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Building Layout Influence on Occupant's Energy Consumption Behaviour: An Agent-Based Modeling Approach †

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Abstract: Building energy consumption is affected by several factors, including its physical characteristics, indoor/outdoor environment, and appliances. However, the occupant's behaviour that governs and controls the building's energy consumption must not be forgotten. In most of the earlier studies, occupant behaviour is modelled as static or fixed occupancy profiles. These profiles are acknowledged as the main source of discrepancy between the predicted and actual building energy performance. Several studies have been performed to identify the occupant's sustainable energy behaviours related to social, climate, economic, regulations, and personal aspects. However, building indoor configuration such as space-layout planning has various impacts on occupant sustainable energy consumption behaviour as indoor space layout might affect occupant's movement and presence. Furthermore, it may link to the occupant's particular activities or actions that happen at a specific position within an indoor space. So, this study used an Agent-Based Modeling (ABM) approach to understanding the influence of indoor layout configuration on occupant energy consumption behaviour in residential households in Chittagong, Bangladesh. The study has shown a considerable amount of building energy savings while using a sustainable space layout configuration. The simulated energy consumption data from the ABM model was further validated using the real data collected from the available smart meters in the case study location. Thus, the study will assist in recognizing the proper space layout arrangements with occupant choice and their behavioural intentions of residential building energy savings for low-income economies.

Keywords: building layout; occupant's behaviour; energy-consumption; agent-based modeling

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1. Introduction and Background

The residential and commercial building industry is an important opportunity for accelerating the transformation of energy-saving and ensuring a worldwide low-carbon future [1,2]. According to the IEA-EBC (International Energy Agency-Energy in Buildings and Communities) [3], the typical building energy performance might be influenced by six essential factors such as climatic condition, building envelope, interior design, building energy and service systems, building operation and maintenance, as well as occupant behaviour [4,5]. Reviewing the current findings on building energy conservation, one can recognize that, for the most parts of such studies focus on operational energy, comprising building energy and maintenance, as well as building service systems. Nevertheless, moving beyond the technological approaches studied by these findings to buildings analysis, variations in occupants' and energy consumption behaviour of occupants have recently been noticed to be a comparatively economical option for building energy saving. Occupant energy consumption behaviour is mostly well-defined as the occupants' actions towards the building energy-related events, i.e., controls of appliances such as HVAC, lighting, windows, blinds, etc. [6,7]. However, it has been noticed that precise predictions of occupant behaviour have frequently been achieved because of its arising from the intrinsically different characteristics of individual occupants. Moreover, many researchers have also observed that there can be tremendous discrepancies between the inhabitant's or occupant's annual energy consumption, even for nearly identical buildings [8,9]. Nevertheless, this study focuses on energy saving from a different point of view by emphasizing occupant-oriented perspectives, based on the assessment of accounting for saving components that neglect the actual energy consumption of the building occupants [10]. In this regard, Occupant Centred Design (OCD) techniques (i.e., space layout deployment) may incorporate an investigation into how and why individuals' occupants use energy [11,12], and this knowledge can advise the plan about the proper interventions to improve energy conservation [13]. Moreover, occupant's space layout deployment is one of the design efforts between 'design development' and 'scheme design' in the initial design phase. It is a significant part of the building that affects the overall building energy consumption in the future. Furthermore, earlier studies have demonstrated that there is an incredible gap between the energy-saving potential and data availability to help the design in the early stage [14,15]. As one significant task in the early design stage, space layout is required to have great possibilities of energy saving. In addition, a small number of analyses have been approached to evaluate the impacts of indoor space layout on building energy consumption [11,16]. All studies have revealed that space layout can considerably influence building energy performance. Furthermore, the bigger part of these studies is the mixed space model with several aspects, for instance, occupant's operation and movement strategy [6], shading framework [17], and window to wall ratio [18]. It makes it problematic to evaluate the effect of space layout dependent on the existing research. It is fundamental to confine a space plan from different parameters to completely recognize its influence on the energy consumption of a building. Thus, this comprehensive study targets breaking down the unfinished effect of occupant space layout configuration on building energy conservation. Moreover, previous studies have made significant attempts for modeling building occupant behaviour by applying various methods [19]. One of the methodologies is the implementation of agent-based modeling (ABM), which could be considered for stochastic behaviour prediction from the individual to group-level occupants [20]. Typically, ABM is a simulation-based system that comprises multiple or single autonomous operators, called "agents", that interact with each other and their environmental condition in accordance with specific behaviour rules or laws. Similarly, the entire parts of an agent in ABM might be symbolized with the aim that the agents might think and act similar to human [13].

Thus, this study aims to introduce an Agent-Based Modeling (ABM) approach in the field of space layout deployment on occupant energy conservation behaviour. Here, building space layout is characterized as the interior collocation of various spaces, which incorporates the interior arrangements, the position of interior furniture, equipment, etc. [21]. Moreover, since most occupant-related investigations are designed on synthetic data and scenarios, therefore this study also tries to fill this gap by presenting a validation approach using real data obtained from the available smart meter in a residential building in Chittagong, Bangladesh.

This article is structured as follows; Section 2 describes the methodology of the study; Section 3 clarifies the results and discussions, including the validation approach, and Section 4 concludes the study.

2. Methodology

The research approach of the study has been divided into three phases: Phase I: predicting occupant behaviours and their action within the layout; Phase II: calculating the energy consumption using the ABM model and Phase III: validating the output with real data. Here, the ABM model is constructed using the AnyLogic modeling tool, which is a broadly established simulation platform, especially in the engineering, business, and sociology domain. Figure 1 represents the basic components of the proposed study framework. In this framework, assigning behaviour, agent decision-making process, agent interactions, and learning addresses Phase I; layout deployment, energy interface, Revit, Dynamo_Excel platform and simulation outputs address Phase II, and the "Model Validation & Interpretation" address Phase III.

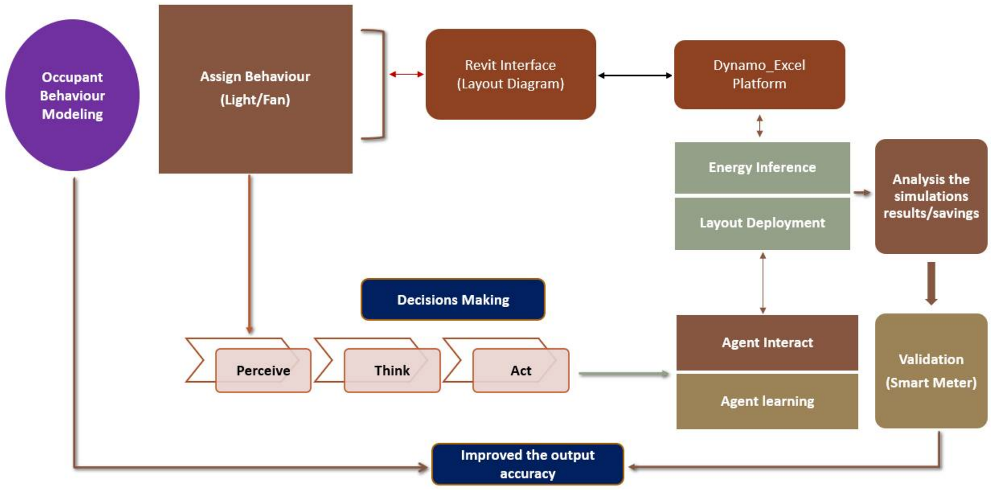

Figure 1. Whole research framework.

Usually, an occupant agent observes its surroundings, which is well-described by the input data and the space layout information as well as thermal and visual situations of the specified spaces. The layout conditions (Figure 2) correspond to the individual's agent's destination (e.g., seating point) and other parameters (e.g., switch distance) that allow an occupant agent to realize its motivation to keep track of the energy calculation. The goal of the energy estimation is to describe how agent (occupant) behaviours influence the interior of allocation within the space. This can expressively influence the occupant's destination; switch distances and environmental conditions that also consider the behavioural variations made by occupant agents. The last part of the framework is intervention and model validation, which determine the flexibility and robustness of the proposed model.

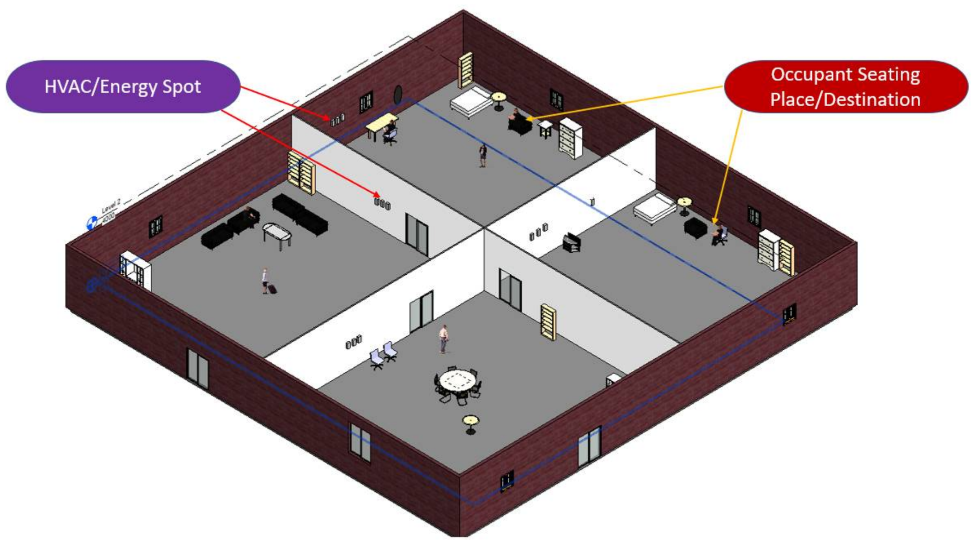

Figure 2. Occupant seating place and energy spot.

3. Results & Discussion

3.1. Model Output

Using the developed ABM model, several simulations were executed. The simulation outcomes were calculated in one-minute interval. The following figures (Figures 3 and 4) show the simulation outcomes for two individual rooms (similar size, dimension, and indoor allocation) of a residential building. This includes individual energy consumption patterns without and with intervention for a group of occupants. The simulated results indicate a considerable amount of building energy savings while using a sustainable space layout configuration. However, the energy consumption pattern and potential savings for similar rooms were different. It may connect to the occupant's number related to metabolic gains from the human body as well as indoor and outdoor environmental conditions [19]. In general, during the summer season, the outdoor solar radiation and temperature are above average, as well as heat gains from the building envelope are also high [19,22].

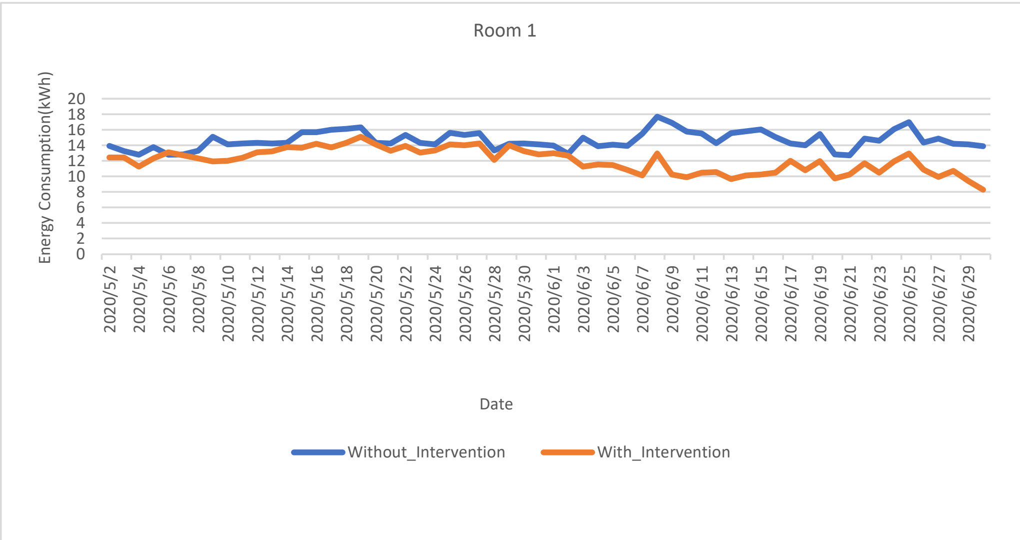

Figure 3. Simulated energy consumption profile for space layout 1 (Room 1).

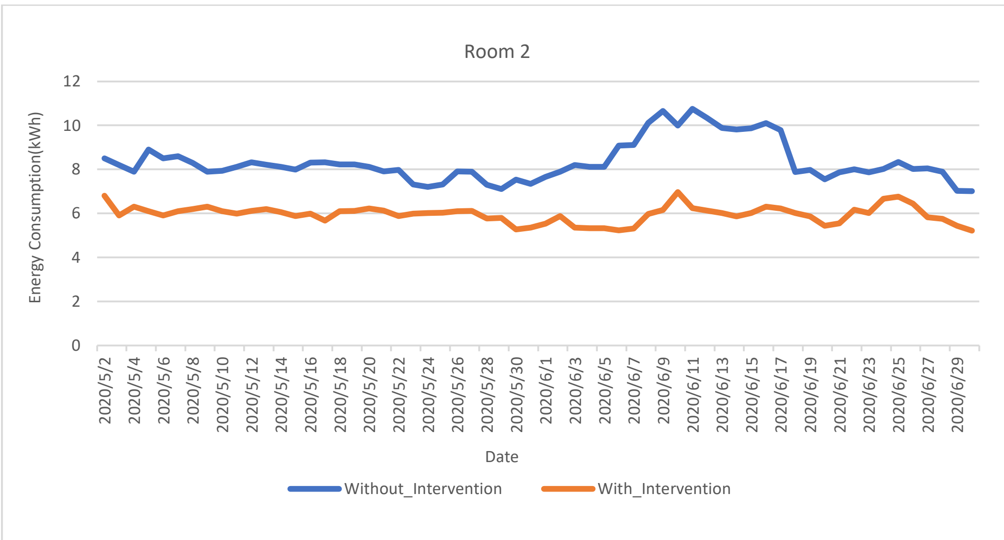

Figure 4. Simulated energy consumption profile for space layout 2 (Room 2).

3.2. Validation

Typically, a validation approach is required for the simulated model to check its robustness and feasibility. The purpose of this approach is to compare the energy consumption data obtained from the real occupied building. Typically, real energy data are empirical, commonly called "true" data; it is recommended as a powerful validation tool because it can be manipulated to evaluate the reviewing data [23]. In this regard, simulated energy consumption data were further validated using the real data obtained from the smart meter (Figure 5).

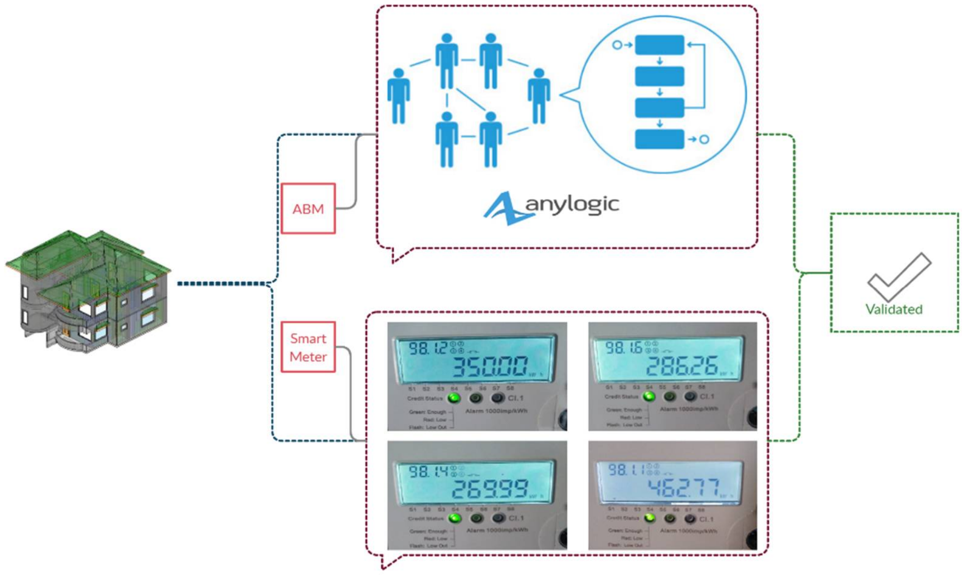

Figure 5. Model generated data validation approach using smart meter available in the case study location.

Herein, upon the prior consent from the inhabitants of the four apartments, the time interval for smart meter data collection was set to approximately 24 h, and these data were collected and written in a Microsoft Excel file. Figures 6 and 7 show the model and smart meter estimated (during intervention) monthly energy consumption data for the multi-family houses at XX Port Connecting Road, Chittagong. XX is a fictitious number as we do not want to disclose the address of the building for data security purposes.

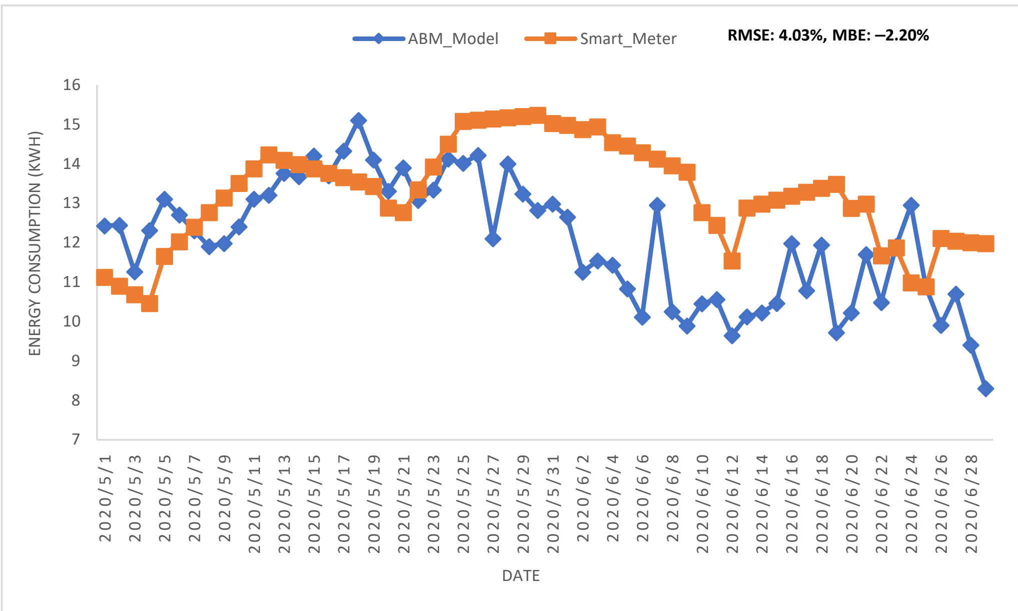

Figure 6. Model vs. Smart meter data for Room 1(RMSE: 4.03%, MBE: −2.20%).

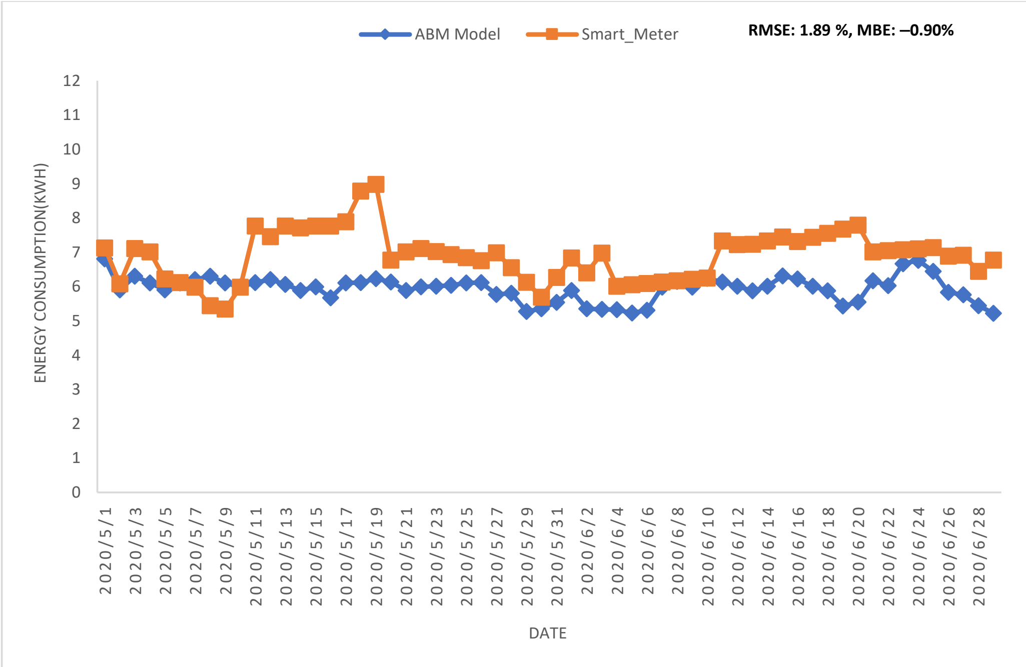

Figure 7. Model vs. Smart meter data for Room 2 (RMSE: 1.89%, MBE: −0.90%).

The data demonstrates that the simulated model slightly underestimated (i.e., negative MBE values) the occupant energy consumption for Room 1. On the other hand, there is a similar energy consumption pattern for both simulated and smart meter provided energy consumption profiles for Room 2.

Several reasons exist for the energy discrepancy between the model-generated output and real energy data. However, for data reliability checking, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard 14-2002 [24] and Federal Energy Management Program (FEMP) guidelines [25] were considered to check the data correction tolerance. It includes verifying two dimensionless errors, called Mean Bias Error (MBE) and Coefficient of Variation of Root Mean Square Error CV(RMSE). Normally, the standard correction tolerance of MBE and CV(RMSE) are ±10% and 30%, respectively. This study showed that in all cases, MBE and CV(RMSE) values lie within the acceptable range (e.g., for Room 1: RMSE: 4.03%, MBE: −2.20%; and Room 2: RMSE: 1.89%, MBE: −0.90%).

In summary, although there are substantial variations that appeared between the simulated and observed data, still the majority of the data fall within the standard tolerance limit specified by ASHRAE and FEMP guidelines. Indeed, occupant behaviour is tough to show due to the randomness and highly stochastic nature of residents. The study also revealed that it is essential to explore the general pattern of individuals' behaviour and integrate the data with an energy simulation model as well.

4. Conclusions

The study seeks the influence of occupant behaviour in building energy conservation in the context of indoor layout configuration using agent-based modeling (ABM). The study aim is satisfied with the implementation of the ABM approach to promote an energy-efficient building system and identify the key players through appropriate intervention. The study also offers a validation approach to improve the simulation reliability, trustworthiness as well as robustness of the model. Although there is a smaller amount of energy-saving prospects noticed due to applied intervention, however, both the simulation model and the experimental study revealed that layout re-configuration (i.e., intervention) plays a significant influence on occupant energy consumption profile.

It is mentioned that the study only considers a few space layouts (e.g., only two rooms) for data validation purposes, as extended data gathering cannot be possible due to the COVID-19 pandemic. A wide-ranging space layout selection and broader data collection, including further behavioural laws/rules, should be identified and incorporated into the framework for modeling more complex occupant comfort and behaviour in buildings. Moreover, comprehensive knowledge of occupant behaviour will assist in simulating an advanced energy prediction model which keeps direct cause and impact that would provide superior control algorithms and systems design. From a diverse point of view, one might also predict energy inadequacies due to occupant behaviour, permitting engineers and architects to improve occupant control at an early phase in the design.

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Data Availability Statement: Data are available on-demand from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Wang, H.; Chen, W.; Shi, J. Low carbon transition of global building sector under 2- and 1.5-degree targets. *Appl. Energy* **2018**, *222*, 148–157. [CrossRef]
2. Wang, C.; Engels, A.; Wang, Z. Overview of research on China's transition to low-carbon development: The role of cities, technologies, industries and the energy system. *Renew. Sustain. Energy Rev.* **2018**, *81*, 1350–1364. [CrossRef]
3. Yan, D.; Hong, T.; Dong, B.; Mahdavi, A.; D'Oca, S.; Gaetani, I.; Feng, X. IEA EBC Annex 66: Definition and simulation of occupant behavior in buildings. *Energy Build.* **2017**, *156*, 258–270. [CrossRef]
4. Balvedi, B.F.; Ghisi, E.; Lamberts, R. A review of occupant behaviour in residential buildings. *Energy Build.* **2018**, *174*, 495–505. [CrossRef]
5. Uddin, M.N.; Chi, H.-L.; Wei, H.-H.; Lee, M.; Ni, M. Influence of interior layouts on occupant energy-saving behaviour in buildings: An integrated approach using Agent-Based Modelling, System Dynamics and Building Information Modelling. *Renew. Sustain. Energy Rev.* **2022**, *161*, 112382. [CrossRef]
6. Hong, T.; Taylor-Lange, S.C.; D'Oca, S.; Yan, D.; Corgnati, S.P. Advances in research and applications of energy-related occupant behavior in buildings. *Energy Build.* **2016**, *116*, 694–702. [CrossRef]
7. Hong, T.; D'Oca, S.; Taylor-Lange, S.C.; Turner, W.J.; Chen, Y.; Corgnati, S.P. An ontology to represent energy-related occupant behavior in buildings. Part II: Implementation of the DNAS framework using an XML schema. *Build. Environ.* **2015**, *94*, 196–205. [CrossRef]
8. Ren, X.; Yan, D.; Hong, T. Data mining of space heating system performance in affordable housing. *Build. Environ.* **2015**, *89*, 1–13. [CrossRef]
9. Thomas, A. Modeling Occupant Behavior, Systems Life Cycle Performance, and Energy Consumption Nexus in Buildings Using Multi-Method Distributed Simulation. Ph.D. Thesis, University of Michigan, Ann Arbor, MI, USA, 2017.
10. Patterson, M.G. What is energy efficiency?(Concepts, Indicators and Methodological Issues). *Energy Policy* **1996**, *24*, 377–390. [CrossRef]
11. Del Zendeh, E.; Wu, S.; Lee, A.; Zhou, Y. The impact of occupants' behaviours on building energy analysis: A research review. *Renew. Sustain. Energy Rev.* **2017**, *80*, 1061–1071. [CrossRef]
12. Uddin, M.N.; Anwer, S.; Wei, H.-H.; Chi, H.-L.; Ni, M.; Tamanna, N. Energy Efficient Behavioural Trends in Residential Sectors for Low-Income Cultural Background: A Case-Study of Slums in Chittagong, Bangladesh. In Proceedings of the 37th Annual ARCOM Conference, Online, 6–7 September 2021; Scott, L., Neilson, C.J., Eds.; Association of Researchers in Construction Management: Glasgow, UK, 2021; pp. 774–783.
13. Uddin, M.N.; Wei, H.-H.; Chi, H.L.; Ni, M. Influence of Occupant Behavior for Building Energy Conservation: A Systematic Review Study of Diverse Modeling and Simulation Approach. *Buildings* **2021**, *11*, 41. [CrossRef]
14. Chen, Y.; Hong, T.; Piette, M.A. Automatic generation and simulation of urban building energy models based on city datasets for city-scale building retrofit analysis. *Appl. Energy* **2017**, *205*, 323–335. [CrossRef]

15. Soares, N.; Bastos, J.; Pereira, L.D.; Soares, A.; Amaral, A.R.; Asadi, E.; Rodrigues, E.; Lamas, F.; Monteiro, H.; Lopes, M.; et al. A review on current advances in the energy and environmental performance of buildings towards a more sustainable built environment. *Renew. Sustain. Energy Rev.* **2017**, *77*, 845–860. [CrossRef]
16. Reinhart, C.F.; Davila, C.C. Urban building energy modeling—A review of a nascent field. *Build. Environ.* **2016**, *97*, 196–202. [CrossRef]
17. Han, Y.; Taylor, J.E.; Pisello, A.L. Exploring mutual shading and mutual reflection inter-building effects on building energy performance. *Appl. Energy* **2017**, *185*, 1556–1564. [CrossRef]
18. Troup, L.; Phillips, R.; Eckelman, M.J.; Fannon, D. Effect of window-to-wall ratio on measured energy consumption in US office buildings. *Energy Build.* **2019**, *203*, 109434. [CrossRef]
19. Uddin, M.; Wang, Q.; Wei, H.H.; Chi, H.L.; Ni, M. Building information modeling (BIM), System dynamics (SD), and Agent-based modeling (ABM): Towards an integrated approach. *Ain Shams Eng. J.* **2021**, *12*, 4261–4274. [CrossRef]
20. Zhang, Y.; Bai, X.; Mills, F.P.; Pezzey, J. Rethinking the role of occupant behavior in building energy performance: A review. *Energy Build.* **2018**, *172*, 279–294. [CrossRef]
21. Pasalar, C. The Effects of Spatial Layouts on Students' Interactions in Middle Schools Multiple Case Analysis. Ph.D. Thesis, North Carolina State University, Raleigh, NC, USA, 2004.
22. Uddin, M.N.; Wei, H.H.; Chi, H.L.; Ni, M. An Inquisition of Envelope Fabric for Building Energy Performance Using Prominent BIM-BPS Tools-A Case Study in Sub-Tropical Climate. In Proceedings of the 2019 International Conference on New Energy and Future Energy System, Macao, China, 21–24 July 2019; p. 12129.
23. Uddin, M.N.; Wei, H.H.; Chi, H.L.; Ni, M.; Elumalai, P. Building information modeling (BIM) incorporated green building analysis: An application of local construction materials and sustainable practice in the built environment. *J. Build. Pathol. Rehabil.* **2021**, *6*, 13. [CrossRef]
24. American Society of Heating, Refrigerating Air-Conditioning Engineers. *Measurement of Energy and Demand Savings*; ASHRAE: Atlanta, GA, USA, 2002.
25. M&V Guidelines: Measurement and Verification for Performance-Based Contracts (November 2015), Version 4.0. Available online: https://www.energy.gov/sites/prod/files/2016/01/f28/mv_guide_4_0.pdf (accessed on 3 August 2021).