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A virtual reality supported approach to occupancy engagement in building energy design for closing the energy performance gap

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Abstract

There is a trend in the world to adopt low or zero carbon building design principles and technologies. However, energy performance gap is a significant barrier to the development of low or zero carbon buildings. A predominant reason of the performance gap is the insufficient consideration of residents' needs, which may lead to subsequent inappropriate user behaviours. Previous research on energy-related occupant behaviour is built either on statistical analysis from post-occupancy evaluations or stochastic models. There is a lack of pre-occupancy measurement of the interaction between occupant behaviour and building design alternatives. This paper aims to develop an innovative analytic approach using virtual reality (VR) technology to help building designers (architects, system engineers and interior designers) to identify the design pattern which guides the occupants to behave in the most energy-efficient way, so as to closing the energy performance gap resulting from occupants' misconduct. The paper presents a VR-assisted innovative occupant-engaged framework in building energy design based on Design with Intent (DwI) method. Then the approach is validated by a case study on lighting control design for a sample residential building project in Hong Kong. The combination with decision-making is recommended for further research.

Keywords: Building energy performance gap; Occupant engagement; Design with Intent (DwI); Virtual reality

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1. Introduction

Climate change leads to remarkable natural disasters worldwide. According to IPCC, building construction, operation and maintenance together account for 40% of the energy sources used, which has led to energy-related carbon emissions of 36% in industrialized countries [1]. More and more researchers are getting aware of the discrepancy between the perceived outcomes of original building energy design and the buildings' actual performance, which is usually referred to as "performance gap". Compared to many other factors that lead to the performance gap, such as inappropriate envelope design, occupants' misconduct plays an equally important role, but gets far less attention. Traditional research methods (post-occupancy evaluations and mathematical models) tend to regard occupant behaviors as intrinsic characters regardless of the influence of building design. On the other hand, unlike manufactural products, only one physical product is built from its design in architecture, engineering and construction (AEC) industry without any prototypes for testing and evaluation. For this reason, it is difficult to observe actual human behaviors in a pre-designed environment. This paper aims to fill this knowledge gap by integrating virtual reality (VR) technologies with the process of building design.

At first, based on literature reviews, the significance of the influence of occupant behaviour on building energy performance gap is presented. Then the Design with Intent (DwI) method is introduced to building energy design process, and the availability of applying DwI to building design is also discussed. Finally, this paper proposes a framework combing DwI and VR, and validate it by a case study on the lighting design process of a sample residential flat in Hong Kong.

2. Occupant behavior and building energy performance gap

The term "building energy performance gap" or "performance gap", which refers to the mismatch between the predicted energy performance of buildings and actual measured performance [2], appeared in the mid-1990s [3] and has been drawing more and more attention. There are a group of evidences from practical research showing its real existence [4-6].With the rapid development of data harvesting technology such as automated meter reading (AMR), performance gaps become more and more visible [2]. Various causes lie behind the appearance of building energy performance gap. Generally speaking, imperfections in the design stage, such as unrealistic assumptions, mainly account for prediction failures, while quality and management issues in construction and operation stages lead to unintended actual performance of the building.

User behavior, or occupant behavior, has great impact on the indoor environment and is often cited as the main reason for the performance gap [2]. Many of the previous studies have revealed the relationship between energy consumption and occupant behavior [7-10]. In the operation stage, occupants may not tend to perform "correctly" as building designers anticipated. Building designers usually blame the occupants for lacking awareness to save energy in their mind despite the fact that sometimes building system controls are over-complex or in bad positions in order that occupants cannot behave correctly.

Multiple solutions are proposed by many experts in order to predict and assess user behavior precisely, and post-occupancy evaluation is one of the most commonly used data collection methods [10-12]. Nevertheless, such studies are intrinsically empirical models. Occupant behavior patterns may differ from building to building, and have great uncertainties. Further improvement is made by a group of researchers, who try to embrace stochastic models, such as Sub-Hourly Occupancy Control (SHOCC) model developed by Bourgeois [13], and User Simulation of Space Utilization (USSU) model proposed by Tabak [14]. Though such models are well developed mathematically, they are mainly based on or validated by data from post-occupancy evaluations. In addition, neither the occupants nor the building is exactly the same as the original data source based on which these models are established. Traditional research methods lack the consideration of "timeliness" (to observe occupant behavior before the building is built) and "customization" (to test exactly on the building that is to be built). In current practices, prospective occupants are seldom engaged in the process of building design. Mostly it is due to the obstacles in testing how occupants will interact with a building when the building is not physically completed. With the development of BIM to represent the building prototype and VR technology that immerses users into an artificial environment, the way of data collection in occupant behavior prediction can be fundamentally changed. It ideally solves the problem of "timeliness" and "customization".