Potential and limitation of AI system in building services and control management system

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Abstract. In the construction industry, traditional method for analysing human comfort is time consuming. Thus, artificial intelligence (AI) has been slowly being applied in the software stimulation and building management system to solve the typical comfort analysis method. The potential and limitation of the AI system in the building service are presented through PRISMA review. The AI system enables the building service system to analysis in real-time, optimising energy efficiency, enhance occupant's satisfaction, risk mitigation, cost minimisation and work efficiency increased. However, the AI system application in the building service still faces some challenges such as lack of big data and the varying parameter of data input in the software system, expensive initial cost and required expertise.

1. Introduction

After years of improvements, the Artificial Intelligence (AI) has slowly enroled in human’s daily life, especially in sustainable architecture. The application of AI in sustainable architecture includes energy consumption minimization, energy-efficient building design, mitigation of impacts on the environment, and enhancement of the living environment's security and quality [1].

Artificial Intelligence (AI) is the capability of a machine or a system to perform a task that requires some kind of human intelligence as if was carried out by a human being [2]. AI can have two components to it which is the Fuzzy Logic and Machine Learning. The machines can learn through Supervised Learning, Unsupervised Learning and Reinforcement Learning.

Besides that, IoT (Internet of Things) is the network of physical objects that exchange info with other devices and systems over the internet through embedded sensors, software, and other technologies. [3]. Nowadays, all the equipment or supporting facilities that feature "Smart" systems have IoT features such as Google Dot or smart home appliances.
2. Problem Statement
According to the International Energy Agency statistic, the building sector has consumed about 40% of the total energy produced worldwide [4]. The problems of building services and control management system are as follows:

1. Traditional Method in Thermal Comfort Analysis
The Predicted Mean Vote and Predicted Percentage Dissatisfied (PMV-PPD) is the most common method to analyse the range of thermal comfort for regular users. However, the conventional method presents limitations in accommodating the disabled and elder group of people's comfort level [5]. Traditionally, the comfort level's dissatisfaction problem can only be identified through questionnaire surveys [6]. There is a weak relationship between the comfort conditions defined by the conventional method and those perceived by users [7].

2. Conventional control methods for indoor spaces
Notable instabilities and frequently overshoot thermostats usually find in conventional control method such as on/off, Proportional-Integral (PI), and Proportional-Integral-Derivative (PID) controllers that will result in unnecessary energy waste [8].

3. Unnoticeable Buildings Services Component Failure
Building energy systems have thousands of sensors, actuators, controllers and devices. They have a high chance of suffering from various malfunctions and degradations, leading to uncomfortable and poor indoor environments and severe energy waste [9]. The user usually would not notice the defect till further devastating failure happens.

2.1. Research objective
The research objectives are as follows:
1. To study the potential and benefits to apply artificial intelligence system in building service and control management system
2. To study the limitation and challenges to apply artificial intelligence system in building service and control management system

3. Literature review
In the construction field, the AI system can be applied in different aspect of the building services such as transportation, indoor environment control, security, and stimulation analysis. After the screening, the literature review of the AI system in the building services are presented in Table 1. The table also explain which area does the research is focused on and its methods to conduct it.

| Title (Focus) | Methodology | Potential / Opportunity | Findings | Limitation / Challenges |
|---------------|-------------|-------------------------|----------|-------------------------|
| The use of artificial intelligence (AI) methods in the prediction of thermal comfort in buildings: energy implications of AI-based thermal comfort controls | Review publications related to AI methodologies in thermal comfort levels control by occupants. | 1. Opportunity to analyse data that is dynamic and highly variable. 2. An ideal approach for optimising building energy performance without sacrificing occupant thermal comfort | 1. Lack of AI-based modelling in residential buildings and non-waking occupants 2. Lack of sufficient amounts of data and biases in datasets 3. Inconsistent type of data or parameter to be considered in the modelling 4. High dependency on “supervised learning” methods 5. Lack of generalisation. |
|   |   |   |
|---|---|---|
| 2. | **Artificial intelligence for the modelling of water pipes deterioration Mechanisms** | Comprehensive Literature Review |
|   | 1. A new model that able to maximize the profit and minimize the cost associated with water infrastructure management. |
|   | 2. Can accurately locate the **error and leak size** to prevent failure incident |
|   | 1. Not enough input parameters |
|   | 2. Involved complex calculations |
| 3. | **Convergence of blockchain and artificial intelligence in IoT network for the sustainable smart city** | Literature Survey |
|   | 1. Patient’s health was assembled in real-time, are comprehensive and up to date |
|   | 2. Transit management |
|   | 3. Traveler Information |
|   | 4. Crash Prevention |
|   | 5. Arterial Management |
|   | 6. Commercial vehicles operation |
|   | 7. Freight Management System |
|   | 8. Incident Management |
|   | 1. Uncertainty |
|   | 2. Storage capability |
|   | 3. Healthcare Data Ownership |
|   | 4. Cost and Regulations |
|   | 5. Privacy and Security issues |
| 4. | **Digital Construction: The Known Past, the Uncertain Present, and the Optimistic Future** | Research Review |
|   | Smart tools for: |
|   | 1. **Design support and/or automation**, topology optimisation, generative design. |
|   | 2. **Design review**, checking compliance to standards and codes. |
|   | 3. Building performance simulations and engineering analyses. |
|   | 4. **Digital delivery** of design and construction method directly to workers on site. |
|   | 5. **Real-time measurement**, assessment and interpretation of project status. |
|   | 6. Quality assurance and control. |
|   | 7. Safety planning and control. |
|   | 8. Sustainability and life-cycle costing assessments. |
|   | The information in models is incomplete and inaccessible. |
| 5. | **The Adaptive Thermal Comfort Review from the 1920s, the Present, and the Future** | Literature Review |
|   | 1. The adaptive method is used to accommodate a specific group of people like the elder, temporary ill and disable people for thermal comfort |
|   | 2. The adaptive method has the potential to alter the comfort zone to minimise the energy use |
|   | 3. Minimising the computational load |
|   | If the learning process is not carried out correctly will lead to a dangerous situation |
| 6. | **Energy management of intelligent building based on deep reinforced learning** | MATLAB simulation with a new algorithm |
|   | New algorithm with reduced error and better energy efficiency |
| 7. | **Artificial intelligence-based fault detection and diagnosis methods for building energy systems: Advantages, challenges and the future** | Literature review of AI-based fault detection and diagnosis (FDD) methods for building energy systems in the past twenty years from 1998 to 2018 |
|   | 1. **higher fault detection and fault diagnosis accuracy**. |
|   | 2. Very sensitive to the changes of patterns in monitoring data. Thus, it can detect the failure at low severity level |
|   | 1. data driven-based methods |
|   | 2. the training data cannot cover all possible cases |
| 8. | **A review of the applications of artificial intelligence and big data to buildings for energy-efficiency and a** | Review publications on the application of AI and BD to energy-efficient buildings, |
|   | 1. Prediction and **reduction of building energy consumption** |
|   | 2. **Solar energy utilisation Illumination** |
|   | 1. Need fast data mining and optimal weighting of weather data from different sources |
| No. | Description |
|-----|-------------|
| 4. | comfortable indoor living environment with emphasis on the use of ML and large databases such as satellite data and personal weather stations |
| 2. | Need to be more user-friendly interfaces to suit different users' preferences and operating conditions and patterns |
| 3. | Require highly adjustable building components in the smart home and building |

| 9. | Anti-logic or common sense that can hinder machine's energy performance: Energy and comfort control models based on artificial intelligence responding to the abnormal indoor environment |
| Building Model (Physical Experiment) |
| 1. Integrated energy control model improves thermal comfort and mitigates an increase in energy consumption. |
| 2. Communication between heating and cooling, thermal comfort, and decision-making models optimises energy supply. |
| 3. Integrated model can be extended for managing risks caused by fire or disasters. |

| 10. | Smart Sensors Enable Smart Air Conditioning Control |
| Mathematical Modelling of Air Conditioning Control & Physical Experiment |
| the smart air conditioner with mobile phones and wearable devices could carry out the intention causing control as a significant improvement of air conditioner technology, and be improved for human comfort and energy conservation |

| 11. | A wireless intelligent thermal control and management system for piglet in large-scale pig farms |
| Physical Experiment using ATCS (Automatic Temperature Control System) and suitable thermal ranges of each piglet growth-stage as the intelligence control strategy |
| 1. Energy conservation |
| 2. Save labour cost and improve work efficiency. |

| 12. | A Design Model for Building Occupancy Detection Using Sensor Fusion |
| Physical Experiment within De Montfort University Campus |
| Employing low-cost non-invasive instrumentation for building occupancy monitoring for improved energy efficiency and comfort control |

| 13. | Enhancing occupants’ comfort through BIM-based probabilistic approach |
| A field experiment in Universitat Politècnica de Catalunya (UPC), Terrassa Campus |
| Improve occupants' comfort and optimise building operation strategy to increase occupants comfort |
| 1. The analysis software does not correspond with other software |
| 2. Occupants’ satisfaction depends upon their age and level of fitness |

| 14. | Light-weight AI and IoT collaboration for surveillance video pre-processing |
| Field Test |
| AI filtering the frame to ease the transmission pressure dramatically |

| 15. | Building information modeling (BIM)-based module integrated construction risk management – Critical survey and future needs |
| Comprehensive Literature Review |
| The most complete form of offsite construction which lead to: |
| 1. Reduced construction time, waste, cost and onsite manpower |
| 2. Improved safety, quality, productivity and sustainability |
| Sensing and Tracking Technology (STT) not mature |
| 16 | An Expandable, Contextualized and Data-Driven Indoor Thermal Comfort Model | Field Experiment | A simulation model considering: 1. Age 2. The Activity Time 3. The Clothing Level 4. The Comfort Zone |
| 17 | Roles of artificial intelligence in construction engineering and management: A critical review and future trends | Systematic Review | 1. Automation (Reduce Bias and Confounding) 2. Risk mitigation 3. High Efficiency 4. Digitalisation and Computer Vision |
| 18 | Experimental study of an indoor temperature fuzzy control method for thermal comfort and energy saving using wristband device | Comparative Physical Experiments | 1. Increased thermal comfort 2. Less energy consumption 3. Thermal sensation prediction by AI is better than Thermal sensation feedback. |
| 19 | Advanced automation control system (AACS) for Energy and Comfort Management in a Building Environment | Stimulation with FCM (Fuzzy Cognitive Maps) | Lower building operating cost Focus on the HVAC system only |
| 20 | Towards smart sustainable cities: Addressing semantic heterogeneity in Building Management Systems using discriminative models | Computer Mapping | 1. Reduce the energy consumption of buildings in the cities 2. Improve the well-being of building dwellers and promote liveability Heterogeneity of IoT devices: 1. Meta-data incorrectly labelled and did not standardised. |
4. Methodology

Qualitative method is used to review the potential and limitation of AI in building service and building management system in the paper. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) is being used in this paper as shown in Figure 1.

The author screen through the relevant publications in specific journals and conference proceedings associated with building technology in the last ten years from a few databases: Scopus, Google Scholar, Elsevier and Thomas Reuters’ Web of Science, Science Direct and ResearchGate.

During the screening, the following keywords: building services, ML, AI, adaptive PMV, construction field, smart control. The author used these keywords as single items and combined with two or more keywords in the screening. For example, the author tried the keyword "Artificial Intelligence" individually and then tried combining two keywords, such as "Artificial Intelligence and Building Service" to have better and variety search results.

After analysing the journal, the results and findings are presented in a table format for easy understanding of the potential and limitation of AI in building services and control management system.

![Figure 1. Data collection and screening flow diagram adopted from PRISMA 2009.](image-url)
5. Results and discussions
After reviewing the literature materials in-depth, the AI system’s potentials and limitations in the building are summarised, as shown in Table 2. The summarised table is arranged according to its AI application with colour coded.

Table 2. Compilation of potentials and limitations of AI system in building Services and control management system.

| Title                                                                 | Focus                                                       | Potentials / Opportunities | Limitations / Challenges |
|----------------------------------------------------------------------|-------------------------------------------------------------|----------------------------|--------------------------|
| 1 Experimental study of an indoor temperature fuzzy control method for thermal comfort and energy saving using wristband device [10] | Indoor Temperature Control                                  | X X X                      | X                        |
| 2 The use of artificial intelligence (AI) methods in the prediction of thermal comfort in buildings: energy implications of AI-based thermal comfort controls [8] | Thermal Comfort Control                                     | X X X                      | X X X X                  |
| 3 The Adaptive Thermal Comfort Review from the 1920s, the Present, and the Future [5] | Thermal Comfort Control                                     | X X                        | X X X                    |
| 4 A wireless intelligent thermal control and management system for piglet in large-scale pig farms [11] | Thermal Control                                             | X                          | X                        |
| 5 An Expandable, Contextualized and Data-Driven Indoor Thermal Comfort Model [12] | Thermal Comfort Simulation Model                             |                            | X                        |
| 6 Anti-logic or common sense that can hinder machine’s energy performance: Energy and comfort control models based on artificial intelligence responding to the | Thermal Comfort                                             | X                          | X                        |
| Abnormal Indoor Environment [13] | Indoor Living Environment | A Review of the Applications of Artificial Intelligence and Big Data to Buildings for Energy-Efficiency and a Comfortable Indoor Living Environment [1] | X | X | X | X | X | 7 |
|---------------------------------|--------------------------|----------------------------------------------------------------------------------|---|---|---|---|---|---|
| A Design Model for Building Occupancy Detection Using Sensor Fusion [14] | Building Indoor Environment & CEM | X | X | 8 |
| Smart Sensors Enable Smart Air Conditioning Control [15] | Air Condition Control | X | X | X | 9 |
| Enhancing Occupants' Comfort through BIM-Based Probabilistic Approach [6] | BIM | X | X | X | 10 |
| Digital Construction: The Known Past, the Uncertain Present, and the Optimistic Future [16] | BIM | X | X | X | X | X | X | 11 |
| Roles of Artificial Intelligence in Construction Engineering and Management: A Critical Review and Future Trends [17] | CEM | X | X | X | 12 |
| Building Information Modeling (BIM)-Based Module Integrated Construction Risk Management – Critical Survey and Future Needs [18] | MiCRM | X | X | X | 13 |
| Energy Management of Intelligent Building Based on Deep Reinforced Learning [19] | EMS | X | X | 14 |
| Towards Smart Sustainable Cities: Addressing Semantic Heterogeneity in Building Management Systems Using Discriminative Models [20] | BMS | X | X | X | 15 |
| Advanced Automation Control System (AACS) for Energy and Comfort Management in a Building Environment [21] | BMS | X | X | 16 |
| Artificial Intelligence for the Pipe Deterioration | X | X | X | X | X | 17 |

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Abbreviation:
BIM (Building Information Modelling)
CEM (Construction Engineering and Management)
EMS (Energy Management System)
MiCRM (Modular Integrated Construction Risk Management)

5.1. Potentials / opportunities
Several studies and systematic literature review about the AI system in building services and control management system, with the aim of uncovering the potential and limitation of it. The results were tabulated into Table 1 and Table 2 for better comparison of the data. Building comfortable environment is not only related to people’s thermal comfort and physical health but also affects building energy consumption and resource sustainable development. The Heating, Ventilation, and Air Conditioning (HVAC) system, which provides a comfortable thermal environment, is the fundamental part of the building energy consumption. It accounts to about 40% of total building consumption. Therefore, the most obvious potential of applying AI systems in building services, especially thermal comfort control systems, is optimising energy performance to solve resources and energy crises. From the results, 10 out of 20 studies (50%) shown that AI technology has been utilised in different field (i.e., thermal comfort control, Indoor living environment, BIM, BMS and Security).

Furthermore, the scientist and researcher enhance the building service system by in cooperating real-time analysis. 8 out of 20 studies (40%) show that software nowadays will incorporate with AI algorithm and advanced learning to further mature the system. The AI system will keep track of the user condition and adjust the indoor air environment accordingly to optimise energy performance and enhance occupant's satisfaction. This is because the heating and cooling set point may not always be accurate and reflects the occupant's comfort level. With the data of the user's preference and multi-sensor fusion of the system, the AI will act beforehand. For example, the room temperature will be adjusted accordingly ahead considering the exterior environment, the metabolism rate of the user, and the user's working pattern before the user entered the room. Thus, the user would not feel discomfort when entering into the room and energy would not be further wasted in cooling the indoor environment that eventually cause the user to shiver.

In the Control Management System of the building, 7 out of the 20 studies (35%) show that AI will be used to diagnose and evaluate the building system's risk failure. The AI system will prevent the
component from being further broken down, leading to severe injuries or extra energy consumption. The AI system will also self-diagnose the overall building system and report to the user about the overall condition and performance from time to time. With the advancement of smartphone and IOT, user can monitor and update the firmware of the AI system from time to time.

Besides that, 5 out of the 20 studies (25%) mention that AI is useful in model stimulation such as BIM and BMS to increase work efficiency and reduce operation and labour cost in the long run. This is because the AI system can predict the result outcome that can be as close as real scenario with the correct input of data. Thus, human factor error can be minimised in order to get more accurate data.

Moreover, 5 out of the 20 studies (25%) show that the AI system also alters traditional methods such as ASHRAE chart in determining the comfort level in the building to have a more accurate result. The AI system can able accommodate other specific groups such as senior citizen and young kids that cannot be found in traditional method.

5.2. Limitations / challenges
After going through the literature review on the AI system in building services and control management system, it shows that there are some limitations and challenges of applying the AI system in the building services.

There are 6 out of 20 studies (30%) show that applying AI system need expensive hardware and skilful worker to support and initiate it regardless of any field. The initial cost of setting up the system is high and some system required high maintenance cost to sustain it. another challenge to apply the AI system in the building service is that it required complex calculation and sophisticated hardware support to let the system function. This is because the AI will rely on various type of data input. Thus multi-sensor fusion is needed, and the adaptability and flexibility of the building components also pricy. The complex calculation will eventually lead to lack of generalisation of it in the modern world. People would not apply the AI system due to lack of knowledge and unfamiliar to it. Thus, this hinders the development of AI in the building system.

Furthermore, another significant challenge, 5 out of 20 studies, mention the lack of sufficient data to become AI’s learning material. The AI system required a large amount of data to become reference and process before making a decision. Thus, the significant challenges of AI system in the building services is the source of data collection in a new parameter.

Besides that, 4 out of 20 studies show that the inconsistency of parameter being used in the software system post a limitation to applying AI in the building service system. This is because the measurement or the parameter that the system used to consider the output results is different. For example, some system model used clothing insulation as their parameter to determine the comfort level while some of the models do not. This eventually creates a not reliable and not convincing result that can be applied to the public. To aggravate the scenario, some software model does not share their information with others, which will delay using the AI system in the construction industry.

In addition, 4 out of 20 studies show that the unfriendly interface, lack of generalisation and exposure to the public eventually slow down the process of application of AI system in the building system. Nevertheless, only 2 out of 20 studies show that the data ownership and privacy is the main concern in applying AI system in the smart city management.

6. Conclusions
Overall, the AI system application is being applied in building services such as thermal comfort control system and the Building Management System (BMS) have several benefits such as energy efficiency optimization and enhancement of occupant's satisfaction. The AI system's most useful tool is that the AI system can analyses the situation in real-time and act upon it.

Currently, the AI system is not broadly applied throughout the building services system because there is still the lack of big data in the construction field to support the AI system. The data, such as thermal comfort range for physical disability or sick patient, should be collected to enhance the AI system's
reliability. The manufacturers of software designer of the BIM model should share the information and come to a standardized parameter to analyses the building services. Furthermore, there is lack of expertise in the current field and the AI system required workers with specific knowledge to operate it. Some investor does not see the long term benefit of applying AI. Thus, training and workshop should be conducted to educate the public about the usefulness of using the AI system in the building services.

In conclusion, applying the AI system in the building services is the next future trend and offers plenty of benefits. However, there are few considerations before applying it, such as lack of big data to support the system and varying data input parameters. Thus to apply the AI system in the building services, data availability is the most crucial aspect to consider.

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