environmental room'. In this room, people will work in isolation whilst various parameters (such as the facade type) are changed and monitored. Throughout the course of both types of experiments, regular, detailed surveys are given whilst occupants are also monitored by a camera. A small-scale proof of concept pilot study was conducted, and is discussed herein. This allowed for many lessons to be learned, ranging from the practicalities of the process of monitoring itself to the analysis of the data.

PILOT STUDY AND CONCEPT

The James Dyson Building is a mechanically assisted naturally ventilated office building located in Cambridge, United Kingdom. It consists of 4 almost identical floors, each with large open plan offices for PhD students and several cellular offices along the west side for administrators and academics. Six participants took part in the pilot study. They were each filmed every day for 2 months in the summer of 2017 from 9am until 5pm via a webcam connected to a laptop. This created over 500GB of data, which was then processed to assess the emotions of the occupants using Microsoft Emotion Recognition API in 100MB chunks. This process will be automated in future studies to save time. It also highlighted the fact that a lot of data was captured when people weren't in the office, with the Microsoft API indicating that it could find no faces. The six participants were also given surveys to measure well-being (WEMWBS) and satisfaction with the office environment (Center for the Built Environment (CBE), Berkley).

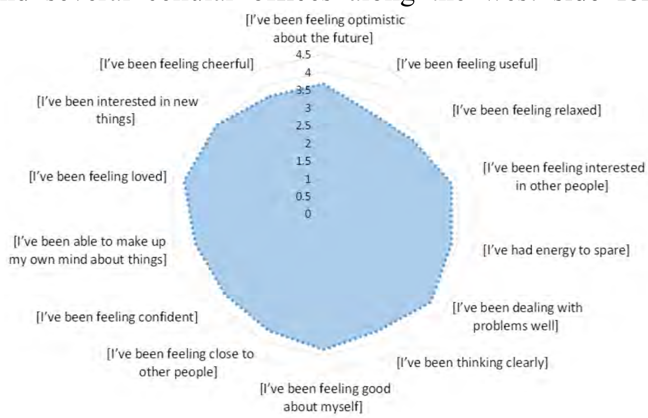

Figure 3 - WEMWS survey, average occupant response to each question

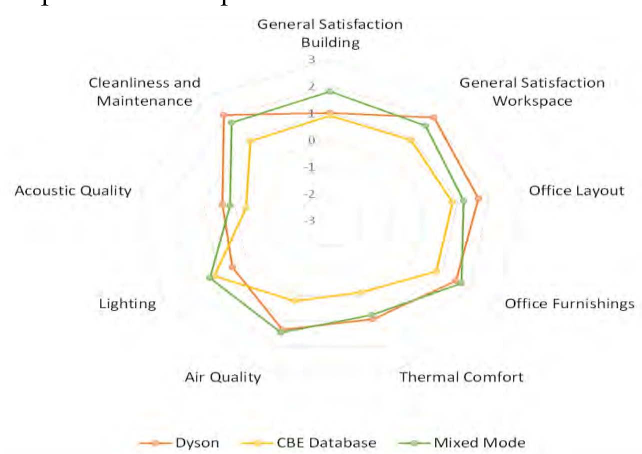

Figure 4 – Average occupant response to the CBE survey on satisfaction with the office environment.

RESULTS

The results are limited due to both the small sample size and the limits of Microsoft's API on data size. Further, Microsoft stopped supporting the emotion from video API halfway through the study. Figure 3 shows the average occupant response to the WEMWBS questionnaire. Figure 4 shows the average response to the CBE survey, showing that the office performed well when compared to buildings in the CBE database and similar to mixed-mode buildings, although the lighting could be improved. Figure 5 plots these two survey results against each other. While there are too few points to find a definitive connection, there does appear to be a link between occupant satisfaction and mental well-being. Figure 6 incorporates results from the Microsoft Emotion API, again there are too few points to find clear correlation between variables.

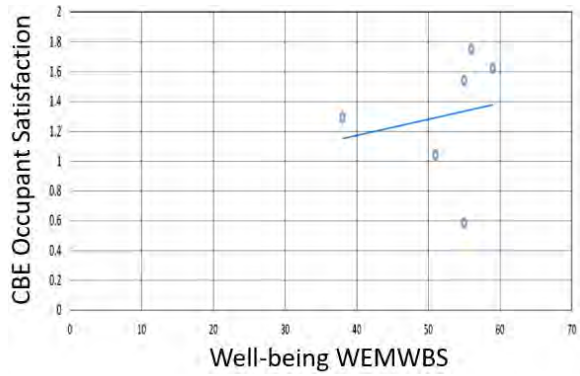

Figure 5 - CBE occupant satisfaction (left) plotted against WEMWBS (bottom).

DISCUSSIONS

Interpreting this data is difficult due to the small number of participants and the labour and computer intensive data analysis method chosen for this pilot study. It is however quite clear that occupants lie on a spectrum of well-being, even in this small study. There is insufficient data to support a correlation or indeed a relationship between occupant satisfaction and well-being. The pilot study did however provide important lessons for future experiments. Online surveys proved to be simple to create and complete, providing data in an easy to use format. Further, the method of monitoring via web-cams atop occupant's computer monitor was also successful.

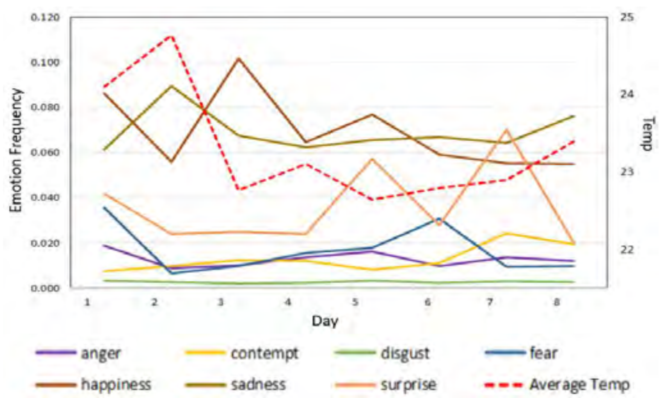

Figure 6 – Average group emotions and average office temperature on the same graph over 8 days.

CONCLUSIONS AND FUTURE WORK

A lot was learned in the course of this pilot study, particularly in how to better acquire data. The data is really too large to be post-processed and so, in future experiments, it will have to be processed in real time. The lessons from this pilot study form the basis of a newly-developed data capture method which uses a Raspberry Pi and camera in a user-friendly case which enables data to be captured and processed onboard, or on the cloud. Further, they can be placed either on top of monitors or simply as desk decoration. They are currently being deployed in a much larger experiment which will cover the entire four floors of the James Dyson Building, as well as MATElab (a living laboratory based in Cambridge) and several other offices. We hope that this new, larger dataset will allow us to find any statistically significant correlations between the facial action units or emotions and the level of comfort, health and well-being of the occupants. This could then be used to control building elements, such as adaptive facades (Loonen *et al.*, 2017), in a more intelligent, occupant centred manner, providing a very useful input into future building management systems.

ACKNOWLEDGEMENTS

I would like to thank the EPSRC, Trimble, BRE and Microsoft for enabling this research. Further to my supervisor and colleagues in the gFT and FIBE research groups for their support.

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