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Post-occupancy evaluation for enhancing building performance and automation deployment

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ABSTRACT

Building automation systems are building control and management systems that control/operate different systems in a building such as HVAC, lighting, safety systems, security and access control, surveillance, indoor air quality, and waste management. These systems manage, control, and integrate other building systems to enhance living experience and optimise energy use through a set of sensors and actuators that are deployed in the building to collect data and execute commands that are sent through a gateway. These management systems generate real-time commands and act or reacts to stochastic occupant behaviours. Buildings in Oman used to be built with burned clay mixed with date palm leaves, and wadi stones and date palm trunks are used for building structure. This architecture keeps the indoor environment warm in winter and cold in summer. However, with advancing technology there has been a shift in building towards using concrete and steel that have high thermal conductivity and pose some challenges for energy use. This paper will show that the main concern of occupants in Oman is indoor temperature control, especially during summer months. This has raised concerns for building performance in Oman and shows a need to review building materials, recommend sustainable alternatives, and more widely, implement sustainable building techniques. This paper seeks to develop recommendations to overcome these issues by exploring post-occupancy satisfaction measures and potential use of BAS and sustainable building materials to enhance building performance in Oman. Following on from this, this paper explores the motivations behind people's decision in Oman to deploy home automation and explore techniques to enhance building performance.

1. Introduction

Building and construction is responsible for 30% of total global energy consumption and 27% of total energy emissions [1]. Sustainable energy is a global concern since the present energy system relies on about 80% fossil fuel [2]. Achieving a more sustainable energy performance is a global concern to mitigate carbon footprint and its disruptive affects.

These issues are particularly felt in Oman as more than 90% of electricity generation depends on natural gas, according to the 2021 Authority for Public Services Regulation annual report. The Authority set a target to reduce carbon footprint by using 10% renewable energy by 2025 and 39% by 2040. Working towards this target, the Authority launched the “Mirror” Solar Thermal Project in 2018 producing 1000 MW of PV and wind energy; the Dhofar Wind Project in 2019 producing 50 MW; the “Amin” Solar PV Project in 2020 producing 100 MW; the Ibri Solar PV in 2021 producing 500 MW; and launched the National Hydrogen Alliance in 2022 to

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achieve future security of sustainable energy. 44,7% of energy production is used for residential buildings compared to non-residential 9.5%, 0.8% agriculture and fisheries, and 45% for Commercial Registered Tariff [3].

Cooling consumes 60–70% of total energy used in residential buildings in Oman [3] and therefore it is no coincidence that the occupants' biggest concern is indoor temperature control, especially in summer. Therefore, enhancing building performance is an important target that shall be addressed when talking about sustainability in Oman and the Gulf Cooperation Council (GCC) region. Through this research we will explore sustainable solutions to enhance building performance in Oman.

The cost of building utilities in Oman has increased in recent years and a new tax policy has been implemented [4]. While electricity, desalinated water, and gas used to be subsidised by the government and supplied to buildings in Oman for reasonable rates [3] this caused cultural barriers which hindered the thriving of sustainable buildings in the region due to reasons such as easy access to mortgages and free attribution of lands to the civils [5]. The increase in utilities cost triggered new occupancy behaviours aimed at reducing the cost by using insulated bricks for construction, selecting new building materials with high performance to resist thermal conductivity, deploying smart devices to optimise energy use, installation of solar products, exploring home automation (especially since smart products became widespread in the market with the emergence of the Internet of Things (IoT)), 5G internet and the connected-home concept. Advent of smart homes has the potential to reduce and shift energy use, especially during peak hours when demand is high and tariffs are also higher than normal hours [6–8] and to reduce water usage thanks to laser sensor water tabs equipped with a flow timer, and smart maintenance of building systems. Smart homes also enhance indoor environmental quality and improve comfort, convenience, and quality of life. An emerging building paradigm takes a holistic approach to the building process starting from the very early design phase and doesn't end by handing over the building to the owner but predicts building age and recycling of building materials that were used in the construction to be used sustainably. This revolutionary holistic approach to the building process exploits technology to execute construction on or off-site; the so-called Construction 4.0 (C4.0) [9].

A building that lacks any of the essential aspects for occupant satisfaction must be renovated and enhanced to attain the occupant's comfort and convenience. Deploying building automation is a part of building management that reduces the efforts of physical administration of the building and remotely controls building systems for optimum energy use and maximum occupant satisfaction [10]. Sensors and actuators can be deployed to manage room temperature, switch on/off and control light intensity, open and close curtains to attain a comfortable indoor environment, secure the building by surveillance camera and security alarms, protect the building from potential hazards such as fire, gas and smoke, and alert for any potential building maintenance.

Construction is one of the sectors that has high potential to reduce these impacts by using sustainable building materials and techniques to achieve sustainable energy use. Towards this, this paper will survey issues around building performance in Oman from occupants' perspective. This will consider energy consumption of buildings, sustainable building materials and their efficiency in reducing energy consumption in Oman and similar countries in the region Gulf Cooperation Countries (GCC).

Following this, the paper will then explore the techniques and measures that can be used to enhance building energy usage and attain occupants' satisfaction. Among these are promoting building automation systems, which are often touted as a key solution to building energy concerns [11]. To understand how this concept impacts Oman, this paper will also study if people in Oman are ready to deploy smart systems in their dwellings.

To achieve these aims in line with global concerns and answer this paper's questions, data of building performance are required. A survey was conducted with 105 occupants to obtain information about their dwellings, building performance, and understand readiness to deploy smartness for building management. Post-occupancy Evaluation (POE) survey is used as an essential tool to gather data from occupants regarding their dwelling conditions, it explores occupants' readiness to improve their building environment and explores their readiness to deploy building automation. The use of POE survey has been chosen as a tool for this research because it collects data directly from occupants, provides accurate information about occupants' satisfaction, provides information about building performance, alerts building owners about potential maintenance, as well informing them of building enhancement requirements to improve occupants' satisfaction.

The following sections cover different aspects of this paper: Section 2 will cover the methodology we followed to obtain and gather the data from occupants and the references used. Section 3 will cover our survey outcome, data interpretation and the main causes of occupants' dissatisfaction. Section 4 will discuss technology in construction and the role of home automation in building management and occupants' satisfaction, it will also review Oman's building code and the need to implement new technology, measures, and practices for sustainable buildings. Section 5 will discuss global energy use and the importance of exploiting Building Automation System (BAS) in building energy design. Section 6 will discuss smart building, BAS, and Internet of Things concepts, architecture, and their global market. Section 7 will discuss techniques and recommend practices and use of sustainable building materials to improve building performance in Oman. Section 8 will cover a review of green building certifications and rating systems globally and a review of incentive programs in Oman for the use of solar systems. Section 9 will cover the importance of Post-occupancy Evaluation (POE) in building performance review and the gap between building energy design and post-occupancy energy performance. Finally, Section 10 is about the gap in this paper's questions and the roadmap for future research.

2. Methodology

Understanding and assessing building performance in Oman requires data collection from buildings, utilities providers, field measurements, and occupants' feedback. Perception of building performance by occupants and their ability to evaluate the dwelling that they live in is an important tool to evaluate and enhance building energy performance, building renovation, and exploiting all tools and measures such as using Building Automation Systems (BAS) to optimise building performance and attain occupants' satisfaction.

Post-occupancy Evaluation (POE) is one of the tools used in this paper to collect information from the occupants and utilise the data for outcomes and recommendations.

To meet the aims of this paper this work will seek to answer the following questions.

1. From occupants' perspective, is energy consumption of buildings in Oman too high?
2. What techniques and measures can be used to enhance buildings, reduce energy use, and attain occupants' satisfaction?
3. Are people in Oman ready to deploy building automation systems in their dwellings? What concerns do they have about smart systems?
4. What can be done to allay the concerns that occupants have over the deployment of building automation systems?

These questions will be answered through a survey and supporting literature review. This process is summarised in Fig. 1. The survey will consist of 30 questions divided into three sections conducted with 105 occupants. The survey link has been distributed through social media to a specific targeted group in Oman aged between 18 and 65 years old and focused on the age group between 36 and 45 years old as this group potentially owns their dwelling and could provide clear experience and insights.

The survey is designed to motivate occupants to evaluate their dwellings from several aspects, so they have better understanding of the place they live in. It also explores occupants' readiness and willingness to enhance their dwelling performance by introducing new aspects such as Building Automation Systems.

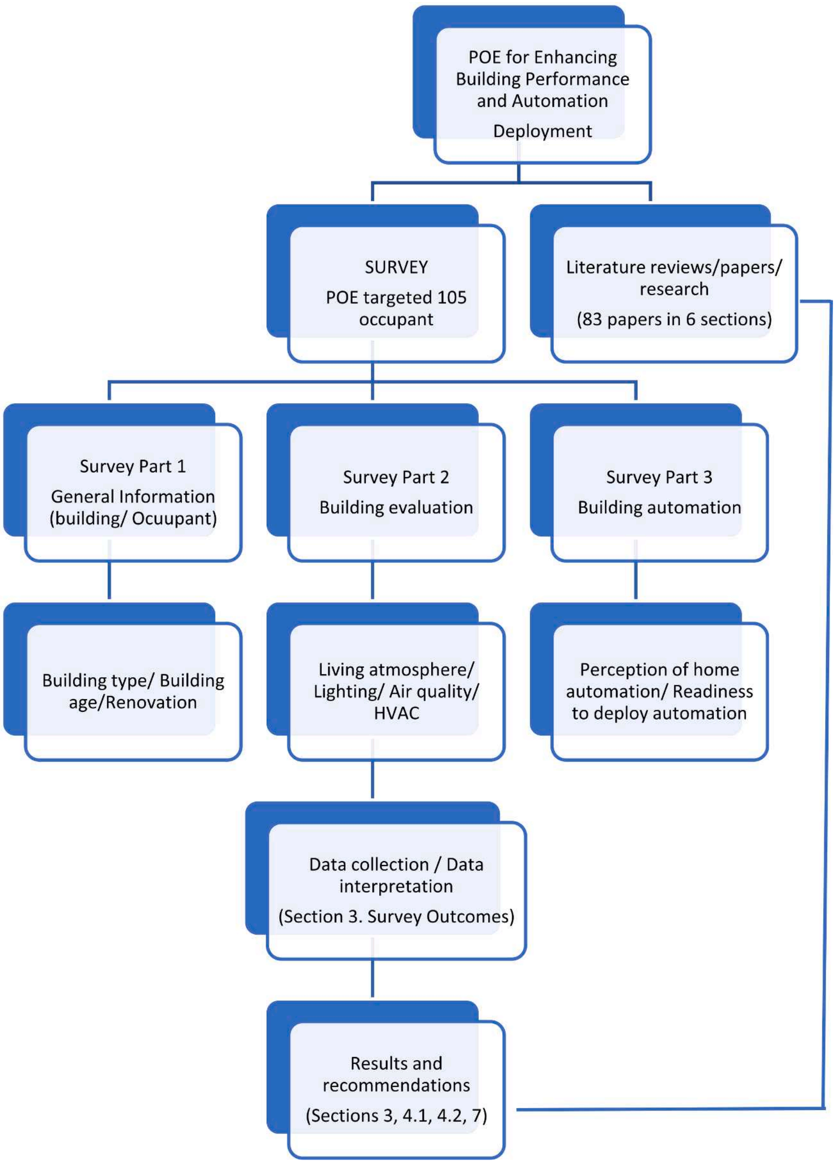

Fig. 1. Flowchart for data-obtaining methodology.

The first section in the survey is to obtain general information about the occupant, type of building and recent renovation. The second section is for building performance from the occupants' perspective of building systems and assesses the occupants' readiness to enhance their building. The third section assesses occupants' perception of home automation and readiness to deploy automation in their dwellings.

The first section elaborates on questions related to the number of years the occupant lived in the building, building age, renovation if any, cost of renovation, and willingness to renovate the building. This section aims to obtain information from occupants to understand their perception of the building they live in and to introduce this information to occupants, so they have a sense about their building before going deep into the next sections which provide some concepts of Indoor Environment Quality (IEQ), Artificial Intelligence (AI), smart home, building automation, and energy performance. It also helps us to understand and evaluate the responses in the next sections and their impact on overall comfort and satisfaction.

The building evaluation section of the survey contains questions related to quality of indoor environment, natural and artificial light, indoor air quality, availability of indoor temperature control during winter and summer, and to explore readiness level to improve indoor environmental quality. This provides an indication about indoor building quality and performance during the summer and winter seasons that shall provide useful information to the concerned authorities to evaluate and assess the building process and materials to improve building performance, especially building envelope insulation, and recommendations to add mandatory articles to Oman's building code to use low thermal conductivity building materials to achieve a robust controlled indoor environment with minimum use of energy, especially during high temperatures in summer. The questions are designed to increase occupants' attention to building architecture and their awareness to building systems. For instance, use of natural light, building insulation, indoor temperature control, indoor air quality, and use of smartness and automation are given as questions to increase occupants' understanding of the building, they live in.

The third section of the survey is about building automation, and it is designed to obtain information from occupants regarding the level of automation in their dwellings and to explore occupant perception level of building automation as well as their readiness to deploy home automation. This section explores current automation levels in Oman's buildings, the potential of future widespread automation, raises occupants' awareness of the importance of automation in reducing energy consumption, providing comfort and convenience, and to understand occupants' concerns and interest in automation.

Additionally, to understand the related literature review in the field, this paper will review literature that reports on; (a) potential sustainable and state-of-the-art building materials that could benefit Oman's construction sector by enhancing building performance, (b) building automation systems, (c) landmarks and their role in building performance, (d) green certification tools and techniques, (e) post-occupancy evaluation and its role in building performance and occupants' satisfaction.

The literature review enriched this paper with information and supported the findings from some parts of the survey, such as using nano-materials for sustainable building, enhancing building envelope with insulation materials, and understanding techniques to enhance building performance. The literature also provided important information to address occupants' concerns such as indoor temperature control and the role of automation in building management. Furthermore, it provided robust information on insulation techniques, isolation of indoor environment, and use of IoT to optimise energy use. On the other hand, the survey showed low use of automation in Oman, and therefore, the literature promotes the use of BAS and clarifies its role in occupants' convenience and satisfaction.

Only 83 reports and relevant references were used to support this paper. The references were obtained from Scopus, Elsevier, ScienceDirect, IEEE, and Google Scholar using specific keywords. These were "building automation, building automation system, building performance, sustainable buildings, green building, smart buildings, sustainable building materials, internet of things, post-occupancy evaluation, building rating systems".

3. Survey outcomes

The survey results were obtained from 105 occupants of different types of building in Oman showed that 46.1% are very satisfied and 34% are somewhat satisfied in the dwelling quality and living atmosphere. This could be because 70% of the occupants live in a detached owned house and they have the freedom to modify and renovate their houses to meet their satisfaction level compared to the occupants who live in rentals where building modification decisions are down to the landlord. It could also be related to the building age as survey data shows that 30% of the houses are brand new houses with an age less than five years. The survey also shows that 26% of the occupants rated between 1 and 2 for Likert questions regarding the level of temperature control during summer and winter where 1 is full control over home temperature and 5 is no control. This explains why 79% of the occupants are willing to invest money to improve temperature control in their dwellings. It also highlights poor building insulation and calls for measures needing to be taken to increase building efficiency and consider sustainable building materials for new buildings, and core and shell renovation to reduce energy consumption, attain rigorous control over building temperature, and realise comfortable ambient temperature. Table 1 lists stakeholders who have roles in promoting sustainable building materials and building automation to enhance building performance in Oman (see Table 2).

The survey also shows that 89% don't have any automation systems in their dwelling, 60% of whom are interested in installing automation. The dearth of automation deployment in Oman has many reasons, such as a shortage of automation products off the shelf, special tech companies being required to install, product cost, Wi-Fi being required for automation when not all buildings have it, electricity cost recently becoming more expensive and people still exploring solutions to tackle the utilities cost hike.

The driving reason to install automation according to the survey is to reduce electricity cost, then comes the desire to have a home control system, and lastly for comfort and convenience. The survey revealed that 78% of the occupants agreed that installation of an

Table 1
Research stakeholders.

Stakeholder	Area of work
Municipalities and government authorities	Legislation for use of sustainable building materials, building codes and policies
Energy sector	To promote the use of energy-efficient products, solar systems, and a building rating system with incentives
Municipalities and government authorities	Legislation for use of sustainable building materials, building codes and policies
Building materials manufacturers	Consideration to produce sustainable materials as competitive alternatives
Tech companies and business owners	Promote using home automation as a cost-effective solution in the long term
Engineers, labours unions and professionals	Lobbying to implement sustainable building; conferences to raise awareness about building automation
Architects	Consider insulation materials in the design; sustainable building material recommendations
Contractors	Use sustainable building materials in construction
Landlords	Enhance building quality and reduce energy use should they choose to use sustainable materials in their buildings and deploy automation

automation system in their dwelling will reduce their utility bills and increase safety, security, and comfort. This highlights a high level of awareness and perception of automation and smart home concepts as well as the importance of automation in building management to reduce energy consumption and increase comfort and convenience.

Only 11% of the surveyed occupants have basic automation in their dwellings such as a remote control for the external gate. Automation perception to many occupants is to control HVAC, lighting, and appliances remotely to add safety and security measures to their dwelling. Some occupants related their interest in automation to having comfort and convenience and were interested in using the technology. However, the biggest interest was to reduce electricity cost, which is the main trigger that changes people's culture and affects their decision. Recently, electricity and water subsidy has been partially lifted in Oman, with people's behaviour and decisions being shaped by tax implementation and the need to reduce living burdens making people look for solutions to increase building performance. Among those solutions are home automation, replacing aluminium windows with UPVC, sealing window gaps to prevent heat penetration and cold air escape, use of LECA bricks in new buildings and core and shell renovation, white or light colour façade painting, and building insulation although this is still not common.

The survey also measures the level of occupants' readiness to invest money in their dwellings to improve temperature control at 78%; installing a Building Automation System (BAS) at 60%; enhancing natural and artificial light control at 49%; and enhancing indoor air quality at 39%. Fig. 2 shows occupants' readiness level to invest money to enhance their dwelling systems. Again, temperature control is the main concern of occupants in Oman and could also be in neighbouring GCC countries that have similar environmental conditions which raises a flag for upgrading air conditioning (AC) cooling efficiency and energy consumption since keeping them working for long hours to attain a comfortable ambient temperature would be costly, and at the same time building envelope enhancement should not be ignored to achieve this goal. Automation may not be very effective in reducing energy consumption, particularly with HVAC since the outdoor temperature is between 40 and 50 °C during summer and therefore automation should keep AC switched on to attain a comfortable indoor temperature. It will certainly reduce energy consumption of lighting while HVAC accounts for the major energy use in the buildings.

The collected data showed that 66% of occupants related their interest in home automation to cost saving, 28% to safety and security, 28% to the need for home and temperature control, 14% to comfort and convenience, and 2% were interested in the use of tech-

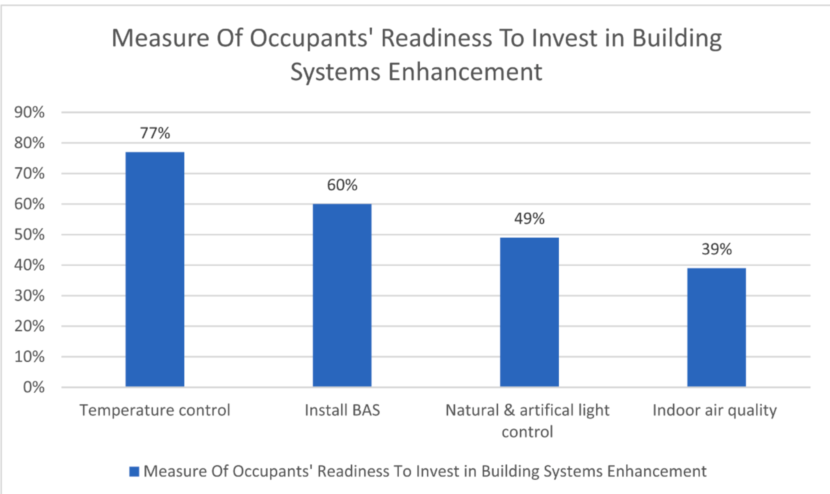

Fig. 2. Measure of occupants' readiness to invest money to enhance their dwellings.

nology. This is summarised in Fig. 3. Most of the occupants' concern is in reducing the cost of energy and this is the main reason triggering the technology to improve efficiency of home appliances and manufacture of sustainable materials. The Internet of Things also deployed home automation for the same reason, to reduce energy consumption and provide safety, security, and convenience.

The survey also shows that 34 dwellings are new buildings aged less than five years, and among those dwellings only six are equipped with BAS while 28 dwellings have no automation. From the 28 dwellings, 50% of occupants were interested in installing automation. This highlights a big interest in automation but there are reasons that made occupants not deploy automation in their dwellings. This can be related to the cost of the automation, extra cost of having internet in the buildings, awareness and perception of the role of BAS in building management and reducing of energy consumption, availability of automation products off the shelf as these are high-tech products and need specialised companies to install, and also some occupants are not interested in the complexity of the automation especially automation schedules which may change during seasons. It could also be related to the wrong perception of some occupants that BAS could increase the cost of energy, especially for AC units.

4. Technology in construction

The construction industry has never undergone disruptive transformation and it's slowly responding to technology unlike other industries such as automotive and aerospace which have exploited digital technology and adapted to quick productivity and accuracy in quality. This radical shift in the industry towards digital technology is known as Industry 4.0 [12–14].

The slow response of the construction industry to technology is due to unskilled and low-income labourers and the nature of construction projects that are limited in time and budget that makes it hard to respond to technology and innovations. The nature of construction projects is limited by scheduled time from planning to handing over, since using technology onsite requires implementing technology methods during the construction process which in turn requires extra time that affects the delivery schedule and has a direct impact on project cost. Implementing technology in the construction industry requires collaborative work between architects, contractors, project owners, authorities, and all stakeholders involved in construction to make a transformation towards construction technology.

The two major drivers of construction projects are project budget and project schedule which are interrelated, and they must be under strict control to avoid any costly variation that could impact project delivery. This entails a thorough follow up of construction progress to deliver it within its scheduled timeframe and hence this rushed pace does not allow a relaxed time to experience new technology or implement a new construction method except in very limited circumstances where there could be a way to expedite project delivery or in some cases when the project delivery method is a turnkey project where the contractor has all in-house products. In recent years there has been progress in the use of technology post-construction thanks to the emerging of 5G, the Internet of Things (IoT), smart sensors, and actuators.

However, the quick pace of construction produced prefabricated buildings in the United States in the 1940s. Post-war there was a huge demand for economical and quickly delivered housing camps for humanitarian aid. The shortage of materials and skilled labourers led to poor-quality prefabricated houses and created the perception of prefabricated houses that they are a poor quality, cheap, and ugly option [15]. However, the continuous demand for less-costly buildings and the requirement for quick delivery of construction projects have spurred off-site prefabrication aided with better design and engineering which cut a lot of in-situ costs such as labourers, construction waste, and environmental pollution, and proven to improve workflow and reduce construction duration [16].

Building Automation Systems (BAS), also known as Building Automation and Control Systems (BACS) or Building Management Systems (BMS) are one of the technologies and tools to manage, integrate and control most if not all building components including lighting, HVAC, safety and security, and building envelope [9]. BAS aims to integrate building systems to talk to each other to achieve

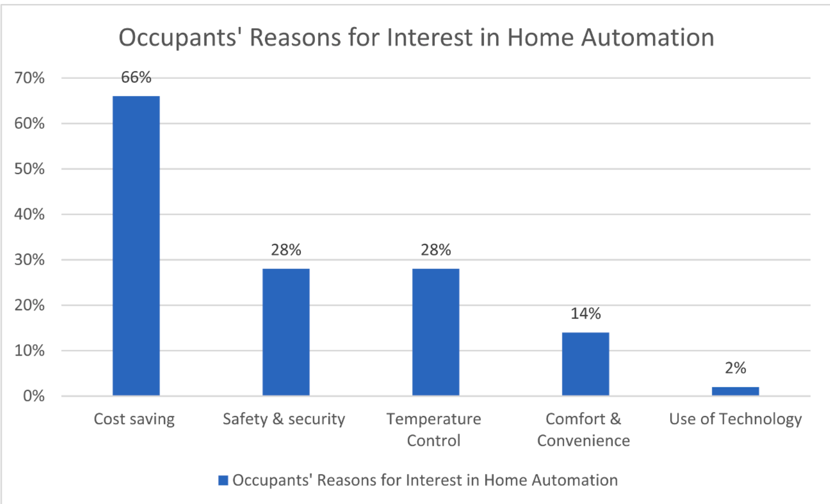

Fig. 3. Occupants' reasons for interest in deploying home automation.

high building performance, reduce operation cost, and optimise energy use. This requires deploying a set of smart devices, sensors, and actuators to obtain information from the surroundings, and occupants to control building systems and provide comfort and convenience for occupants with the lowest possible energy use. The start of automation was with hardware devices to control TV, sliding gates, socket timers linked to electric devices and so on. The importance of hardware was the focus of research more than the importance of software [10,17,18] with the advent of sensors, actuators, and control over gateways that all require algorithm data to operate and tackle many real-time commands and stochastic occupant behaviours. The Internet of Things (IoT), cloud computing, machine learning (ML), and big data processing have drastically shifted the importance of software over hardware in BAS.

The benefits of building automation in building management are clear, reducing electricity consumption and water usage particularly after the advent of machine learning (ML) and Intelligent Building (IB), Smart Building (SB), and nearly Zero Energy Building (nZEB) concepts that respond to external dynamic weather conditions [19]. While 'intelligent' refers to the infusion of ICT in the building, 'smart' is more about improving interaction with humans, and the terms are synonymous [20]. Building automation improves drastically the control of the building system to the optimum energy use and highest level of occupant satisfaction and exceeds occupant expectation not only in controlling building systems but even predicts occupant behaviours and reacts accordingly with what is known as machine learning. Building readiness for coupling with automation should have three indicators: readiness to adapt to occupant needs and control over energy, readiness to adapt to the needs and response of the grid, and readiness to facilitate building operation and maintenance in an automated manner [21].

Early research focuses on building automation to control building systems such as lighting, HVAC, security, safety alarms, and overall building automation aimed at reducing energy use. However, this could impact occupants negatively since building systems are usually programmed to maximise reduction of energy consumption and therefore to reduce the use of light, HVAC, and so on for other building systems. This usually happens in the buildings with third party management such as commercial residential buildings i.e. condominium apartments in which building management aims to reduce the cost and maximise profit through a tough reduction in use of lighting, HVAC and other building systems, which can affect occupants comfort negatively. However, for private dwellings the occupants can choose to control their dwellings to the optimum comfort and satisfaction, balancing energy consumption and comfort.

Additionally, feedback from occupants then becomes an important tool to optimise automation programs to satisfy occupants, provide convenience, increase productivity and wellbeing [22].

4.1. Review of Oman's building code

The construction code in Oman needs to be reviewed to fulfil the 2030 UN Agenda for Sustainable Development, namely Goal 7: Affordable and Clean Energy; Goal 9: Industry Innovation and Infrastructure; Goal 11: Sustainable Cities and Communities; as well as Goal 13: Climate Change. The temperature during summer is between 40 and 50 °C and buildings are built with concrete bricks that are known for their high thermal conductivity (1700–2500 mW/mK) and without any additives that improve insulation. In addition, no insulation materials are used in roofing nor in envelope walls. However, in the recent years white bricks that contain Lightweight Expanded Clay Aggregate (LECA) have become popular and many landlords have requested to build the exterior walls with white bricks which are basically made by heating clay to around 1200 °C in a rotary kiln and the final product yields clay pebbles expanded by small bubbles [23]. These are added to a concrete mixture to form lightweight bricks that increase thermal and sound insulation and fire resistance. However, LECA bricks have been introduced to the market without a mandatory code to use them in construction and they are available as an alternative with extra cost compared to solid concrete bricks. Building insulation would save a lot of energy that's used for cooling during summer and could save the environment from using unsustainable natural resources for energy generation.

Most detached houses in Oman have four to five bedrooms, one family hall and a kitchen with an AC split unit in each space and they are switched on for more than 10 h daily for at least eight months a year (March to October). There is a massive loss of money in building cooling because of lack of insulation practice in the exterior walls and roofs of the buildings. The home space needs AC to work for long hours so that room temperature reaches occupant satisfaction and comfort of 24 °C or lower. Furthermore, achieving convenient room temperature exhausts ACs and there should be maintenance during the season or there could be a failure in the compressor unit. Switching off ACs for a few minutes will require turning the AC on for hours to regain a comfortable room temperature. Insulation is not a mandatory practice in Oman buildings since electricity used to be subsidised by the government and it was costless, but this could also be related to the lack of experience and perception of insulation in reducing energy use. Professional building insulation could save up to 65% of the energy used for cooling [24].

Old buildings in Oman were built with clay mud mixed with palm leaves and burned to form a sticky mixture then added to white cement additive for extra binding; this primary mixture is known locally Sarooj which replaces concrete bricks and mortar in their function. Natural wadi stones were used to reinforce the structural stability of the building. The ceiling slab is supported by date palm trunks which are usually vertically cut into four equal columns to attain the maximum length especially for the family hall and master bedroom that have long span slabs. Wall thickness is usually not less than 40 cm, especially if the building is more than one level high. Old buildings have small windows to prevent heat penetration into the building, especially as there was no air conditioning, and the rooms get fresh air circulation from circular holes of approximately 25 cm diameter every 1 m distance along the walls just under ceiling level to allow room ventilation during summer. Use of clay and mud provide high efficiency in cooling the indoor environment and resisting thermal conductivity during the summer (Fig. 4).

Buildings in Oman must be painted with a light colour paint by code, either white or light colour shades to reduce heat absorption and maintain better indoor temperature. In general, building architecture in Oman has a similar theme in terms of colour, rare use of glass curtain wall façade, but windows are either aluminium or Unplasticized Polyvinyl Chloride (UPVC). Although wood has better

Fig 4. Omani heritage house built with Sarooj, wadi stones, and date palm trunks. Picture attribute Bait Al Safah Museum.

insulation and low thermal conductivity compared to aluminium and UPVC, it also expands and shrinks corresponding to weather temperature, so the use of wood is undesirable for windows given the radical change in temperature between summer and winter. Keeping a comfortable constant room temperature in Oman during the summer means needing to keep the air conditioning on 24 h a day during summer months, as room temperature quickly becomes hot and uncomfortable when air conditioning is turned off for a few minutes especially during day hours due to an external weather temperature which exceeds 50 °C some days in June and July specifically. In summer daytime hours building envelope walls store sun heat radiation in concrete blocks and reinforced steel columns, beams and slabs and release the heat during night hours if the air conditioning is turned off. Concrete has high thermal mass which is defined as the capacity of material to absorb, store and release heat. This is noticeable as walls remain hot during the night and flush heat indoors to keep room temperatures uncomfortable even with the AC on in some circumstances although currently AC cooling efficiency is high and could achieve comfortable room temperature by keeping the AC compressor on a lower thermostat temperature which is more costly than setting a room temperature to auto-mode where the AC compressor turns off as it reaches the desired temperature.

There are several construction practices that contribute to exhausting ACs and prevent in achieving comfortable room temperatures. In addition to lack of wall and roof insulation and use of concrete bricks, there is a massive quantity of rebar steel used for reinforcement during the construction process without any thermal conductivity reducing additives that could assist in reducing heat effect on the walls. Use of aluminium and single glazed windows is another practice that needs to be changed by codes. Aluminium is known to have good thermal conductivity, so it works as a good medium for heat exchange between outdoor and indoor environments. Using double- or triple-glazed windows works as a good insulator [24] and should be mandated in the Omani market, especially as the architectural trend nowadays is to use big windows as part of modern design. However, insulating AC ducts that air flows through is important to maximise AC efficiency, and annual service of AC compressors is also essential especially as Oman is an arid country where rain is rare, and the air carries a lot of dust and dumps it on the compressors which causes failure if not serviced regularly.

4.2. Sustainable materials

Use of sustainable building materials is essential to preserve the environment, save energy, and reuse materials since the construction industry accounts for 40% of annual aggregates consumption (sand, gravel etc.), 30% of global greenhouse gas emissions, 25% of the world's timber consumption, and 16% of water consumption [25]. Therefore, the construction industry has a significant impact on the renewable resources used, however, the advance in the construction industry shows promising potential in exploiting technology to use alternative additives in building materials production that reduce environmental impact on the renewable resources and produce new products with high performance and less use of renewable resources. For instance, adding nanomaterials to building materials enhances the features of the materials, as an example adding nano-limestone to concrete mixture reduces the curing period and improves cementing properties [26].

Another good example for enhancing sustainability of building materials is adding nanomaterials to glass which results in improving energy efficiency by 75% compared to normal glass [25]. In some cases, it's estimated that 80% of building energy can be saved when using high-performance insulation. Ordinary insulation that is embedded in the drywall is thick and heavy and when installed it reduces the useable area. Therefore, innovative materials have been investigated, manufactured and become available in the market with high building insulation that keeps the indoor environment isolated with such materials as double- and triple-glazing windows, rock wool, polystyrene, and polyurethane foam, vacuum insulation panels, nano and dynamic insulation materials [27], Traditional, state-of-the-art and future thermal building insulation materials and solutions – Properties, requirements and possibilities 2011). Aerogel is a special insulation puffed-up material with nano-meter scale pores $<1/3000$th diameter of a human hair providing the lowest thermal conductivity (0.014 W/m K) and high acoustic insulation [28]. Aerogel is considered the best assured insulator compared to all other materials as its flexible in form and derived from gel also known as "frozen smoke" for its ultra-light weight and transparency.

Concrete has high thermal conductivity therefore adding nano insulation materials to the concrete mixture becomes more demanding to reduce concrete thermal conductivity without affecting the mechanical strength and load bearing of concrete properties. Currently in Oman there are three types of concrete blocks: the first is the normal concrete blocks that consist of cement, sand and gravel of different ratios according to desired compression strength; the second type is concrete bricks with a layer of insulation foam; and the third type of bricks is the white bricks known as Lightweight Expanded Clay Aggregate (LECA) which are manufactured from clay with minor or no lime content [29]. Building in Oman is shifting towards using LECA given the fact of high temperatures during summer and electricity subsidy being reduced so energy cost has increased. This triggered a new behaviour from landlords in considering the use of sustainable materials and looking for new solutions to increase building performance and reduce energy consumption.

Future insulation techniques could have better potential in respect to thermal conductivity, durability, freezing-thawing resistance, adaptability, and constructability. Such future materials like vacuum insulation materials (VIM) which are homogeneous materials with a closed small pore structure filled with a vacuum and a thermal conductivity of less than 4mW/(mK), and gas insulation material (GIM) which is basically homogeneous material with small pores and filled with low-conductivity gas such as argon (Ar), Krypton (Kr) or Xenon (Xe) that provides thermal conductivity less than 4mW/(mK). Nano insulation materials (NIM) which is derived from vacuum insulation material but has smaller pore size so to achieve thermal conductivity less than 4mW/(mK) and provides a service life of at least 100 years, and dynamic insulation materials (DIM) where the thermal conductivity can be controlled within a desirable range [30,31], (Jelle, Traditional, state-of-the-art and future thermal building insulation materials and solutions – Properties, requirements and possibilities 2011).

5. Global energy use and BAS for energy

Energy use in the world is rapidly increasing and raised a flag for global energy supply shortage in addition to environmental impacts from heavy use of natural resources that contributes to carbon footprint. Globally, the building construction sector is responsible for one-third of global final energy consumption, and this continues to rise driven by easy access to energy in developing countries, greater ownership and use of energy consuming devices as well as rapid growth of the building sector globally [32]. Furthermore, the environmental impact of heavy use of fossil fuel increasingly contributes to CO_2 emissions, greenhouse effect, ozone layer depletion, and global climate change. However, the demand for energy use has increased dramatically driven by transportation and construction sectors which collectively account for two-third of energy use. New technologies and products become more energy efficient, however, crafting and implementing wise polices is seen to be the cornerstone for energy use reduction [33].

European Union (EU) buildings are responsible for 40% of energy consumption and 36% of greenhouse gas emission. Approximately 75% of buildings in Europe are energy inefficient and a large portion of supplied energy is lost as waste. Renovating existing buildings is suggested by the EU to increase their efficiency and reduce loss of energy and carbon dioxide emissions. There have been new ambitious policies introduced to encourage landlords to renovate their buildings and increase their efficiency. Building Automation Systems (BAS) are one of the important aspects that are proved to reduce energy use in buildings [34–38]. BAS can be digitally simulated and designed through building modelling software based on computational modelling and can provide advantages over field experiments in that they permit energy saving prior to implementation, save time, allow repetitive tasks to check and balance the results, are non-intrusive for building occupants, simplifies performance indicators that are difficult to measure in site, and provide easy to interpret results [39,40].

BAS supports whole lifecycle as indicated by researchers in design, construction, operation and even retrofit phases. For example, during design phase BAS enables HVAC simulation optimization, in Construction phase BAS reduces construction energy consumption and improve construction management, safety and efficiency. During operation phase BAS attains occupants' comfort and satisfaction, reduces operation cost, monitor the facility and manages safety and security. During retrofit phase BAS quantifies specific impact of building retrofit such as building envelope, improves indoor environmental quality and save energy [41].

5.1. Energy modelling

Using building modelling software is powerful in the sense that energy simulation results are accurate and provide predictions for energy consumption through virtual simulation given that implementing experiments can be costly and difficult to apply for research purposes. The major landmark software in the market are EnergyPlus, RADIENCE, MATLAB, and eQuest. While those software and others are powerful in energy design taking into account occupant behaviour, research revealed that there is a discrepancy in the designed energy and the actual building performance [42,43] mainly due to stochastic occupant behaviour which refers to the presence of people in building spaces and their interaction with the building such as switching on/off lighting, opening and closing windows and curtains as well as occupants' preferences of lighting intensity, desired room temperature, and so on. Occupancy modelling is multidisciplinary where different application scenarios require various disciplines to support building simulation and operation. For instance, occupancy design is used for HVAC sizing, elevators size and schedule, lighting and crowd management, which are under different disciplines. Hence, collaboration between all disciplines is essential for occupancy modelling [44].

Occupants' satisfaction entails flexible control of many variables granted to occupants to modify to their favourable preferences. For instance, some occupants like warm light colour temperature 2700-3000k while others like cold light colour temperature 4000-5000k, most LED lights in the market fall withing the tow ranges. The technique of changing light temperature in the same fixture is nowadays becomes popular and available similar like dimmer which provides flexibility to serve occupants' preference. Same concept is also available for room control system where automation or AC thermostat pre-set to a preference temperature and the sensors/actuators attain the desired room temperature. Home automation then become an important tool to be embedded in energy modelling and simulation considering occupants' preference to achieve positive Post-occupancy Evaluation.

5.2. Oman building energy calculation

In Oman, most architects sketch up the initial drawing that lays out rooms and spaces for house building. As for energy calculation, this is usually done for governmental buildings and some commercial large-scale buildings. However, for house buildings there is no software used but each electrical appliance, AC and lighting electrical load are summed up based on precalculated loads for each component to get the total load. Each electrical device is connected to electrical cables of specific amperage loads which are connected to the distribution box that contains fuses of different loads usually from 6 to 60A. The distribution box is connected to the main distribution meter or a smart meter. This is the basic concept that most architects use in Oman based on precalculated loads of electrical fixtures. A distribution box which has all the fuse switches for all electrical fixtures in the building is connected to a meter box that is customised to provide the required load from the main electricity distribution line. The majority of residential buildings are equipped with split-unit AC in each room, and they are available on the market starting from 1.5 to 3.5 ton for home use of which three tons and above requires a 3-phase cable connection. Setting ACs in an auto mode for 24 °C would save energy use as the thermostat works automatically to keep the room within the desired temperature, however this may not save energy use during summer since the ambient temperature is hot and reaching the desired room temperature entails the compressor to be on for long hours given that buildings don't have any insulation but high thermal conductivity concrete bricks. BAS would ultimately optimise operating and scheduling of home systems with the use of occupancy sensors, motion sensors, and time-linked tasks, especially lighting and exhaust fans.

6. Smart building BAS and IoT

The smart building market is forecast to grow from USD72.6 billion in 2021 to USD121.6 billion by 2026 [45]. Research on BAS started in the 1980s with the rise of information and communication technology and the need to provide comfortable accommodation for occupants with less use of energy. Specifications and fundamentals of BAS are prescribed by EN15232 standard energy performance of buildings, Impact of Building Automation, Control and Building Management. It classifies functions of building management systems and the potential for saving in energy consumption with the use of building control systems [9].

The smart building concept thrives with the integration of technology in buildings triggered by cost effectiveness of smart sensors to control the home remotely providing comfort and convenience. Smart buildings can't be smart without deploying BAS components which consist of software and hardware. The last components such as deploying sensors, actuators, storage drives, and gateways with the need for cloud storage, and human-computer or smartphone application interaction. The Internet of Things (IoT) is among the enabler technologies for many industries, and it's defined as the point in time when more “things or objects” were connected to the internet than people. In 2003 the ratio of connected things (500 million) to the people (6.3 billion) was 0.08 which is less than one and therefore IoT is not yet there according to Cisco IBSG's definition, and this is reasonable since smartphones were not yet ubiquitous as the iPhone was unveiled in 2007. However, in 2010 there were 12.5 billion connected devices making the ratio of connected devices per person 1.84 revealing that IoT was born between 2008 and 2009 [46] and the estimated IoT cellular and non-cellular connections is forecast to be 25 billion in 2025 [47]. This prediction reveals the rapid growth of IoT between 2009 where each person had one connected device, and 2025 when the ratio is expected to be tripled so that each person would have three connected devices. IoT and BAS both work to achieve the same goal in the context of home automation, however, BAS is a closed system that is interconnected and pre-programmed to manage specific events or coordinate home automation scenarios that are pre-set. IoT uses the internet to collect data from the surrounding environment, processes the collected data and provides the optimum scenario functions for home management. Data security in BAS is higher since it's a closed system compared to IoT which requires internet to collect data and therefore susceptible to cyber-attacks and data hacking.

IoT architecture is divided into layers depending on the industry; researchers proposed layering based on the applications and industries [48–51]. In the smart building industry IoT architecture is also divided into layers and some researchers prefer to use conventional architecture of three-layers: a perception layer (sensing and actuation), network layer (data transportation), and application layer (user interaction) [52]. One IoT application in the building industry integrated with the electricity sector is smart grids which enable two-way communication between electricity provider and the consumer to control and manage peak-time electricity use since its cost is higher. Smart meters feed back to the electricity station with use of energy in the building and interact to optimise energy consumption which helps both the power infrastructure and the consumer [53].

Post-occupancy Evaluation is an essential tool for enhancing building performance through occupants' who experienced the building and got better understanding of the space they live in. Occupants' convenience and satisfaction is crucial for business to continue in the market especially for real estate and building managemen. Therefore, occupants' feedback about building performance, issues they face and complaints should be considered to improve the building and services and attain their satisfaction. Building enhancement for occupants’ satisfaction entails timely response to any claim or maintenance request in addition to pre-occupancy satisfactory parameters such as rooms design and layout, Indoor Environment Quality (IEQ) which includes air quality, light intensity, temperature control, humidity and security. To achieve this home automation plays important role to control and manage all mentioned parameters.

7. Techniques to improve building performance in Oman

Increasing building performance is not only done by installation of automation systems but also by implementing preventive measures during construction and post-occupancy. These measures are summarised in Table 2. One of the measures in construction is using Lightweight Expanded Clay Aggregate (LECA) bricks instead of concrete bricks given that concrete has high thermal conductivity (1700–2500 mW/mK) compared to LECA bricks which have 12 times better insulation. Another measure is installation of double- or triple-glazed UPVC windows filled with Argon gas to increase thermal resistance. UPVC windows have better insulation as its thermal transmittance is 0.8 W/mK [54] compared to aluminium windows 160W/mK [55]. These practices enhance AC efficiency and help in reducing heat penetration through windows to attain a comfortable indoor environment.

Small arch windows used to be unique Omani architecture and it was convenient at the time when there were no insulation materials except using Sarooj (burned clay mixed with date palm leaves) which acts as an excellent essential building material but is no longer used nowadays. Using small size wooden windows to prevent excessive direct sunlight is another unique Omani architecture feature to reduce thermal conductivity. However, the new trend in Omani building architecture is to have large windows to get more natural light, but this has the disadvantage of heat penetration to the building and increased cooling cost during summer months. The market has a variety of window materials that can reduce heat penetration from windows such as double- and triple-glazed windows insulated with Argon gas, tinted window glass with several grades that reflect direct sun radiation, silicon for sealing window boarders to reduce thermal exchange between outdoor and indoor environment, use of blackout curtains to block direct sunlight, and automation of windows and curtains that are pre-set to open and close to the user's preference or linked to a thermostat sensor to react to room temperature. While fabric curtains are widely used, louvers and window shutters provide a solid block of sunlight compared to fabric curtains but they are not commonly used in Oman which could be due to their high cost compared to indoor curtains. Blind automation is challenging to maximise heat reduction and at the same time exploiting natural light [56] to reduce energy consumption [57,58] given that scheduling time varies between summer, winter and cloudy days [59].

Another practice that needs to be promoted for thermal resistance is applying white colour protection coating over the polyfoam to reflect direct sunlight and reduce thermal conductivity of the concrete. The prevalent practice for roof slab finishing material is to

Table 2
Techniques and measures to can be used to reduce energy use and attain occupants' satisfaction.

Technique/Measure	Affect	Section
Lightweight Expanded Clay Aggregate (LECA) bricks	- Light weight bricks - Low thermal conductivity - High sound insulation - High fire resistance	4.1. Review of Oman's Building Code
Building envelope insulation	- Reduces thermal conductivity - Soundproof-	
White/light colour façade paint	- Reduces thermal conductivity-	
Use of double- or triple-glazed Unplasticized Polyvinyl Chloride (UPVC) windows with argon gas	- Reduces thermal conductivity - Soundproof	
Steel reinforcement (rebar) to be designed to a minimum structural requirement	- Reduces heat flush from walls and floor during hot season-	
AC duct insulation	- Increases Ac efficiency-	
Annual service of AC compressors is essential especially as Oman is an arid country where rain is rare- –		
Avoid exterior installation of AC air flow duct where it could be installed in the interior walls- –		
Nano-materials additives to concrete mixtures such as nano-limestone	- Reduces curing period and improves cementing properties - Reduces thermal conductivity	4.2. Sustainable Materials
Aerogel is a special insulation puffed-up material with nano-meter scale pores	- provides the lowest thermal conductivity (0.014 W/m K) and high acoustic insulation-	
Nano insulation materials (NIM) which is derived from vacuum insulation material but has smaller pore size	- Achieves thermal conductivity less than 4mW/(mK) - Service life at least 100 years-	
Dynamic insulation materials (DIM)	- Thermal conductivity can be controlled within a desirable range-Cardiff, CF24 3AA	
Tinted window glass with several grades that reflect direct sun radiation	- Reduces sunlight heat penetration and greenhouse effect	7. Techniques to Improve Building Performance in Oman
Sealing window boarders with silicon	- Reduces thermal exchange between outdoor and indoor environment-	
Use of blackout curtains	- Blocks direct sunlight-	
Automation of windows and curtains (scheduled/thermostat)	- Attains controlled indoor environment-	
Use louvers and window shutters	- Provides a solid block of sunlight compared to fabric curtains-	
Blind automation	- Maximises heat reduction and at the same time exploits natural light-	
Applying white colour protection coating over the polyfoam (roof system)	- Increases thermal resistance-	

add another layer of light colour terrazzo concrete tiles on top of water insulation, however this adds weight load over the concrete slab, is costly and labour intensive. Building code in Oman specifies using thermal insulation in four types of buildings: governmental buildings, tourism buildings such as hotels, theatres and exhibition buildings, industrial buildings, and any new building that is four stories or more with a construction cost exceeding 120K Omani Rial (USD650K) or its load exceeds 25 ton. However, field execution does not always follow this code and therefore there is a gap between building code and field practice which causes massive energy loss especially in the commercial buildings with the absence of sustainable materials use, code fulfilment and field inspection.

8. Building certification

Green building, or sustainable building, is a popular term for high-energy performance building to attain optimum indoor environmental quality that satisfies occupants and provides comfort, safety, and security. For this intent, building rating and green label certification tools have been used to certify that a building is sustainable and has high-energy performance. However, building certification systems lack some sustainability aspects such as testing toxic substances and emissions embodied in buildings and infrastructure [60].

Feedback from tenants who live or work in a building for several years or more and have experienced the living or working environment is a crucial tool to assess building performance even if it has been green certified and granted a green label. Surveys showed that buildings certified with the Green Mark and considered as sustainable buildings in Singapore for instance have many limitations and the feedback obtained from occupants showed dissatisfaction in several Indoor Environmental Quality (IEQ) parameters. A survey from the Center for the Built Environment (CBE) at the University of California, Berkeley, has been modified into a survey tool which has been implemented in over 900 buildings and gathered more than 90,000 occupant surveys to compare LEED and non-LEED certified buildings. The modified survey was distributed to 666 occupants in seven Green Mark certified commercial buildings in Singapore and found that occupants' dissatisfaction with sound privacy was the highest (42%), then personal control (32%), and temperature (30%) [61].

Sustainable buildings are designed to save energy, reduce the use of natural resources and adverse environmental impacts, and maximise occupants' satisfaction and wellbeing. Studies and surveys have been conducted to verify if the green buildings perform better than conventional buildings in terms of energy saving and suitability as well as providing better living or working environments and Indoor Environmental Quality (IEQ). Some studies conducted a comparison between certified green buildings and non-green buildings and revealed that green buildings showed better energy performance while other studies showed the opposite; this is probably because of high-occupancy rates of green buildings compared to non-green buildings. Xuechen Gui et al. collected a set of 2657 certified green building data from the National Australian Built Environment Rating System (NABERS) and analysed the relationship between rating certification and energy performance. The study revealed that there is a linear relationship between performance indicator data and certification level for Energy Use Intensity (EUI), Emission Intensity (EMI), Water Consumption Intensity (WCI), and IEQ Score (IEQS). A rise in the certification level decreases EUI, WMI and WCI but increases IEQS [62].

A study was conducted by Guy R [63]. to answer a critical question regarding LEED certified buildings regarding whether they are living up to expectations in energy performance after being constructed. The study acquired data from New Buildings Institute and US Green Buildings Council for certified commercial and industrial buildings. He found that LEED buildings use 18–39% less energy per floor area than conventional buildings. The study revealed that energy performance of the buildings has little correlation with certification level or the number of energy credits granted to buildings at the design phase. The study calculated statistically the data collected form LEED-certified buildings and found that there is no significant relationship between the certification level and energy use intensity saving. That means a building with Gold or Platinum LEED certificate does not entail less energy use intensity than a building with silver LEED certificate [63].

Furthermore, Prof. Josef [64] criticised many green buildings for consuming more energy than conventional buildings and stressed that any building has to stand up, resist winds and hurricanes, be flexible in earthquakes, fire resistant, rainwater proofed, not be mouldy, not rot, not corrode, and has to meet applicable building codes so providing green awards for basics and fundamentals of any building is a pointless practice. He argued that points are given to buildings to achieve green status for basic building requirements that are literally required by codes to be called buildings. The author stressed that green programs waste a lot of time and money on things that are irrelevant or unimportant and don't save energy, and some practices proved to consume more energy such as glass envelope façade [64].

The New Building Institute (NBI) is the most comprehensive LEED database for U.S. high-performance buildings. Despite its credit for publishing open-source data, the NBI is criticised for being biased on data collection from voluntary building owners. The fact that the NBI focused on so-called "medium energy" LEED building and ignored data from buildings with higher Energy Use Intensity (EUI) resulted in a conclusion that the mean EUI of the buildings is lower than other commercial buildings, when the opposite is true. Analysis for NBI LEED energy-consumption data was conducted from energy sources and its consumption on-site and off-site to measure use in the building and energy loss due to distribution; the result was that a LEED certified building, on average, is not lowering source energy consumption and therefore not reducing carbon footprint. However, with on-site energy, on average, LEED certified buildings use less energy than non-LEED buildings and the saving is between 10 and 17%. It's worth mentioning that the majority of LEED-certified buildings use less energy than their counterpart non-LEED buildings, however, few large LEED offices are not using less energy than non-LEED counterparts [65].

In Oman there is no certification program for building performance except an incentive program for buildings that integrates solar panels on the buildings' rooftops. Power supply companies provide a list of qualified contractors for solar panels installation and then connect the grids to the main distribution line. The maximum allowed grid capacity to be installed on a rooftop is 50% of building electrical load. This is entirely used after consuming the first 50% of non-green electric supply from the utility companies. If the consumption exceeds the 50% of non-green electricity, the remaining supply will use solar generated power. The surplus will be taken and used by the power supply companies. This policy does not encourage the use of green energy since the use of generated power can't exceed 50% of total building load, and the consumption of generated solar power is allowed to be used after consuming the power share provided by the utility company. This approach promotes heavy use of non-green energy in order to reach the credit of the solar system, and has a heavy impact on sustainability and the use of green energy.

9. Post-occupancy evaluation

Modelling building energy without occupant participation affects the accuracy of energy measurement since the nature of human interaction is stochastic and their behaviour and interaction with their surroundings differs from one human to another. This is one of the factors that causes a gap between energy modelling and the real energy use post occupancy that could lead to occupant dissatisfaction [66], (D. Y. B. Dong, Modelling occupancy and behaviour for better building design and operation—a critical review 2018), [67,68]. Building automation controls building systems to efficiently provide the optimum home needs of HVAC, lighting, water supply, and to provide maintenance, safety and security to the occupants. Setting up home automation design and schedule however should not neglect occupants' comfort and convenience at the same time when providing energy use efficiency.

Towards this end, Post-occupancy Evaluation (POE) gained its importance for designing building energy, verifying building performance and measuring occupants' satisfaction and convenience. Although building certification intent is designed in the preliminary drawings, it is not always checked and balanced during construction and throughout the commissioning phase. Many buildings showed less performance post occupancy than in the energy modelling and many of buildings got performance certification as designed, but when tested and measured in the field showed less performance. This gap in energy causes a shortage in building performance and may cause occupants' dissatisfaction even for highly certified buildings regardless of the massive use of energy for large scale buildings. POE thus becomes an essential part of building performance evaluation and should be added as a mandatory part in rating system evaluation and should have an impact on the overall certification process given that human spend up to 90% of their lifetime indoors [69]. POE, if added in rating system evaluation, will certainly add accuracy to the building performance, collect data about occupant behaviour, provide better management of resources, improve Indoor Environmental Quality (IEQ), inform decisions based on feedback, and achieve occupants' satisfaction [70].

POE is conducted for numerous direct purposes and aims at design evaluation, occupants' evaluation, energy performance evaluation, Indoor Environmental Quality (IEQ) evaluation, and facility evaluation. Furthermore, POE is conducted for other indirect purposes and aims at identifying issues to rectify defects, provide future retrofit projects, inform building software or development of a questionnaire, provide bases to obtain guidelines or standards for building systems such as lighting and HVAC, or to test existing green building standards. It's also used to assess effectiveness of building technology and validate building models such as thermal comfort models and glare probability models.

POE is conducted through several methodologies varying from subjective methods to physical in-situ measurements. Subjective methods include occupant survey which is the most widely used method, and interview and walkthrough to identify issues. Alternatively, physical measurements include in-situ measurements (thermal condition, lighting, IAQ and acoustics) and energy and water assessment. In general, subjective methods are less costly as there is no requirement for in-situ measurements and equipment. It mostly contains Likert open-ended questions to gather information from occupants.

There are some institutional POE protocols which are considered as landmark for their comprehensive building performance evaluation in its early design stage to post occupancy. Evaluation may contain energy-performance assessment, occupant-satisfaction comfort, air quality, acoustic, lighting, insulation, IEQ and thermal comfort. It could be conducted by survey, interview, focus group, utility bills review, walkthrough, web-based, portable UFAD and in-situ cart-and-chair equipped with sensing devices. Post-occupancy Review of Building Engineering (PROBE), UK, is considered a remarkable landmark in POE for building energy performance assessment [70].

Another remarkable pioneer in POE is the Center for Built Environment (CBE) Building Performance Evaluation (BPE) developed by the University of California, Berkeley, which uses an occupant satisfaction survey and reporting toolkit that has been used widely for measuring numerous indoor parameters. The integration includes sensors and software for real-time evaluation of HVAC performance. It's also equipped with special capabilities for detailed analysis of building underflow air distribution (UFAD) or displacement ventilation (DV) systems by aim of mobile measurement cart and up to 70 sensors that may be installed in air flow diffusers. Mobile measurement carts are configured to collect a series of real-time data which are available in a timely manner and stored for historical retrieval. Several field studies show that UFAD and DA are not commissioned in the optimum capacity and therefore they tend to consume energy more than its design. The reporting toolkit provides accurate information in real-time and data history storage to optimise building systems and energy performance [71].

Another pioneer in POE is the National Environmental Assessment Toolkit (NEAT) which was developed at Carnegie Mellon's Center for Building Performance and Diagnostics (CBPD). Performance Measurement Protocol for Commercial Building (PMP) is another remarkable landmark that has three levels of measurements and has the most published data. In Asia, however, POE is uncommonly used although green and sustainable construction projects are thriving, this is probably due to the use of walkthrough check-up and maintenance post occupancy.

It's common that energy performance for a building during the design-construction phase shows gaps when the building is being used. This is because the use of the building is subject to occupants' behaviours and density dependent especially in institutional buildings. Utilising the conventional Energy Use Intensity (kBtu/sq.ft) is not an accurate measure for buildings with variable occupant density. There are several approaches to address this gap: having occupant lifestyle history and using it as a benchmark to identify average occupant's energy consumption would reduce the gap between energy modelling and actual energy use post occupancy. Calculating actual occupancy in a building, however, is necessary to maintain the energy use and this could be achieved by many techniques such as fisheye camera, radio frequency, Passive Infra-Red (PIR), CO_2, GPS, and Device-Free Localisation and Activity Recognition (DFLAR). By applying a deep learning method, Wang J. et al. Leveraged (DFLAR) deep learning to recognise location, activity, and gesture which achieved 85% accuracy. An advantage of DFLAR is that it doesn't need the target to be equipped with a device nor interfere in their privacy which promotes it for many smart applications [72].

BAS limitations can be mitigated through the following recommendations.

1. Implementation of modelling and as discussed in Section 5.
2. Use of Post-occupancy Evaluation as a tool for re-setting and programming of BAS to optimal occupancy satisfaction as in Section 9
3. Consideration of Occupant lifestyle history – discussed in Section 4.

10. Research gap and future research roadmap

Future research is open to address the gap in the effectiveness of Building Automation Systems (BAS) in Oman and the GCC region in reducing energy consumption during the summer when temperatures can reach 50 °C and the impact of BAS on occupant satisfaction and convenience given that BAS aims at reducing energy consumption and maximises occupants' satisfaction. Automation in hot buildings could be effective in lighting control through occupancy sensors but could hardly be effective in reducing HVAC system use especially during summer as indoor environmental quality might also be affected. Our survey showed that there is a big interest in automation but at the same time only a few dwellings have been equipped with BAS (Section 3).

To understand the obstacles that defer or obstruct the spread of BAS in Oman and the GCC region, the following recommendations shall work as a roadmap to understand the barriers of BAS deployment.

1. A thorough study of available BAS in the market, their cost and availability off the shelf.
2. Field experiment research of the effectiveness of BAS in reducing energy consumption in Oman and the GCC region given that the temperature reaches 50 °C while keeping indoor environments within a comfortable level entails keeping HVAC switched on for long hours. This will provide a strong base for effectiveness of BAS in energy control and will allow to explore alternative solutions for reducing energy use in hot countries as shown in Sections 3 and 5.2.
3. Legislation for adding BAS to building codes.
4. Explore the reasons for occupants' reluctance to deploy BAS and furnish a roadmap to make BAS widespread.

11. Conclusion

Research showed that large-scale, green-certified buildings consume more energy than their conventional counterparts, however, certified buildings have better energy performance in general. Furthermore, energy performance of buildings post occupancy is usually less than its design pre-construction. This sometimes happens because of higher occupancy rate than that calculated in the design phase as well as occupants' stochastic behaviour and lifestyle contribute to the energy gap. BAS deployment is not the sole solution for energy gap since it only manages, controls, and integrates building systems to enhance living experience and optimise energy. To overcome this limitation Occupant behaviour benchmarking is essential to be embedded in early energy design to reduce the energy gap between design and post-occupancy energy use. This requires integration of occupant behaviours into historical data, analysis, and calculation to add an occupant lifestyle coefficient in the energy design, BAS modelling and simulation has to be considered during design phase. POE is an important tool to verify building performance and attain occupant satisfaction, it is gaining importance in many countries and continues growing as people realise its role in real-time feedback. Some studies suggests that POE needs more momentum to become a standard that will be an essential part of building at the level of green building rating systems such as BREEAM and LEED.

As for building energy performance in Oman, there are important recommendations to be considered and added to the building code to improve building efficiency and optimise energy use. Among these recommendations is a mandatory use of LECA bricks instead of concrete bricks to reduce thermal conductivity, mandatory use of insulations especially on external walls and building envelope, mandatory use of double- or triple-glazed UPVC windows instead of aluminium windows as research has proven that UPVC has less thermal transmission. Another recommended practice is to install insulation on the roof slab and application of white colour exterior protection coating to reflect sunlight and reduce thermal transmission. In terms of building design recommendations, it's suggested that building direction should consider sun direction especially during the summer so that bedrooms and sitting areas where occupants spend most of the time could be designed to be on the internal part of the building and detached from the walls that are directly hit by sunlight. Building direction is an effective measure and proven to reduce energy consumption for the rooms that are not in direct sunlight.

All the practices, recommendations and measures mentioned would certainly reduce energy use, attain robust control of buildings, enhance occupancy experience and improve occupants' health, comfort and convenience. Our survey shows that in Oman and maybe in the GCC region temperature control is the main concern for occupants, which reveals lack of insulation in building stock causes high energy consumption which can be reduced by some measures such as changing concrete blocks to LECA bricks that reduce thermal conductivity and mandatory use of insulations for walls and slabs by code and other measures and practices as shown previously. Occupants showed high readiness (79%) to invest in their dwelling to improve temperature control. Occupants also showed high interest in deploying automation in their dwellings (60%) which reveals high perception of occupants to use automation, and 78% of the occupants agreed that installation of automation system in their dwelling will reduce their utility bills and increase safety, security and comfort. Towards this end, POE survey is an essential tool we've utilised in this paper to collect data about building performance, occupants' satisfaction, maintenance and means, and will furnish the roadmap for further research.

Author statement

Majid Al Mughairi: Conceptualization, Methodology, Formal analysis, Writing - Original Draft, Project administration.
Dr. Thomas Beach: Conceptualization, Validation, Supervision, Project administration.
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Declaration of competing interest

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Data availability

Data will be made available on request.

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