POE Framework for Assessing User Connectivity of Intelligent Buildings

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Abstract--- *In the last decade, the focus of building research has slowly shifted from sustainable building to Intelligent Building (IB) and both concepts are expected to merge in order to cater to the growing requirement for a better, productive and efficient environment comprising of functionality; safety-security; thermal, acoustical, indoor air-quality, visual comfort and building integrity etc - without consuming excessive energy. Many of these requirements are indicators of user satisfaction falling under the realm of IB and were beyond the scope of the preceding era of sustainable building research. With time, definition of IB has changed from purely technical to more humane - driven by fast-paced information and communication technology or ICT. Today's IB is primarily user-oriented and its success factor relies on its active interaction with occupants or user-connectivity. Hence, IB demands systematic evaluation of its performance by its users. Unfortunately, such feedback is not very structured in case of IB which differs significantly from its traditional counterpart. As a result, Post Occupancy Evaluation (POE) - a highly acknowledged evaluation tool used by occupants of conventional building has been implemented in many IBs with certain level of compromise. To bridge this knowledge gap, this research proposes the conceptual POE framework exclusively designed for IB. After considering intelligent attributes and their influence on user-connectivity, the framework is planned which is suitable for indicative level POE study for lighting system (representative of a traditional system) and access control system (representative of a smart system). It was noted that in the first case, traditional POE is insufficient and needs to incorporate the intelligent features. In the second case, there is a conflict of interests of user-connectivity and system performance. As more buildings are adopting IB environment and more designers are considering seriously the notion of feedback, the proposed model can be beneficial for a knowledge-based paradigm shift of the building industry.*

Keywords--- *Building Evaluation, ICT, Intelligent Building, Performance, POE, User Connectivity*

I. INTRODUCTION

IN recent past, construction industry has evolved with building performance as its focus. As performance means 4Es of economy, efficiency, effectiveness and efficacy [1], the

two most significant trends are sustainable or green building and Intelligent Building (IB). The first one deals with energy efficiency, while the second one is focused on building automation and intelligent environment to provide multi-user multi-tasking facility [2]. The distinction between the two is disappearing fast because of the facts that: (1) both have many common parameters [3] and (2) are meaningful not through rigid definitions, but rather as a concept or process with certain purpose [4]. Probably, in near future, both concepts may converge and decide the fate of civilisation.

Research on IB is still in a nascent stage [5]. Though there are highly developed grading tools for sustainability such as, LEED, BREAM, CASBEE, SB Tool etc, they don't precisely concentrate on the building performance in terms of occupants' satisfaction or well-being [6]. According to R.J. Cole - former director of Canadian Green Building Council, in general, these tools focus on external environmental issues at local and global scale with little or no reference to building performance concerns [7]. Building performance essentially indicates a building's ability to fulfil the functions of its intended use i.e. meeting the requirements of the occupants [8] and usually is judged in terms of thermal, acoustical, indoor air-quality, visual, spatial and building integrity [9].

Unlike sustainable building, IB covers them all along with many other parameters such as safety-security, communication etc [10, 11] without compromising on energy efficiency. As elaborated in the next section, IB is primarily user-oriented and its success factor relies on its active interaction with occupants or user-connectivity rather than on sophistication of its systems and services. Hence, IB demands systematic evaluation of its performance by its users. For this purpose, Post Occupancy Evaluation (POE) is a highly recognised tool, but using a conventional POE may overlook many important aspects of IB that distinguishes it from a traditional building [12]. To bridge this knowledge gap, this research article delves into the user-connectivity of IB and proposes a POE framework to assess the same.

II. HUMAN FACTORS OF IB

2.1 Changing Definitions of IB

Concept of IB has changed with time from purely technical to humane. For example, Cardin cited in [13] defined IB as a building with fully automated service control systems or "one which integrates various systems to effectively manage resources in a coordinated mode to maximize: technical performance, investment and operating cost savings, flexibility" (The Intelligent Building Institution in Washington, 1988 – cited by [14]). Any building designed to

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fulfil only technical requirements suffers from functional obsolescence with the arrival of newer technology [15]. This is more severe in the case of IB as information and communication technology (ICT) is a very fast-paced industry. Hence, the later definitions of IB shifted its focus on human factors or user satisfaction [16]. Encompassing a continuous interaction among its four basic elements, namely, places, processes, people and management to provide occupants productive, communicative, cost effective and environmentally approved conditions [17] such that overall human satisfaction is achieved [5].

2.2 Intelligence of IB

IB can be characterised by four key intelligence attributes pertaining to its subsystems as [18]:

- *Autonomy*: ability to perform self-operative functions.
- *Controllability*: level of control over complicated dynamic systems.
- *User connectivity*: connection between human senses emotion and cognition to a machine (here IB) via mouse, arm, switch, screen etc.
- *Bio-inspired behavior*: capability to perform bio-inspired behavioral traits and ability to interact with the building environment and the services provided.

Among these attributes, user connectivity and its relation with other intelligence traits are the main focus of this study. These intelligent characteristics are discussed by Das [12] for the following major systems of IB:

- Heating ventilation, air-conditioning (HVAC)
- Digital addressable lighting interface (DALI)
- Electric power management system (EPMS)
- Access control, security system
- Addressable fire detection and alarm system
- Smart/energy efficient lift control system
- Audio-visual system
- Telecom and data system
- Maintenance management system
- Integrated building management system

2.3 User Connectivity in IB

IB may have enough machine intelligence, but its occupants may not have adequate capability to explore the same. In Intelligent Building Survey on 12 buildings with 537 occupants, Himanen [19] reported that 52% occupants in spite of holding a university degree lacked the information and skill to use effectively the available technology. That means their connectivity with the IB services or facilities are insufficient. Here study of social aspect of occupants is also important because of two reasons. Firstly, machines cannot understand social context as they don't have the same. Secondly, users from different backgrounds show varied level of requirements and connectivity skill [20]. However, IB is argued to have senses [5] as it is interactively aware of number of occupants, their requirements, indoor and outdoor conditions etc. For example, such buildings allow access only to authorized visitors or reduce solar gain on a hot day. Table 1 shows how various aspects of human intelligence are lent to implementation of different IB concepts. Earlier researchers

have established that IB borrows its intelligence and senses from the occupants themselves in either involving them in finalizing the design brief of a new building or as feedback on existing building [5]. Unfortunately, such feedback is not very structured in case of IB and hence, conventional POE has been implemented in many cases [16] though such implementation may be considered as incompetent or incomplete [12].

Table 1: Human Intelligence in Implementation of IB Concepts [5, 19]

Components of human intelligence	Corresponding IB features
Visual-spatial	<ul style="list-style-type: none"> • Measures for spatial instinct • Lighting
Linguistic	<ul style="list-style-type: none"> • Speech/ voice recognition • Signs
Musical	<ul style="list-style-type: none"> • Acoustics • Background music or silence
Bodily-kinaesthetic	<ul style="list-style-type: none"> • Ergonomics • Empty space • Interior design
Logical-mathematical	<ul style="list-style-type: none"> • Cabling • Integrated control • Communication technology • Building automation
Inter-personal (social)	<ul style="list-style-type: none"> • User interface • Sensoring
Inter-personal (intuitive)	<ul style="list-style-type: none"> • Automated control • Personalized facilities • Rest area /relaxation

2.4 Importance of POE for IB

Castells [21] describes this present era as third wave of industrial revolution driven by ICT resulting in end-user empowerment. In this information age, understanding human behaviour and cognition plays the key role in every industry and IB is not an exception. The human intelligence of occupant operates when the building is in use. Ideally, user can find designer's intention and similarly designer can understand users' need. For this purpose, POE is the most authentic tool. POE evaluates whether a building is able to fulfil its intended functions and provide a satisfactory environment for the occupants. This holds true for any type of building. In case of IB, POE is essential because by virtue of its definition, IB concept is user-oriented. However, IB may require customized POE methodology because [22]:

- Irrespective of context, IBs usually exhibit a global style and are generally designed by collaborative effort of a local and foreign/ international designer firm. Here materials and design are chosen irrespective of location. For example, glass is used profusely in facades without appropriate environmental comfort studies and local climate considerations. The space design lacks thorough understanding of human behavior in accordance with local physical, social, economic and cultural conditions.
- Partial understanding of the meaning of IB results in ineffective building design that fails to fulfill the precise requirement of the occupants.

- Feedback from occupants is absolutely essential for defining the maintenance needs. However, this point is often overlooked during design or construction of IB.

III. THE POE TECHNIQUE

POE is a vast concept and is defined and interpreted in many ways. As per the US Federal Facilities Council [23], it is a process of systematic evaluation of the performance of buildings after they have been built and occupied for some time. But POE is essentially an evaluation from the occupants' perspective and it assesses client satisfaction and functional aptness in order to identify ways to improve building design, performance and fitness for purpose [24]. RIBA or the Royal Institute of British Architects [25] defines POE in architectural context as "a systematic study of buildings in use to provide architects with information about the performance of their designs and building owners and users with guidelines to achieve the best out of what they already have". Hence, for maximum utilization of an existing building, POE may act as a

diagnostic tool for the evaluation of building performance for planning a proper facilities management [26].

Because of its variability, more than 150 methods of POE have been practised worldwide [27]. Among them most popular are: De Montfort method, Design Quality Indicators, Overall Liking Score, PROBE, BUS Occupant Survey, Energy Assessment and Reporting Methodology, Learning from Experience etc. Reference to their detailed description can be found from literature [28].

Any given method generally can be carried out in three levels of effort, namely, indicative, investigative and diagnostic as shown in Table 2 [29]. The choice of level depends on the required outcome and availability of resources and access to information. However, irrespective of the level of POE, the general approach adopted in carrying out the same includes three phases, namely, (1) planning the process; (2) conducting the study and (3) interpretation of the results [16]. These three phases can be further subdivided under nine sub-phases as illustrated in Figure 1.

Table 2: Effectiveness of Various Levels of POE

Parameters	Indicative	Investigative	Diagnostic
Aim	Highlight POE issues	In-depth study of performance and problem solving	Find rectifiable deficiencies and propose future designs
Methods	<ul style="list-style-type: none"> • Expert walk-through and general inspection of performance • Structured interviews • User group meetings • Archive referral 	<ul style="list-style-type: none"> • Survey questionnaires and interviews • Results are compared with similar facilities • Report appropriate solutions to problems 	<ul style="list-style-type: none"> • Sophisticated data gathering and analysis • Questionnaires, surveys, interviews and physical measurements
Timescale	Short: < 1 week	Moderate: 1 week to few months	Long: Few months to few years
Remarks	<ul style="list-style-type: none"> • Quick, simple, less intrusive /disruptive • Judgmental overview 	<ul style="list-style-type: none"> • In-depth/useful results • Intrusive/time-consuming if more personnel involved 	<ul style="list-style-type: none"> • Greater value in usability of results • More time consuming

Figure 1: POE Process Model (Derived from [16])

Questionnaires, survey of occupants which is the essential part of POE, were reviewed from various past researches [28, 30]. For example the typical questions for lighting include:

- Impact of light quality on your work performance.
- Amount and brightness of natural light.
- Amount and brightness of artificial light.
- Effectiveness of blinds/shutters in blocking out glare.
- Personal control over artificial lighting.

- Presence of light on computer screen.

Hence it is apparent that questions to address the effectiveness of artificial lighting or control are very rudimentary in nature especially for IB with features using state-of-the art technology (please see the next section for working principles of the systems) to fulfil precise requirement of the occupants. For features such as access control, surveillance etc, which is usually absent in traditional

buildings, the question usually does not exist or is limited to whether occupants consider the system significant or not.

IV. PROPOSED METHODOLOGY

In order to bridge the gap between existing POE and IB features, user connectivity was focused upon while developing the POE framework because this is the area where human occupants directly come across the performance of each system and are able to give precise feedback. It can be complemented with data generated through constant monitoring of facilities or database of past records. Hence, it can be inferred that IB is better candidate than the traditional buildings for conducting POE in great detail [16].

However, due to restricted space, the proposed framework will be restricted to questionnaire used for structured interviews under indicative POE. Instead of covering all of the major systems [12], two systems, namely, lighting and access control are selected as representative examples. Conventional POE method [28] exists for the first one which is present in traditional buildings as well, for but smart systems like access control, till date there exists no POE methodology. The work is divided into two sections:

- Understand working principle of the systems.
- Develop the questionnaire to measure their performance.

The grading scale for performance depends on the context. In this case a 5-point Likert scale is selected to suit the data collection strategy via structured questionnaire. Such method ensures unbiased and unambiguous opinion [31]. As per the

parameters to be evaluated, the scale ranges from: excellent to very poor, very fast to very slow or never to always.

A. Working Principle of Smart Lighting System

Lighting deals with visual comfort of building occupants. Smart lighting uses the following principles [32, 33]:

- *Scheduling*: It automatically turns on, off, or dims lights at specified times of the day. This applies to lights in the entire building or from a specific zone. The control can be made more precise by using occupancy sensors, photo-sensors or timers.
- *Daylight harvesting*: When sufficient daylight is available, the artificial light automatically dims to the appropriate level with the use of photo sensors and dimmers. That means lights at deep interiors are brighter than those near periphery.
- *Window coating*: Smart windows change opacity and as a result solar penetration with or without the help of electricity passing through them. Voltage is controlled by photo sensors.

B. POE Questionnaire for Smart Lighting

In smart lighting system, user interface takes place with various properties of light such as lighting level, dimming, glare, contrast, colour rendition etc rather than with devices like luminaries, ballasts, dimmers etc. The proposed POE questionnaire is shown in Table 3 [12]. Though the list of POE questions is not exhaustive, but it is interesting to note that, the intelligent performance parameters are almost equally important as the conventional performance parameters.

Table 3: Sample POE Questionnaire for Evaluating Smart Lighting System

Performance parameters		Grading in 5 point scale						
Questions for both conventional and IB								
1.	Natural lighting level	Excellent	5	4	3	2	1	V. Poor
2.	Artificial lighting level	Excellent	5	4	3	2	1	V. Poor
3.	Control over natural light (blocking by blinds/ shutter etc)	Excellent	5	4	3	2	1	V. Poor
4.	Glare from window/ screen	Never	5	4	3	2	1	Always
5.	Reflection from VDU or table surface	Never	5	4	3	2	1	Always
6.	Contrast & brightness	Excellent	5	4	3	2	1	V. Poor
7.	Color rendition of artificial light (seeing the true color of an object)	Excellent	5	4	3	2	1	V. Poor
8.	Fatigue, eyestrain and other symptoms of stress at work due to prolonged use of VDU, environment around the VDU, glare or reflection on screen?	Never	5	4	3	2	1	Always
9.	Level of visual comfort in general	Excellent	5	4	3	2	1	V. Poor
Extra questions for IB								
10.	Response of auto on-off / dimming control towards presence of people	Excellent	5	4	3	2	1	V. Poor
11.	Response of auto on-off / dimming control towards presence of natural light	Excellent	5	4	3	2	1	V. Poor
12.	Discrimination between task and ambient lighting achieved by automatic control	Excellent	5	4	3	2	1	V. Poor
13.	Manual override (manual control over smart system)	Excellent	5	4	3	2	1	V. Poor
14.	Frequency of using the manual override	Never	5	4	3	2	1	Always
15.	Dimming or brightening of artificial light (if applicable) is noticed	Never	5	4	3	2	1	Always
16.	Flexibility to add a new luminary at any place as required	Excellent	5	4	3	2	1	V. Poor

C. Working Principle of Access Control System

Access control is a practice to restrict entry of unauthorized persons or vehicles to a space. User identification/ authentication are done by using one or combination of [32-35]:

- Something that user knows (e.g. PIN, password or passphrase)
- Something that user has (e.g., key, token, card with magnetic strip or barcode, badge, passport etc).
- Something that user is or biometric identifier (e.g. fingerprint, retina, face, voice etc).

The system searches in its database for the input and verifies it. Each of the options has its pros and cons. Though PIN and password is tough to remember, it is easier to change if the database is manipulated. On the other hand, scanning fingertips are easy, but rejection of authorised user is possible, if hands are greasy or placing is not proper. Also the system is not suitable for people with disability or deformity. Once the authorised person is accepted, signal is sent from control panel (local or central) to door hardware to open the door.

D. POE Questionnaire for Access Control System

The proposed POE questionnaire is shown in Table 4. Here no question is pertains to conventional system and hence the section 'Questions for both conventional and IB' appearing in Table 3 is absent here. Additionally all of the questions may not be applicable for one building as seldom all of the access control technologies are applied in a single building. Hence, occupants need to answer only what are applicable to their building. Unlike smart lighting, in access control system, user interface takes place with various peripheral devices such as [32]:

- Electrified door hardware for auto lock-unlock.
- Reader (bar code, magnetic stripe, proximity type, biometric reader etc.)
- Request to exit: allows a person to exit assuming only authorized persons are inside. E.g. Button on inner wall next to ATM door.

Table 4: Sample POE Questionnaire for Evaluating Smart Access Control System

Performance parameters		Grading in 5 point scale						
1.	Ease of remembering PIN, password or passphrase	Excellent	5	4	3	2	1	V. Poor
2.	Frequency of system generated request to change PIN, password, card etc.	Never	5	4	3	2	1	Always
3.	False rejection of authorized person (several attempts)	Never	5	4	3	2	1	Always
4.	False acceptance of unauthorized person (similar face, photocopied barcode of smart card)	Never	5	4	3	2	1	Always
5.	Proximity card needs to be taken out from bag / wallet to get recognized	Never	5	4	3	2	1	Always
6.	Ease of face/ fingerprint/ eye scanning	Excellent	5	4	3	2	1	V. Poor
7.	Ease of operation for disabled persons	Excellent	5	4	3	2	1	V. Poor
8.	Time taken to verify the authorized user	V.fast	5	4	3	2	1	V. slow
9.	Time taken to open the door after verification	V.fast	5	4	3	2	1	V. slow
10.	Reset time of system to accept new access request after one person has entered	V.fast	5	4	3	2	1	V. slow
11.	Operation is hampered during power cut (even for exits)	Never	5	4	3	2	1	Always
12.	Frequency of using the manual override	Never	5	4	3	2	1	Always

V. CONCLUSION

This paper illustrates the development of a conceptual model for the POE framework exclusively customized for assessing the performance of IB. These buildings are significantly different from their traditional counterparts and it is evident that influence of such intelligent environment will not only promote a better work scenario in terms of technical parameters but at the same time, will improve the occupants' productivity and interaction with the built space. However, its success relies heavily on efficient user-connectivity with the building systems and services. Considering this fact, the POE framework was developed to check user-connectivity rather than technical advancement of system performance. For example, high rejection rate of authorised persons or frequent change in password indicates a high security of the access control system. But users consider it as a frustrating situation [36]. Hence, while putting these points in POE questionnaire, users' point of view was given priority and such situation if occurring frequently were assigned a low grade of '1'. As, this

is a clear example of conflict of interest, probing research is recommended for resolving the issue. For the lighting system which is present in a traditional building as well, it was observed that both conventional and intelligent parameters are equally important. Hence, unless POE framework is not customized for IB, a significant amount of valuable information remains under-utilized.

As there exists a vast communication gap between the designer community and facility management, POE is still considered as an irrelevant input for design process [37]. But there are a growing number of examples of architects and clients, particularly among the elite firms, that are beginning to take the concept of feedback from occupants seriously [38]. Hence, this proposed model can promote a holistic form of POE customized for IB which can be proved to be essential in the property sector in order to address analysis of organizational or business needs; psychosocial requirement of occupants' and comparative "scientific" data, such as

environmental monitoring, energy audit etc. As more buildings are being designed as IB, this model will help in a knowledge-based paradigm shift.

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