Survey-based Exploratory Factor Analysis of Building-Occupant Behavior Interaction: A Case Study in Panama

Eric Parker, Engineer[1,3], Miguel Chen Austin, Ph.D.[1,2,3], Dafni Mora, Ph.D.[1,2,3,*],
[1]Research Group Energy and Comfort in Bioclimatic Buildings (ECEB), Faculty of Mechanical Engineering, Universidad Tecnológica de Panamá, Panama, [eric.parker, miguel.chen, dafni.mora]@utp.ac.pa
[2]Centro de Estudios Multidisciplinarios en Ciencia, Innovación y Tecnología AIP (CEMCIT-AIP), Panama
[3]Sistema Nacional de Investigación (SNI), Clayton Ciudad de Panamá, Panama
[*]Corresponding author: dafni.mora@utp.ac.pa

Abstract*– Surveys, as a tool for data collection, allow us to carry out exploratory factor analysis studies in an agile, efficient and economical way. This report consolidates the aspects that define the behavior of occupants in office buildings together with the external or internal stimuli that provoke reactions. Consequently, the objective may or may not be adaptive, to adjust the conditions of the environment and whose purpose is to preserve the comfort and/or good quality of the interior environment. For this purpose, two population samples are chosen for convenience and in different spaces and periods, to understand and estimate the possible impacts on electricity consumption in office buildings, of the Technological University of Panama (UTP).

***Keywords:* Exploratory factor analysis, surveys, probabilistic behavior modeling, neural networks, presence detection.**

INTRODUCTION

In recent decades, it has been possible to determine that around 40% of primary energy consumption in large cities in Europe and the United States has been derived from activities related to the construction sector and operations within buildings [1][2]. Of which specifically 60% is due to the energy consumption of human activities and their interaction with control systems [3] of buildings such as administration and operational management of ventilation and lighting, cooling and/or heating depending on the season of the year, as well as maintenance within interior spaces in terms of comfort, satisfaction, and health. With these challenging aspects for project developers, builders, engineers, and, architects; great challenges are faced in the challenge of saving money in terms of energy consumption and taxes compared to the emission of carbon dioxide emitted into the atmosphere [4]. While conserving and continually improving comfort aspects ensuring that these spaces meet the quality standards of the indoor environment (IEQ), where levels of occupant presence are recorded [5][6]. Therefore, the implications of the behavior of the occupants (OB, from now on) and their interaction with the equipment designed for the selected and installed building, allow the ideal level of well-being in the internal spaces of the building while optimizing the energy consumption and less impact on the external environment.

One of the challenges for the development of new buildings is to fully understand the interactions between humans and buildings. Its impact on the performance of the building becomes key to the optimization and sustainability of energy use. With the use of modeling and simulation technology tools, new low-energy building designs are being created. Therefore, by taking into account the influence of the OB, it will be possible to maximize the design of the building, its operation, and modernization, aligned with the fulfillment of sustainable development objectives [7][8]. Since the OB is complex and requires a multidisciplinary approach, some elaborated studies expose a schematic representation to facilitate its scope and general basic understanding. It can be pointed out that one of its edges is influenced by external factors such as culture, economy, and climate, as well as internal factors such as individual preference for comfort, physiology, and psychology. On the other hand, OB drives occupant interactions with building systems, strongly influencing building operations and thus energy use/cost and interior comfort, which in turn influences the behavior of the occupants thus forming a closed circuit. At the moment that the scope is structured in the form and substance of the behavior context, [9][10][11], Figure 1.

From the research and development of studies carried out in this area of knowledge, it has been possible to highlight the greater importance of the interaction of the human being with the control systems and their respective envelope, categorizing it, as an inherent part of the dimension of the control system, energy consumption [12]. Therefore, achieving optimal conservation by attending to technical and human aspects represents a double challenge. Energy consumption in buildings varies widely due to the way occupants carry out their daily activities by interacting with various devices such as thermostats, light switches, air conditioners, etc. Meanwhile, concerning its envelope, it can be identified: Windows, doors, blinds, and curtains [13]; which contribute as adaptive activities, to improve the thermal and visual to the interior environment. In-office buildings, the fundamental role of the various activities and situations that register the presence and occupation of people lies in determining the wide variability that arises concerning the configuration of comfort and the use of energy and involves the interactions of occupants with energy control systems (thermostatic valves and HVAC system setpoints), building components (windows, shades, and drapes), and appliance use (artificial lighting, computers, and cell phones) [14], who determined that there could be higher energy consumption during non-working hours due to the OB; by

Digital Object Identifier (DOI):
http://dx.doi.org/10.18687/LACCEI2022.1.1.211
ISBN: 978-628-95207-0-5 **ISSN:** 2414-6390

leaving lights, plugged-in equipment charging, or just inadvertently turned on at the end of the day, as well as poor zoning and building controls [15][16][17].

Consequently, there is a growing need to promote what could be called energy awareness towards OB and its impact on energy consumption in buildings; being its interaction with technology, building design, location, and climate, among others, the broad way to achieve savings during its use [18]. However, since human behavior is stochastic its analysis can be expected to involve different approaches to deepen and understand its essence [19]. Regardless of occupant type categorized as wasteful to austere, in conjunction with building technology conceived with net-zero energy performance designs; statistical analyses, occupancy simulation studies, and behavioral patterns in open-plan offices could infer that occupants with a "wasteful" work style consume up the twice as much energy as standard i.e. non-wasteful occupants. not austere [20][15][21]. Meanwhile, lean work style occupants are likely to use half the power of standard occupants. Studies have shown that energy consumption at the household level varied greatly depending on the behavior of residents, and this was an international phenomenon with no geographical boundaries [22][23][24].

In Panama, efforts are being made to achieve the energy transition as described in the roadmap outlined in the National Energy Plan (PEN 2015-2050) [25], integrating various legal, technical and economic, factors to mitigate CO_2 emissions into the environment within its primary objectives. Within the proposed plan, the country has created and updated the character of the standard with the implementation of the rational and efficient use of energy (UREE) [26]; as well as the adoption of the sustainable construction guide for energy savings in buildings [27]. Therefore, knowing the aspects in which discrepancies between building-human interaction are generated, the Project of the International Energy Agency ANNEX 53 [18], involves six aspects to be considered in energy savings in buildings: Climate, envelope, service, and energy systems, operation and maintenance of the building, activities, and behavior of the occupants; quality of the indoor environment. The last three aspects are closely related to the OB. According to reports from the Public Services Authority (ASEP) of Panama, there is a distribution of electricity consumption registered by sector, during the first half of 2021, as follows: Residential 35-48%; Trade 45-30%; Industry 2-5%; Government 10-15%; public lighting 2-4% [28].

However, quantifying and analyzing the consumption of electrical energy in a building due to factors of human behavior linked to the level of comfort satisfaction within the premises; will be one of the edges of our study hypothesis. However, for this purpose we must, know the definition of comfort, as well as the aspects that it involves. Previous investigations [29][7], indicate that convenience or comfort involves aspects that closely intertwine the OB and how it uses space, systems, and services within the building [30][31]; therefore, energy consumption is linked due to internal climate adjustments or specifying how the actions and reactions of a person in response to stimuli, whether internal or external; they suggest being part of a cluster of observations that manifest a process of adaptability to conditions such as temperature, visualization, and acoustics at a given time [32][9].

Similarly, predecessor research related to occupant behavior [33][34], is treated with a multidisciplinary approach. A condition that is to be expected, since the scenarios related to comfort and energy use are not recognized as a basic and simple relationship through physical parameters. Therefore, it is required to establish facts through the description of each discovered layer of social, contextual, and group interactions which, depending on individual motivations, form the key dimensions of human-building interaction, as outlined in Figure 1. Among the essential dimensions to highlight about said interaction, we have:

a) Behavior drivers, (D)
b) Needs of the occupant, (N)
c) Actions performed by the occupants, (A)
d) Construction systems on which the occupants act. (S)

As specified in the Theory of Planned Behavior (TPB) [35], motivations are driving behaviors and can be assumed as a surrogate to describe actual behavior. As studies on the occupant's behavior are expanded using questionnaires, to conduct interviews, it is conjectured that the confirmed motivation is the immediate antecedent of the behavior. In consequence, the investigations carried out to date, focus on direct observations with sensors, for example, thermographs, which do not correspond to self-reported data [36]. Such characteristics occur in the social sciences environment where they deal with this type of data or with latent variables such as motivations, beliefs, perceptions, emotions, and attitudes. Thus, when, the respondent's behavior is considered true, it will act as a latent variable for real control and may contribute to the prediction and estimation of behavior. When using the methodology of survey applications as a strategy [37][10], it has been possible to broaden the understanding of occupant behavior as well as comfort requirements in office and residential buildings. This type of study through surveys, has a low response rate of around 11% -16%, despite the incentives that can be offered to the participants [23][38].

Habits	Impulses (D)	***Comfort***
Needs (N)	**Occupant Behavior**	System(S)
Intentions	Actions (A)	***Control***

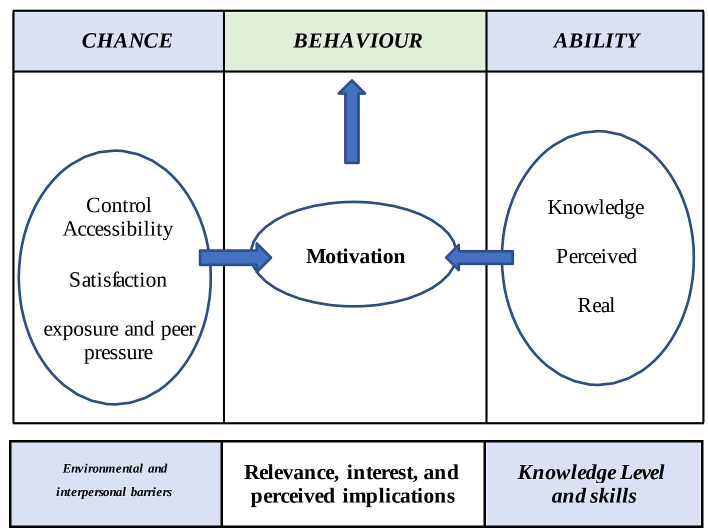
Source: self-made

Fig. 1 Conceptual framework generating the behavior of the occupant

II. METHODOLOGY

The structuring of a questionnaire [10][39], is intended to provide a standardized qualitative description of the driving factors that tend to motivate the actions of the occupant's behavior (OB), within their respective office workspace. Beyond being described as a simple approach to an individual's behavior and the factors that influence it. It is framed from its broad context, to obtain in a generalized way the aspects of human behavior attending to its essence from individuality to the community, gender, norms and social perceptions, geographical, climatic, socioeconomic, demographic, and cultural aspects [11]. To generate a new interdisciplinary framework is system generates a building approach and socio-psychological theories, the exchange of socio-technical knowledge, and learning about the interaction phenomena between man and the building. Therefore, with this approach, the study begins with the elaboration of a questionnaire and the associated measurements will provide information based on data to support the validation of the theoretical framework from the multidisciplinary perspective. The interdisciplinary data collection through the questionnaire contributes to transforming the discovered knowledge into behavior-based energy efficiency solutions, taking into account not only energy metrics and physical properties of building characteristics but also the contextual aspects related to the energy and profile of the OB within the workplace.
Most research related to OB defines it based on occupant movements [40][37] and control actions on the equipment or control devices of the building [14][9]. Likewise, it has been indicated that they can be divided into two aspects: Occupancy, which refers to the rate within the building; and occupant control behaviors on building devices, including windows, doors, shades, air conditioning terminals, lights, and equipment (TVs, computers, printers, etc.). The collected data correspond to four buildings, within the University Campus, of which three correspond to faculties and one is destined for administrative activities in its entirety.
Some studies classified occupant behaviors with direct energy consumption results and time energy use data so that the classification rules were not determined in advance. The authors [20][41] identified 10 distinctive behavioral patterns through unsupervised cluster analysis in light of direct energy consumption results and energy time use data. Similarly, in other research [42], a group of buildings was classified by algorithms, where each group contained a very similar type of occupant behavior. In addition to the occupant behaviors described above by classification, [9][10] presented a DNAS theory to describe occupant behaviors. The DNAS theoretical framework provides a standardized way of representing occupant behaviors from four perspectives, namely drivers, needs, actions, and systems, Figure 1; that can be applied to guide behavior program design, implementation, and evaluation, and facilitate the integration of occupant behavior models with building simulation tools. The resulting self-report characteristics questionnaire is a combination of key questions, arising from an exhaustive review of the survey literature whose occupant behavior questionnaire [9], the Humphreys principle of occupant interaction with control systems in buildings [43][44], traditional theories [24], and adaptive comfort [11] merged with social science theories [4][10][36].
The questionnaire explores the extent to which behavior related to the indoor environment and building control devices are intertwined in workspaces and at the same time how this is driven by an individual motivational sphere influenced by i) comfort requirements, ii) habits, iii) intentions and iv) actual control of building systems (Table 1).

Studies related to this research have structured the scheme of motivation-opportunity-ability (MOA) factors to analyze OB [4], figure 2, which is in charge of annexing socio-psychological constructs of the Norm Activation Model (NAM) and the Theory of Planned Behavior (TPB) to investigate the determining factors of human behavior to save energy, specifically of offices in university buildings [35][39].



Source: self-made

Fig. 2 Conceptual structure of motivation - opportunity - ability, for the analysis of the occupant's behavior

2.1 The Survey Questionnaire

The theoretical framework of DNAS can effectively solve the problem of inconsistency of standards in the process of describing the behavior of occupants and can make the research on OB in buildings more standardized and systematic. Therefore, the questionnaire has been adapted by selecting a group of questions corresponding to each of these perspectives or factors. See table 1.

TABLE I
CONCEPTUAL STRUCTURING OF THE QUESTIONNAIRE

Factors	**Context**	**Targeting**
Control	Knowledge	Royal control Perceived control
	Ability	Perceived access Perceived impairment
	Technology	Perceived achievement
Habits	Adaptive	Past behavior
	psychological	Response automaticity
	Social	Social norms Employment role
	Contextual	Environmental factors Country of origin Work routine
Comfort	Physical environment	Thermal comfort Visual comfort
	Parameters	Indoor Air Quality (IAQ)
	Physiological	Age Gender
Intention	Awareness of the consequences	Perceived subjective norms
	Responsibility situation	Perceived social norms
	Attitude	Perceived will

Source: Project Annex 66

To reference questionnaire was the one defined in Annex 66 [2]. And based on the proposed framework of the research, a questionnaire was designed with 55 previously selected questions to carry out surveys. The variables are measured through Likert-type scales or control questions. Each question in the questionnaire is implemented within the SPSS IBM® Software environment and represents one or more independent variables, correlated with a variable ID, to articulate the measures of the investigation. Each survey response is recorded through the program. Survey data remains anonymous and no personally identifiable or sensitive data is collected; to comply with privacy requirements.

For the execution of the respective surveys, the samples are chosen for convenience and in different periods due to the current decreed situation of public health. The questionnaire was prepared in Microsoft Forms® and was sent by email to the people, whose profiles correspond to students, professors-researchers, and, administrative staff. The character of this research is exploratory and was carried out through a mixed approach, in conjunction with exploratory factor analysis (EFA, from here on) which involves the analysis of qualitative and quantitative data. Since the structuring of the questionnaire is mainly based on the DNAS ontology to define the profile of the OB related to building control systems [10]. In this context, the objective of the experimental research is to generate an additional dimension of knowledge about the behavior of the human being and its link in office buildings, to increase the state of the art and homologation.

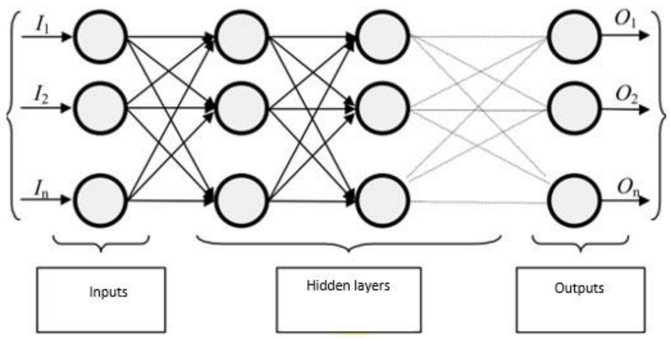
Preliminarily, the data of both surveyed groups are audited (p = 72). Where the first survey corresponds to a group of 53 people (n=53), whose response rate corresponds to 100%, while the percentage of complete records represents 63.01%.

The second survey is represented by a group of 19 people (n=19). Of which a response rate of 100% was obtained however the percentage of complete records corresponds to a percentage of 82.14%.

2.2 Definition of analysis factors

On the other hand, regarding the conceptual framework on which the questionnaire was structured, four major agents of interest that frame and define the OB stand out. There are control, habits, comfort, and intentions. Each one represents a factor of an experimental nature from which a series of relationships emerges between those actions/reactions, internal/external stimuli that determine the reasons why adjustment of the interior environment is sought, among some purposes, as well as the optimum quality of well-being in a certain period and space in the building. The scope of the analysis on each factor is broken down into dimensions that concern the approach, context, questions, and assessment scales; be these qualitative and/or quantitative. In some cases, the experimental multifactorial approach [39][45], models possible scenarios related to each of the control factors, habits, comfort, and intention and consequently achieves the estimation of which variable(s) in each dimension represents the greatest significant relevance; with which it would be possible to predict in each case its level of impact, scope and above all to know the future trend by which the occupant under a certain condition makes decisions to adjust his environment (IEQ) and with this detect its incidence in energy consumption. With a previous selection of stimuli within your work environment, which correspond to the state of the building envelope, such as HVAC system control, building operation and maintenance system, climate, quality of the internal environment as well as related comfort to acoustics, [46][18].

The neural network system, multilayer perceptron (MLP), is used to identify and estimate the most determining variables (v_ID) inherent to OB, on a previously established scenario through the discernment of data acquired through the survey carried out. With the support of neural networks (MLP), the predictors are detected, which helps to classify data from the possible universe of drivers and consequently categorize them to infer of which may have the greatest impact on the electrical energy consumption of the enclosure. Generically, the topologically proposed model corresponds to the one proposed, figure 3.



Source: Neural Networks and applications [47]

Fig. 3 Topology of a neural network

Where the generic input function is expressed as a vector *Ii*, which can be writtens, is indicated in (1).

$$I_i = (in_{i1} \bullet w_{i1}) * (in_{i2} \bullet w_{i2}) * \ldots (in_{in} \bullet w_{in}) \quad (1)$$

Where, n corresponds to the number of inputs to the neuron N_i and w_i to the weight.

* represents the appropriate operator to be used, be it maximum (2), sum (3,) or product (4):

$$\operatorname{Max}_j (n_{ij}\ w_{ij}) \quad \text{con } j = 1, 2, \ldots, n \quad (2)$$

$$\sum_j (n_{ij}\ w_{ij}), \quad \text{con } j = 1, 2, \ldots, n \quad (3)$$

$$\prod_j (n_{ij}\ w_{ij}), \quad \text{con } j = 1, 2, \ldots, n \quad (4)$$

The transfer function used corresponds to (5),

$$\Upsilon(c_k) = \exp^{(ck)} / \Sigma_j \exp^{(cj)} \quad (5)$$

Where the activation function $\Upsilon(c_k)$ takes a vector of real-valued arguments and transforms it into a vector whose elements are in the range (0, 1) and add to 1. Which is only available if all dependent variables are categorical.

The error made by the system corresponds to the form described in (6), where the model will make predictions of the form

$\hat{O} = f(x)$; therefore $\hat{O}$ will only be an estimate of the real value of y.

$$Error\,(x) = E\,[(\hat{O} - y)^2] = E\,[(f(x) - y)^2] \quad (6)$$

III CASES AND RESULTS

Case I – Control

The cross-relationship between the responsibilities to preserve comfort versus the knowledge of controlling energy consumption within workstations. A recorded 70% of the population said they can control the consumption of electricity. However, 64% of the control is by centralized autonomous design; in turn, 26% is due to the supervisor and 10% falls to the employee. ($Chi^2 = 2.985$, df = 5, probability = .703).

Likewise, other evaluations were carried out where the respondents are located in different buildings. Estimating the probabilistic distribution, as well as detecting the variables with the greatest impact linked to electricity consumption, ultimately corresponds to identifying the predictor element. With 83.3% accuracy, it can be inferred that within the context of inherent human ability and the study of OB, our multilayer model (MLP) records that the most important predictor is knowledge in terms of optimizing the use and consumption of information. Energy with (34%) as part of the devices related to the control system (HVAC, lighting, etc.) while having the knowledge control to adjust the thermostat within the internal environment of the workstation represents significant relevance (23%); as see Table II.

TABLE II
PROBABILISTIC DISTRIBUTION

Ask	V_ID	Relevant
How satisfied are you with your degree of control/ability to feel comfortable?	Q2.3CT	0.01
Who is responsible for controlling comfort in your workplace?	Q2.1CT	0.01
Do you have control to turn light switches on or off in your workspace?	Q2.6CT	0.05
How would you rate your knowledge in terms of controlling energy consumption in your office?	**Q2.0CT**	**0.34**
Do you have control to open or close the blinds or curtains in your workspace?	Q2.4CT	0.22
What are your main perceived impediments to interacting with control systems?	Q2.2CT	0.13
Do you have control to adjust the thermostat (set the Operating Temperature of the air conditioner) in the workstation?	**Q2.5CT**	**0.23**

Source: self-made

Case II – Habits

Structured the series of questions to achieve a more exhaustive analysis of the habits factor described in Table III.

The results show a correct overall percentage of 87.5%. And whose precision is around 74% that the most relevant predictors correspond to the variables Q3.15HB (20%) related to the description of the workspace? And also the natural light Q3.6HB (18%).

TABLE III
PROBABILISTIC DISTRIBUTION

Ask	V_ID	Relevant
Indoor environmental control preference in your office space	Q3.1HB	0.04
Remove/add layers of clothing	Q3.8HB	0.12
How would you best describe your workspace?	**Q3.15HB**	**0.20**
Do you have a formal dress code in your office?	Q3.4HB	0.16
With the wind chill of your work area	Q3.5HB	0.08
With the natural light of your work area	**Q3.6HB**	**0.18**
Close curtains/blinds to prevent overheating	Q3.7HB	0.10
How would you best describe your job?	Q3.13HB	0.01

Source: self-made

Case III – Comfort

The most significant predictors related to this factor are broken down as shown in Table IV.

Q1.4CF (26%) falls on the aspect of visual comfort within the workstations; Q1.6CF (18%) is also closely linked to any possible source of visual discomfort in the work environment; while Q1.2CF (16%) corresponds strictly to the thermal sensitivity within the interior environment of the building.

TABLE IV
PROBABILISTIC DISTRIBUTION

Ask	V_ID	Relevant
Rate your typical visual comfort satisfaction	**Q1.4CF**	**0.26**
How do you describe the sources of your visual discomfort?	**Q1.6CF**	**0.18**
How do you rate wind chill?	**Q1.2CF**	**0.16**
How do you perceive the air quality in your workplace?	Q1.3CF	0.13
How do you describe the sources of your CAI discomfort?	Q1.7CF	0.12
Age range	Q1.0CF	0.09
Do you open windows when you feel cold?	Q2.5CT	0.02

Source: self-made

Case IV – Intentions

About the distribution of probabilities, Table V, it is categorically inferred that adjusting windows or any other device in the building to improve the state of well-being within the workstation is the most important predictor element. Therefore, the sum Q4.4IT + Q4.10IT can be considered in its entirety since both converge to the same predictor, therefore its value is (31%).

TABLE V
PROBABILISTIC DISTRIBUTION

Ask	V_ID	Relevant
What type of reward would you be willing to receive to motivate you toward energy-saving behaviors?	Q4.7IT	0.08
Will saving energy at my workplace reduce my comfort level?	Q4.1IT	0.09
Reducing the comfort in my workspace will reduce my productivity	Q4.2IT	0.10
What are the benefits for you of adopting energy-saving behavior in your workplace?	Q4.6IT	0.11
What are, in your opinion, the barriers to overcoming disposition into a habit?	Q4.5IT	0.14
Are you willing to use windows/other devices to get comfortable?	**Q4.4IT**	**0.15**
How do you decide to adjust the quality of the indoor environment in your office (thermostat temperature, opening/closing windows, curtains, and lighting)?	**Q4.10IT**	**0.16**
Are you willing to use windows/other devices to save energy in your workspace?	**Q4.3IT**	**0.17**

Source: self-made

IV. CONCLUSIONS

The study presents the results of the application of a survey to occupants of university office buildings in Panama. The data collection was carried out during the critical public health period decreed. The target population was selected for convenience. Certain limitations allow defining the scope of the study, such as:

1. The respondent's participation is kept anonymous. They do not take into account gender, metabolic activity, age, race, or socioeconomic level.
2. Data whose purpose is the monitoring of electricity consumption data are not contemplated. This will allow follow-up to future research.
3. The questionnaire was adapted from the original ANNEX 66 project and modified to the specific local environment, considering the four study factors: Comfort, habits, intentions, and control.

The results of the analysis provided in each case of analysis of the predictors of greater influence inherent to the OB, for which they are listed below.

Case I – Control Factor

The predictor element (Q2.0CT) with a 34% registered probability, linked to the ability context and perceived control focus area, represents the greatest variable determining knowledge to control energy consumption. Meanwhile, another predictor element (Q2.5CT) linked to the current control context registered a 25% probability of incidence on the possible impact on energy consumption, this predictor is called thermostat control.

Case II– Habit Factor

The predictive elements (Q3.15HB) and (Q3.6HB) with a 20% and 18% probability registered, respectively, represent the largest variables; both determinants and potential elements that impact the energy consumption of the building. However, it can be indicated that even though their contexts are different, the first is aimed at the environment and environmental factors, while the second is adaptive in natured to past behaviors.

Case III– Comfort Factor

Unlike the previously mentioned cases, within the comfort factor, both predictors with the highest weight fall on the same dimension, that is, the same context and area of focus, that is, internal environment and visual comfort. Each of the predictors (Q1.4CF) visual comfort and (Q1.6CF) source of visual discomfort, reported a 26% and 18% probability of influencing the building's electrical energy consumption. Which between the two represents 44%.

Case IV – Intentions Factor

This factor is largely represented from the context of attitude and whose approach is oriented towards the perceived willingness to use envelope devices to obtain possible savings in terms of energy consumption in the building. The predictor described (Q4.3IT) is to use the window to obtain comfort within the space or workstation. Its value fluctuates by 17%. Which link is established between the willingness to save and the use of the devices of the envelope to feel comfortable, which represents (Q4.4IT) 15%. Therefore, belonging to the same dimension, it can be indicated that both represent 32%.

ACKNOWLEDGEMENTS

The authors would like to thank the Faculty of Mechanical Engineering at the Universidad Tecnológica de Panamá for their collaboration. Part of this publication has received funding from the National Secretariat of Science, Technology, and Innovation (SENACYT) under the project code FID18-056, and the Sistema Nacional de Investigación (SNI).

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