Building Occupancy Detection for Energy-Saving: Exploring the Current Technologies and Methods with their Underlying Issues

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Non-intrusive indoor environment sensing for occupancy detection and estimation has attracted extensive research interest in the building domain over the past decade due to the increasing number of applications for improving building infrastructure. Occupancy detection and estimation can be integrated into building appliances to manage lighting applications, intrusion detection in secured building areas, and occupancy-driven ventilation which has the potential to improve the performance of the Heating Ventilation and air-conditioning (HVAC) system through the fine-grained occupant count to enhance the trade-off between thermal comfort and energy consumption. The research strategies for occupancy detection and estimation have utilized different technologies (including camera, wearable, and indoor environmental variables sensing through direct sensing and machine learning), which experience challenges in terms of acquiring essential sensory data related to occupancy information and correctly modeling the occupancy data due to hardware deployment limitations and underlying cost. This study explores existing technologies and methods for occupancy detection and estimation with their underlying issues. It provides a comprehensive procedure for occupancy modeling methodology using different machine learning methods and analyzing their comparative results to assist in decision making for choosing an optimal technique for solving occupancy detection and estimation problem. The results recommend Random Forest as a candidate model with high performance achieving 73.6% to 99.7% for occupancy detection and overall, 99.3% for occupancy estimation.

Keywords: component; Random Forest; Occupancy; Building energy; Machine learning.

INTRODUCTION

Primary energy consumption is predicted to rise at a pace of 1.4 % per year globally [1-3], resulting in a compound annual growth of nearly 32% over the next 20 years. Heating Ventilation and Air conditioning (HVAC) account for over 40% of primary energy. Buildings, for example, utilized 41% of primary energy in the United States (US), 44% more than transportation, and 36% more than industrial sectors [4, 5]. As a result, even slight decreases in building energy consumption will have a big global impact. Better energy consumption habits, particularly in new construction, can help to long-term energy sustainability. Existing buildings, on the other hand, are regarded as critical since they can immediately provide possibilities to increase efficiency over the following many decades. The replacement of obsolete equipment and the aging infrastructure of resources can provide energy-saving opportunities. Low-cost and effective techniques for lowering energy usage in buildings are possible through retrofit and other strategies.

To completely exercise energy consumption control on the HVAC system and eliminate energy waste, the integration of occupancy information in HVAC system management must be maximized [6]. Researchers have recently combined direct sensing technologies such as cameras, wearables, and environmental sensing with machine learning approaches to provide occupancy-based control on current and new HVAC system architecture to reduce energy waste [7]. Many of the camera-based [8, 9] solutions that have been developed thus far may gather training datasets with solid performance without user engagement.

A new approach to building design with an emphasis on environmental dimensions, which is called Environmental House, Sustainable Building and Green Building, has been noticed in industrialized countries in the last decade. It has also provided new professions. The perspective (green building) includes all the stages of design, construction, maintenance and operation and how to deal with materials after the end of their useful life, and emphasizes on increasing efficiency in the use of energy, water, materials and their recycling and providing It is suitable ventilation that provides minimal damage to the environment. In the last five years, some bylaws and building standards have been modified based on the (green building) perspective in industrialized countries, and extensive efforts are being made at different levels of policy, planning, design, and implementation to realize green buildings. Prototyping the green building, mandating the reforms and reconstruction of government buildings, directing subsidies and also generalizing the thinking of green building to other construction and urban planning activities such as green materials, green architecture, green community. Eco-Industrial Park is one of the new directions in this field.

A- Developments of environmental views

The environmental consequences of the development that happened mainly after the industrial development in the 1950s and spread air pollution, water resources, waste and sanitation increased the global attention to the environment and in 1972 the Stockholm Conference to examine global environmental issues [10-14]. Life was formed. The conference published a statement of 106 articles that paid special attention to education, research, structuring, control and purification of pollution. The establishment of the Environmental Protection Organization in Iran and the country's environmental laws are also consequences of the Stockholm Conference.

In 1992, twenty years after the first environmental conference, a conference of heads of state entitled (Environment and Development) was held in Brazil and evaluated the twenty-year performance of countries and the World Organization with the environmental issue [15, 16]. The globalization of environmental aspects (such as global warming, thinning of the ozone layer, reduction of forests) and the relationship between the economic, social and cultural aspects of development and the environment in the set brought up a new perspective on environmental issues, which is called sustainable development. Sustainable Development) is expressed in the last decade.

The concept of sustainable development in simple language is to meet the needs of the current generation in such a way that the future generations are not challenged in meeting their needs. Sustainable development is defined in three main aspects: social, economic and environmental, but generally the most important issue in sustainable development is the way we exploit nature and natural resources. Today, the definition of sustainable development is tied to concepts such as the resilience of cities.

B- Developments in the attitude to improve the environment

The main methods used in the last few decades to control and improve the environment are control methods at the end of the production or consumption line (End of pipe control) and relying on technology. Control methods such as filters for air pollution, sewage treatment, garbage disposal, or vehicle pollution control methods have also had success and important achievements, but the development of the above methods alone is not able to solve environmental problems and will incur heavy costs in the future. It imposes more on the economy of countries.

In the new approach to the environment, the assessment of the full cycle of production or activities (Life Cycle Assessment) and the perspective of life cycle assessment (LCA), which is also called the approach (Cradle to Grave) (Cradle to Grave), all stages of the process pays attention A comprehensive approach includes design, production, construction, maintenance and operation and disposal of materials after the end of the product's life [17-20].

C- The role and importance of the building in the country's economy

Construction activities and its related industries are one of the most important activities of the country's economy. In Iran, about 15% of employment is in the construction sector, which are directly and indirectly active. Despite the wide range of construction activities, the contribution of technology in the construction sector is insignificant compared to other industrial sectors, and implementation methods are mostly traditional. Ten million people work in the construction sector in America. The value of buildings constitutes 50% of the national wealth and 13% of the GDP comes from the construction sector. Per capita consumption in the United States is about 10 tons, of which 90% is discarded as waste, and despite the technology used in this sector, the 1996 report showed that there is 40% scope for saving and improvement in construction works [21, 22]. Any reform that takes place in the construction sector and is in the direction of technicalizing the affairs will be an important contribution to the industrialization of the sector. The attitude (green building) which is to improve the environment in the building can create important savings in energy, water and materials sector while industrializing the construction activities, which is also a valuable contribution to the economic goals of the country.

The primary object objective of this research is as follows:

1. Review of recent literature on state-of-art occupancy detection and estimation in the buildings.
2. Experiment and analysis of occupancy measurement using machine learning i.e. Random Forest methods.
3. Conclusion and future improvements.

A review on different methods for occupancy estimation is given in Section 2. The experimental analysis in Section 3. Discussion and summary presented in Section 4. Section 5 conclude the study.

LITERATURE REVIEW

A study in [23] created the concept of presence in three dimensions. The occupant, geographical, and temporal resolutions are the three dimensions. When it comes to occupant resolution, higher resolution means more accuracy and detail regarding the occupancy and their behavior. However, the total number of occupier's information (occupant) is sufficient in the HVAC energy optimization procedure [24]. Many measurement techniques are accessible in the literature. This section discusses some methods for determining occupancy. In the rest of the paper, the term 'occupancy' refers to the number of persons counted or detected.

Not only can the number of occupants in a room be tallied, but their location can also be identified by placing a camera within the room. The number of individuals can be detected and counted using a high-resolution camera network [25], which can then be used in energy optimization operations. The University of California's BODE project deals with occupancy measurement in order to save energy in buildings [26]. SCOPE was designed as a distributed smart camera object position estimation system that tracked the number of users and their motions [27]. The camera-based occupancy data is used in HVAC and lighting systems, resulting in lower energy consumption [28]. Power-efficient Occupancy-based Energy Measurement uses OPTNet wireless cameras to measure occupancy in real time [29].

METHOD

Obligation to renew in accordance with the building energy law

Energy consumption in buildings is very high! Therefore, many governments have set their goal to reduce the need for heating in buildings by 80% by 2050. Therefore, the Building Energy Law (GEG) has been implemented since November 1, 2020. It also requires the declaration of the specific CO2 footprint of the building in the energy certificate and prescribes the purchase of renewable energy for public buildings. GEG requirements for buildings are regularly renewed and more stringent. In the following, let's introduce efficiency measures in the early stages.

Requirements for existing buildings

The minimum standards of the civil engineering course must be observed: when renovating the exterior of the building, the minimum thermal insulation standards defined in Annex 7 of the GEG apply. On the other hand, the requirements are met if both the annual primary energy demand and the heat transfer coefficient of a reference building defined in the GEG do not exceed 40%.

Minimum thermal protection: GEG prescribes minimum thermal insulation according to DIN 4108-2:2013-02. If this is not met, the floor or ceiling slabs must be subsequently insulated to ensure a maximum heat transfer coefficient of 0.24 W/m2Kis.

Energy certificate: When selling or renting a building, an energy certificate must be given to the buyer or tenant. In high-traffic buildings, the energy certificate should also be displayed. This applies to official buildings with a usable floor area of 250 square meters or more and other buildings with a usable floor area of 500 square meters.

Renewable energy: Public buildings should serve as role models for climate protection. Therefore, it is true that the post-renovation energy demand must be partially covered by renewable energies. Alternatively, the need can be met through the use of waste heat, a CHP plant, purchase of district heating or cooling, or through energy saving measures.

Requirements for building technical systems

Replacement of oil and gas heating systems: Older oil or gas heating systems with an output of 4 to 400 kW must be replaced if they were installed before 1991 [30].

Automatic control of central heating systems: From October 2021, central heating systems must be able to automatically control the supply of heat and the switching on and off of electric drives depending on the temperature and time outside.

Automatic room temperature control: Heating systems must have automatic room temperature control. Group regulations are allowed for rooms of the same type and use.

Insulation on pipes: Open access heating and hot water pipes and their connections should be insulated in unheated rooms.

Control of air conditioning and ventilation systems: It is applied in newly installed air conditioning systems with a cooling demand of more than 12 kW and in room air conditioning systems with a flow of supplied air volume of more than 4000 cubic meters per hour:

1. The specific power of fans is limited according to DIN EN 16798-3.
2. Automatic control of humidity and air humidity, as well as separate adjustable settings, are mandatory
3. If the supply air volume flow of the system to be installed is more than 9 cubic meters per hour per square meter, automatic volume flow control must be possible.
4. In addition, if possible, a heat recovery device is mandatory.
5. Circulation pumps: Newly installed circulation pumps with a rated power of more than 25 kW in the heating circuit of a central heating system must automatically adapt to the delivery requirement at 3 performance levels.

Table 1: Occupancy integration in DCV

Occupancy input	Desciption	Feature	Study	Hardware limitations
Detection	Existence or not existance of the occupancy	Indoor environmental variables	[4-6, 9-20]	Prone to a false alarm, cannot provide additional occupancy information

Amount determination	Amount of occupancy in the system	Camera	[2, 21-25]	Process power, space coverage limitation, occupancy overlapping challenge, privacy challenge
		Indoor environmental variables	[3, 19, 30]	Less accurate than camera
Identify	Indoor application for various cases (hospital, home, state place, …)	Camera	[2, 21, 23]	Process power, space coverage limitation, occupancy overlapping challenge
		Acoustic	[13]	It is influnced via the background noise, not possible to design
Occupancy Activity	Activity in mentioned place	Wearable	[10]	Device capacity limitation, privacy concern
		Passive Infrared	[8]	High false alarm, perimeter coverage limitation
		Wi-Fi Signal	[4]	Tools restriction, privacy issues

RESULTS

Building optimization:

The basic principle in energy optimization of existing buildings is to reduce energy consumption through efficiency measures. At a time of rising energy prices, energy savings are clearly reflected in operating costs. Therefore, investing in energy optimization in buildings usually pays off after a very short period of time. In addition to saving energy costs, optimizing energy consumption also improves their company's carbon footprint and makes a valuable contribution to climate protection. There are many ways to reduce energy consumption.

Saving potential in buildings

Energy consumption in German buildings is very high! Therefore, the German government has set its goal to reduce the need for heating in buildings by 80% by 2050. Therefore, the Building Energy Law (GEG) has been implemented since November 1, 2020. It also requires the declaration of the specific CO2 footprint of the building in the energy certificate and prescribes the purchase of renewable energy for public buildings. GEG requirements for buildings are regularly renewed and more stringent. Here it is worth introducing efficiency measures at an early stage. Compliance is verified by the local chimney sweep and building department.

Insulation Retrofitting

buildings with insulation reduces energy losses caused by air conditioning heat or cold, which is lost to the environment through the building envelope. Especially in old buildings, large amounts of energy are lost through exterior walls and roofs. Thermal insulation can significantly reduce heat transfer and thus energy consumption. Insulation of the facade (from the outside or inside) and insulation of the ceilings of the upper floors or the roof are valuable. One of the ways to identify weaknesses in the building envelope is thermography, for example with the help of a thermal imaging camera. Insulation of factory components and pipes carrying hot water can also help to reduce energy consumption and increase energy efficiency of building services.

Efficient building technology

Installing more efficient technical systems or replacing individual components in building technology can in some cases lead to major efficiency improvements. The simplest form of implementing energy optimization in existing buildings is usually digitization. This enables demand-based control of energy flows and helps identify inefficiencies and potential for further savings. For this purpose, sensors are installed that collect valuable data about the building, environmental impacts and building technology. Automation technology controls building technology on demand and reduces energy consumption. Energy monitoring also allows for the identification of inefficiencies and potential for improvement.

Digitization in existing buildings

Digitization is the future! And not just for new buildings. Especially in existing buildings, the savings that can be realized through smart building automation are huge. But what does the digitization of buildings mean? Digital buildings are also known as smart buildings. This refers to the collection of a wide range of information from all areas of the building and the automatic control of actuators such as ventilation or heating systems that makes this possible. This makes energy to be used purposefully and only where it is needed. Another benefit of building digitization is energy monitoring. The information about the building and the technology installed in it can be read in the software and displayed in a visual form, giving the person in charge a good transparency about the building data and the use of technology. This enables holistic energy management.

According to diagram number 1, in studied area (In hot and dry weather), the building with 10% to 30% external windows on the north and south fronts has the lowest amount of cooling load, and the highest amount of cooling load belongs to 100% external windows. On the south front of the building with 20%, 10% and 30% windows, the cooling load is 57.7kWh/m2, 4.53kWh/m2 and 8.68kWh/m2, respectively. On the north side of the building, with 20%, 10% and 30% windows, the cooling load is 53.9kWh/m2, 6.53kWh/m2 and 5.60kWh/m2, respectively. In Shiraz, on the east and west fronts, the buildings with 10% and 20% with consumption of 54.9kWh/m2 have the lowest amount of cooling load (Chart No. 1) Low cooling load for windows with low percentages due to the low amount of solar gain of the building. is that less radiation enters the environment.

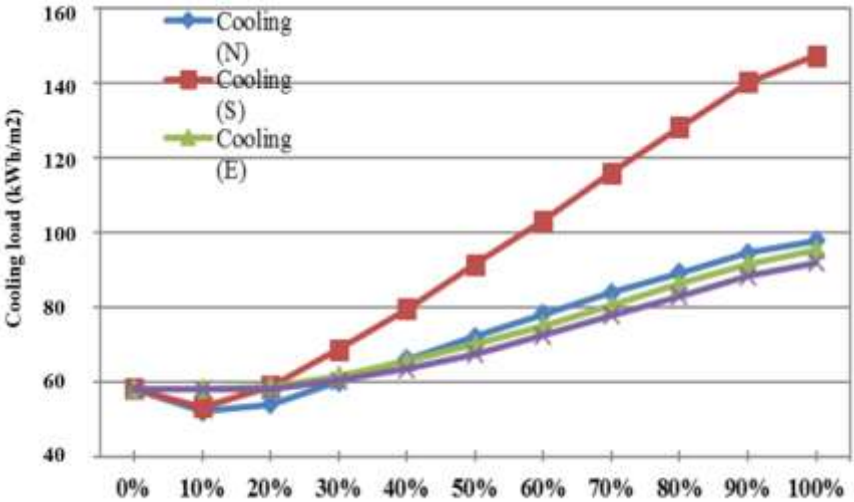

Figure 1. The amount of annual cooling load of the building with the percentage of different windows in different fronts of the building

CONCLUSION

Due to the reduction of fossil fuel resources and the destruction of the global environment, which is often caused by the consumption of fossil fuels, the importance of reducing energy consumption has increased. Since about 40% of the world's energy is consumed by the building sector, the introduction and use of zero energy buildings can reduce global energy consumption. Building low energy buildings is the most important solution to reduce the energy consumption of buildings. Aspects of the building that should be considered primarily to reduce the energy consumption of buildings is the architectural aspect. The design and architecture of a building is one of the first and important stages of building construction, which should be considered more than anything from the environmental point of view, as well as reducing the energy consumption of the building. In order to achieve a zero energy architecture design, it is necessary to determine the location of the building first, so that choosing the right site is very important for the maximum use of available energy. Using new technologies in buildings is one of the most important and effective ways to improve energy efficiency and reduce energy consumption. These technologies are used to better manage energy consumption and reduce harmful effects on the environment by upgrading existing systems and equipment in buildings or using more advanced technologies. Below are some of the new technologies used in buildings:

Intelligent systems: Intelligent systems and building management automation provide the possibility of intelligent control of energy consumption, lighting, air conditioning and electrical equipment. Using advanced sensors and software, these systems automatically adjust energy consumption based on needs and environmental conditions. Smart lighting: The use of smart lamps and lighting that can adjust the light intensity and energy consumption is one of the methods that can help improve energy efficiency and reduce energy waste in buildings.

Smart air conditioning systems: Using advanced technologies, smart air conditioning systems can intelligently and economically reduce energy consumption for heating and cooling. Use of renewable energy sources: Installing solar panels, wind turbines and other renewable energy sources in buildings is one of the effective approaches in creating green energy and reducing the use of polluting energy sources. Benefits of natural light: Proper use of natural light in the design of buildings helps to reduce the need for artificial light and reduce energy consumption for lighting. Optimal insulation: the use of proper insulation in buildings is one of the methods that can reduce energy losses resulting from heat transfer and cooling and heating and improve energy consumption. The use of these new technologies and approaches in buildings, in addition to reducing energy costs, helps to preserve the environment and create energy efficient buildings and is in line with sustainable and smart social and economic development.

References

1. H. Park and S.-B. Rhee, "IoT-Based Smart Building Environment Service for Occupants' Thermal Comfort," Journal of Sensors, vol. 2018, pp. 1-10, 2018.
2. B. Abade, D. Perez Abreu, and M. Curado, "A Non-Intrusive Approach for Indoor Occupancy Detection in Smart Environments," Sensors (Basel), vol. 18, no. 11, Nov 15 2018.
3. J. H. Schwee et al., "Room-level occupant counts and environmental quality from heterogeneous sensing modalities in a smart building," Sci Data, vol. 6, no. 1, p. 287, Nov 26 2019.
4. L. M. Candanedo and V. Feldheim, "Accurate occupancy detection of an office room from light, temperature, humidity and CO 2 measurements using statistical learning models," Energy and Buildings, vol. 112, pp. 28-39, 2016.
5. O. Hänninen et al., "Analysis of CO2 monitoring data demonstrates poor ventilation rates in Albanian schools during the cold season," Air Quality, Atmosphere & Health, vol. 10, no. 6, pp. 773-782, 2017.
6. C. Brennan, G. W. T. , and P. S. , "Designing Learned CO2-based Occupancy Estimation in Smart Buildings," IET Research Journals, 2015.
7. C. Jiang, Z. Chen, R. Su, M. K. Masood, and Y. C. Soh, "Bayesian filtering for building occupancy estimation from carbon dioxide concentration," Energy and Buildings, vol. 206, 2020.
8. M. K. Masood, C. Jiang, and Y. C. Soh, "A novel feature selection framework with Hybrid Feature-Scaled Extreme Learning Machine (HFS-ELM) for indoor occupancy estimation," Energy and Buildings, vol. 158, pp. 1139-1151, 2018.
9. B. Guo, X. Wang, X. Zhang, J. Yang, and Z. Wang, "Research on the Temperature & Humidity Monitoring System in the Key Areas of the Hospital Based on the Internet of Things," International Journal of Smart Home, vol. 10, no. 7, pp. 205-216, 2016.
10. M. L. Hoang, M. Carratu, V. Paciello, and A. Pietrosanto, "Body Temperature-Indoor Condition Monitor and Activity Recognition by MEMS Accelerometer Based on IoT-Alert System for People in Quarantine Due to COVID-19," Sensors (Basel), vol. 21, no. 7, Mar 26 2021.
11. J. N. Lee, T. M. Lin, and C. C. Chen, "Modeling validation and control analysis for controlled temperature and humidity of air conditioning system," ScientificWorldJournal, vol. 2014, p. 903032, 2014.

A. Qurat ul, S. Iqbal, S. A. Khan, A. W. Malik, I. Ahmad, and N. Javaid, "IoT Operating System Based Fuzzy Inference System for Home Energy Management System in Smart Buildings," Sensors (Basel), vol. 18, no. 9, Aug 25 2018.

12. F. Salamone, L. Belussi, L. Danza, T. Galanos, M. Ghellere, and I. Meroni, "Design and Development of a Nearable Wireless System to Control Indoor Air Quality and Indoor Lighting

Quality," Sensors (Basel), vol. 17, no. 5, May 4 2017.

13. F. Salamone, L. Belussi, L. Danza, M. Ghellere, and I. Meroni, "An Open Source "Smart Lamp" for the Optimization of Plant Systems and Thermal Comfort of Offices," Sensors (Basel), vol. 16, no. 3, Mar 7 2016.
14. F. Salamone, L. Danza, I. Meroni, and M. C. Pollastro, "A Low-Cost Environmental Monitoring System: How to Prevent Systematic Errors in the Design Phase through the Combined Use of Additive Manufacturing and Thermographic Techniques," Sensors (Basel), vol. 17, no. 4, Apr 11 2017.
15. P. Wei et al., "Impact Analysis of Temperature and Humidity Conditions on Electrochemical Sensor Response in Ambient Air Quality Monitoring," Sensors (Basel), vol. 18, no. 2, Jan 23 2018.
16. L. Yang, Z. Li, Z. Wu, M. Xie, B. Jiang, and B. Fu, "Independent Control of Temperature and Humidity in Air Conditioners by Using Fuzzy Sliding Mode Approach," Complexity, vol. 2020, pp. 1-12, 2020.
17. M. R. Sisco, V. Bosetti, and E. U. Weber, "When do extreme weather events generate attention to climate change?," Climatic Change, vol. 143, no. 1-2, pp. 227-241, 2017.
18. Z. Chen, M. K. Masood, and Y. C. Soh, "A fusion framework for occupancy estimation in office buildings based on environmental sensor data," Energy and Buildings, vol. 133, pp. 790-798, 2016.
19. M. Gruber, A. Trüschel, and J.-O. Dalenbäck, "CO 2 sensors for occupancy estimations: Potential in building automation applications," Energy and Buildings, vol. 84, pp. 548-556, 2014.
20. N. Cao, J. Ting, S. Sen, and A. Raychowdhury, "Smart Sensing for HVAC Control: Collaborative Intelligence in Optical and IR Cameras," IEEE Transactions on Industrial Electronics, vol. 65, no. 12, pp. 9785-9794, 2018.
21. H. L. J. Ahmad, R. Emmanuel and M. Mannion, "Occupancy detection in non-residential buildings – A survey and novel privacy preserved occupancy monitoring solution," Applied Computing and Informatics, vol. Vol. 17 No. 2pp. pp. 279-295, 2021 2021.
22. Y. Acquaah, J. B. Steele, B. Gokaraju, R. Tesiero, and G. H. Monty, "Occupancy Detection for Smart HVAC Efficiency in Building Energy: A Deep Learning Neural Network Framework using Thermal Imagery," presented at the 2020 IEEE Applied Imagery Pattern Recognition Workshop (AIPR), 2020.
23. K. Naik, T. Pandit, N. Naik, and P. Shah, "Activity Recognition in Residential Spaces with Internet of Things Devices and Thermal Imaging," Sensors (Basel), vol. 21, no. 3, Feb 2 2021.
24. Y. Bapin, K. Alimanov, and V. Zarikas, "Camera-Driven Probabilistic Algorithm for Multi-Elevator Systems," Energies, vol. 13, no. 23, 2020.
25. C. Duarte, K. Van Den Wymelenberg, and C. Rieger, "Revealing occupancy patterns in an office building through the use of occupancy sensor data," Energy and Buildings, vol. 67, pp. 587-595, 2013.
26. S. Zikos, A. Tsolakis, D. Meskos, A. Tryferidis, and D. Tzovaras, "Conditional Random Fields - based approach for real-time building occupancy estimation with multi-sensory networks," Automation in Construction, vol. 68, pp. 128-145, 2016.
27. C. Jiang, M. K. Masood, Y. C. Soh, and H. Li, "Indoor occupancy estimation from carbon dioxide concentration," Energy and Buildings, vol. 131, pp. 132-141, 2016.
28. S. Walker, W. Khan, K. Katic, W. Maassen, and W. Zeiler, "Accuracy of different machine learning algorithms and added-value of predicting aggregated-level energy performance of commercial buildings," Energy and Buildings, vol. 209, 2020.
29. J. Vanus et al., "Monitoring of the daily living activities in smart home care," Human-centric Computing and Information Sciences, vol. 7, no. 1, 2017.