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# Consumer Central Energy Flexibility in Office Buildings

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**Abstract:** Energy flexibility in buildings will play an important role in the smart energy system. Office buildings have more potentials to provide energy flexibility to the grid compared to other types of buildings, due to the existing building management, control systems and large energy consumption. Consumers in office buildings (building owners/managers and occupants) take a main role for adopting and engaging in building energy flexibility. This paper provides a systematic review of consumer central energy flexibility in office buildings with the discussion of social, technical and business aspects. This paper clarifies the correlations of consumers' concerns, external influential factors, energy flexibility resources and technology with eight hypotheses. This paper suggests that technical solutions with the integration of distributed energy resources, building management and control system can boost energy flexibility in the office buildings.

**Key words:** Energy flexibility, office buildings, occupants, building managers, hypotheses.

## 1. Introduction

Buildings consume large amount of energy [1]. In Europe, buildings are responsible for about 36% of $CO_2$ emissions [2] and about one-third of energy resources are wasted in buildings [3]. Towards an efficient and low carbon economy, European Commission develops a roadmap to address energy challenges [4, 5]. Energy efficiency and flexibility by buildings are emphasized in the EU energy policies.

Energy flexibility refers to "the ability of a system to respond to changes in net load" [5, 6]. Energy flexibility solutions such as DR (demand response), energy storage and DERs (distributed energy resources) are present in buildings [7, 8].

DR is defined by the European Commission as "voluntary changes by end-consumers of their usual electricity use patterns—in response to market signals" [9]. Through DR, consumers can provide flexibility by load shifting, peak shaving or filling [7]. For example, consumers shift to an alternative type of energy source during the peak period and it can be done manually or automatically [10].

Therefore, building owners and occupants take important roles in the building energy flexibility. Their acceptance and adoption of the energy flexibility solutions in buildings influence the performance of building energy flexibility. Research shows that consumers' behavior has significant impacts on energy use (e.g. HVAC, lightings, appliances and building controls) [3, 11-14]. Consumers' energy consumption pattern, comfort and preferences vary due to consumers' behaviors [1].

However, changing consumer behaviour is a challenge in building energy flexibility [28]. Occupants spend around 80% to 90% of their time indoors [15]. One reason for the low energy performance of buildings is due to poor occupant behaviors [16]. A study of offices in Africa and Botswana shows that 56% of energy is consumed during non-working hours [16].

Therefore, to clarify this issue, this paper aims to investigate the consumer central energy flexibility solutions in buildings by: (1) Examination of building

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internal stakeholders' concerns and behaviors that affect the energy performance in office buildings. Building internal stakeholders are the main actors in buildings that consist of office managers who supervise employees' productivity and comfort [7], and occupants (e.g. employees) who occupy and use the building technologies [16]. (2) Evaluation of the external influential factors' impact on building energy flexibility. (3) Discussion of energy flexibility resources and technologies installed in the office buildings, and the impact of consumers' concerns and behaviors on the technology adoption.

Office buildings are chosen in this paper due to: their presence of flexible resources and technologies. Meanwhile, the diverse characteristics of office buildings due to different building stakeholders' concerns and behaviors can provide depth of understanding about the correlation between consumer behavior and building energy flexibility.

In the following section, this paper presents the consumer central energy flexibility in office buildings based on various literature and information. Several hypotheses are discussed with three aspects (consumers' concerns, external influential factors, and energy resources and technologies). Literature analysis in each hypothesis also clarifies the interrelation between building managers and occupants as well as their involvement in the energy flexibility in office buildings (shown in Fig. 1).

## 2. Hypotheses and Literature Review

### *2.1 Consumers' Concerns*

There are several factors that affect the consumer energy behavior in buildings including internal factors (e.g. personal background, attitudes, preferences), external factors (e.g. air temperature, wind speed) and business properties (e.g. ownership, installed devices) [17]. An observation research on occupant behaviors in 48 offices presents that the average number of occupants spend 50% of their time away from their workstation [16]. Balancing energy consumption and indoor comfort [16] is one of the challenges in achieving flexible energy [18]. The literature shows that there are several concerns influencing consumers' willingness to adopt energy flexibility programs (Hypothesis 1).

There are four sub-hypotheses regarding building managers' and occupants' concerns and behaviors to the energy flexibility in office buildings:

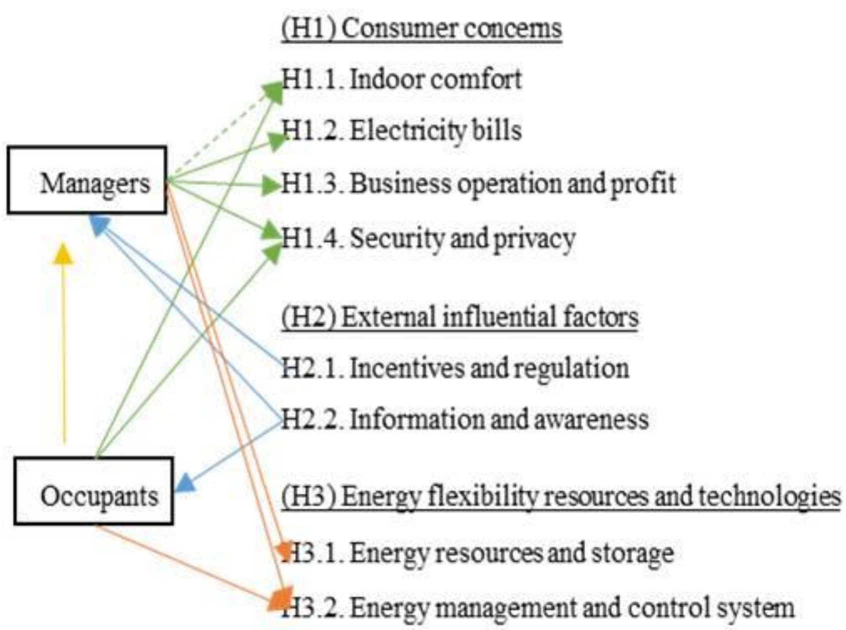


**Fig. 1 Hypotheses and sub-hypotheses.**

*Hypothesis 1.1—Indoor comfort influences occupants' willingness to provide energy flexibility in buildings.*

Pattern of energy consumption in buildings depends on indoor comfort required by occupants [18, 19] and managers' concern of energy savings [20].

Indoor comfort includes thermal, visual and air quality [17]. According to Amasyali et al. [20]:

- Thermal comfort is defined as "condition of mind that expresses satisfaction with thermal environment".
- Visual or lighting comfort is "a subjective impression related to quantity, distribution and quality of light".
- Indoor air quality is defined as "the quality or air within and around the buildings and structures".

Indoor comfort affects occupants' behavior (e.g. using window blinds in the office when too much lights coming from outside) [13, 21]. Kjærgaard et al. [15] state that occupants' comfort in accordance to national standards and regulations needs to be considered in designing DR systems.

Therefore, Hypothesis 1.1 predicts that occupants have high acceptance of energy flexibility programs, if the energy flexibility solutions do not significantly reduce the indoor comfort level. Building managers concern indoor comfort, mainly because building managers are responsible for occupants' satisfaction.

*Hypothesis 1.2—Building owners/managers responsible to pay electricity bills are more willing to participate in the energy flexibility program.*

The intelligent use of energy in buildings improves energy efficiency and lowers energy cost [3]. Many commercial buildings invest on efficient technologies to reduce electricity consumption [22].

In addition, residential building occupants (e.g. owners, tenants) keep balance of their comfort and energy consumption pattern [1, 20]. A research shows that occupants whose electricity bills are included in their rentals consume more energy than those who pay their own electricity bills [23].

On the other hand, occupants who do not pay electricity bills (e.g. employees) are more concerned on indoor comfort (e.g. lightings and office performance) [20] and not so much concerned on their waste-energy behaviors [1].

Therefore, Hypothesis 1.2 predicts that building owners/managers are responsible for energy bills or occupants paying their own bills more concern about electricity bills, and more willing to participate in the energy flexibility programs if the programs can reduce their electricity bills.

*Hypothesis 1.3—Building owners/managers are more willing to adopt energy flexibility program if their business operations and profit are not influenced significantly.*

Business operations or processes are important for office building managers/owners [24]. Building owners are willing to embrace energy efficiency but unwilling to invest on high cost energy related technologies due to return-on-investment speed [12, 25].

Due to the consideration of business operations and profit, some commercial building owners (e.g. stores) and managers are reluctant to shift their electricity patterns [26]. For example, to improve the productivity of workers, some commercial building managers consider paying high electricity bills to maintain a high comfort level of employees [18].

Therefore, Hypothesis 1.3 predicts that business operations and profit have higher priority to building owners/managers compared to the energy flexibility programs. Building owners/managers are more willing to participate in the energy flexibility program if their business operations and profit are not significantly reduced or the energy flexibility program can bring sufficient benefit.

*Hypothesis 1.4—Participation of energy flexibility programs increases building privacy and security risks.*

Security and privacy are challenges in the implementation of automated control [27, 28]. Security and privacy influence consumers' adoption of automatic control system [29].

Moreover, most of consumers are concerned about the protection of occupants' personal or private information (e.g. contact information, address) and may not be ready to give full access to third-party entity to control their appliances [27]. In addition, building occupants are reluctant to utilize building technologies with complicated functionalities [28].

There are two types of DR programs: explicit and implicit demand response. Direct load control is a traditional incentive-based program in the explicit demand response that DR Service providers can control consumers' appliances within a short notice [30]. In the implicit DR (sometimes called price-based DR program), consumers are exposed to time-varying electricity prices or time-varying network tariffs (such as a day/night tariff) (or both) [30].

Therefore, Hypothesis 1.4 predicts that building owners are more willing to participate in the implicit DR compared to the explicit DR that needs to provide direct control to third parties due to the concern of security and privacy.

### *2.2 External Factors Affecting Consumers' Adoption of the Energy Flexibility Programs*

External stakeholders can influence consumers' behaviors on energy efficiency and adoption [29]. Literature shows that there are various external factors that can influence consumers' adoption and participation to the energy flexibility in buildings (Hypothesis 2):

*Hypothesis 2.1—Incentives and regulations may influence consumers' willingness of energy flexibility adoption.*

The success of energy flexibility and efficiency depends on the level of consumers' participation [31].

Incentives can change energy habits and preferences of consumers [16, 32-34] and as a result, reduces energy consumption [30]. Therefore, in some countries, government and utilities (e.g. grid operators, suppliers and aggregators) provide incentives to consumers to participate in the energy flexibility programs [23, 27, 31]. For example, a governmental subsidy can encourage building owners to install DERs (e.g. photovoltaics) [35].

On the other hand, regulations have had a strong influence to consumers in building energy efficiency [22, 36]. For instance, the EU commission established energy policies of energy performance standards for new and existing buildings (reviewed at least every 5 years) and certificates of building energy performance [37]. These policies significantly influence the constriction industries and building designs (e.g. HVAC and lighting systems) [38].

Therefore, Hypothesis 2.1 predicts that incentives from governments and utilities and regulations can encourage building owners to adopt energy flexibility solutions (e.g. purchasing EVs) and participate in energy flexibility programs.

*Hypothesis 2.2—Received sufficient information can encourage building owners more willing to adopt the energy flexibility solutions.*

The International Energy Agency states that barriers of energy efficiency include lack of cooperation, motivation [39] and information [2, 23]. Moreover, reviews show that lack of concrete information about potential benefits of building automation can affect building investors' decision on the technology investment [2].

Occupant's presence and building managers' control decisions affect energy flexibility in office buildings [40]. Buildings can reduce their energy consumption by 10% if energy consumers (e.g. managers, occupants) are aware of their energy usage information [28]. Furthermore, campaigns and educational trainings can improve energy performance by enhancing consumers' awareness through information [16, 25, 29]. For example, governmental campaign programs encourage buildings to install solar PVs and/or small wind turbines [19, 41]. However, a research on energy performance on retail stores shows that majority of store customers are not aware of the technologies used in stores [22].

Therefore, Hypothesis 2.2 predicts that building owners/managers are more willing to participate in the energy flexibility programs if they receive sufficient related information. Comparatively, there might be significant influence on occupants.

### *2.3 Energy Flexibility Resources and Technologies*

Building management systems and technologies enable to optimize energy consumption of appliances and devices [42]. Lighting has an energy-saving potential up to 40% by adopting control strategies (daylight harvesting, occupancy sensing, scheduling and load shedding) [3]. Different appliances, devices and distributed energy resources installed in buildings can provide different energy flexibility [7]. Parys et al. [40] argue that diverse characteristics of buildings should be acknowledged when developing building systems. Therefore, the integration of renewable energy resources and building management and control system can encourage building owners to participate in the energy flexibility programs (Hypothesis 3).

*Hypothesis 3.1—Building owners who have DERs are more willing to participate in the energy flexibility programs.*

DERs that consist of supply-side resources (distributed generation, energy storage) drive energy efficiency and flexibility in buildings [16, 39, 43, 44]. Distributed generation units [43] (e.g. biomass and biogas, small solar PVs and wind turbines) and energy storage are connected to the micro grid [28, 45, 46]. Energy storage (e.g. battery, electric cars) stores the surplus energy for buildings [44, 47]. For instance, HVAC systems that use storage system (e.g. thermal, photovoltaic, heat pumps) provide flexibility [48].

Demand response provides buildings opportunities to participate in the energy flexibility market [44]. Through DR, loads (e.g. space heating/cooling, water heater, cloth dryer and EVs) are shifted in response to the price signals [49, 50]. DR is mainly participated by large electricity consumers (e.g. commercial and industrial buildings) [27].

Therefore, Hypothesis 3.1 predicts that buildings installed DERs can provide more resources of energy flexibility to the grid, and can potentially receive more benefits by participating in the energy flexibility programs.

*Hypothesis 3.2—Building owners with BMS and BACS are more willing to participate in energy flexibility programs.*

Building management systems (e.g. BEMS, BACS) is mainly installed in large office buildings due to the complexity of office building systems (e.g. devices and appliances) [3, 36, 51]. BMS (building management system) and BACS (building automation and control system) are used to control, monitor and optimize building technologies (e.g. lighting, heating, security and ventilation) [3, 11, 18, 24, 52]. BMS and BACS improve energy efficiency [53] and security [8], and lower energy consumption [53, 54]. Compared to building retrofit, BACS is cheaper for improving the building energy performance [2, 10].

Furthermore, automatic control systems use sensors [4] and actuators to monitor and collect information on indoor temperature, $CO_2$ concentration, zone airflow, daylight levels, occupancy levels and others [4]. Parise et al. [54] argue that visual comfort of office employees improved through automatic control of lighting.

Building management and control systems provide customers opportunities to participate in the electricity flexibility market and optimize building resources and technologies (e.g. DES/RES and appliances) [44]. For example, automatic control integrating smart thermostat (e.g. heating and cooling) can provide energy flexibility (e.g. peak shaving) while maintaining the thermal comfort [13, 30, 40].

Although research shows that automatic control achieves higher level of participation in demand response than manual control [10]. Some research shows that BMS fails to consider the interaction among building occupants [12]. So consumers are not willing to participate in the energy flexibility programs due to the negative influence of indoor comfort. Therefore, research on building management and control system in the energy flexibility becomes an attractive area. Nguyen et al. [3] present automation projects in the building energy flexibility area (shown in Table 1).

Therefore, Hypothesis 3.2 predicts that buildings with BMS and BACS are easier and more willing to participate in the energy flexibility programs.

## 3. Discussion

This paper discusses the energy flexibility potentials of office buildings and its influential factors. The influential factors are presented as hypotheses and literature analysis. The hypotheses and sub-hypotheses discuss the impact of occupants' concerns and behaviors along with external factors, and energy flexibility resources and technologies on the energy flexibility potential in office buildings.

This paper finds that the main barriers for providing energy flexibility by office buildings are due to

**Table 1 Collected office buildings automation system projects.**

| Project | Systems |
|---|---|
| Intelligent buildings project | MAS (Multi-Agent System) monitors and controls the lighting system in an office building and a BSA (badge system agent) that tracks occupant's location, users' preferences and their associations to persons (badges) |
| Greener buildings project | Recognition system that uses wireless sensors to perform indoor activity recognition for energy savings in office buildings |
| EcoSense project | Control system that uses wireless sensor and actuator networks to collect occupancy information for controlling the heating system |
| The University College Dublin, Ireland Project | Lightwise (lighting evaluation through wireless sensors) that evaluates lighting control systems in existing office buildings (detecting ambient light and luminaries state and PIR sensor to detect people presence) |

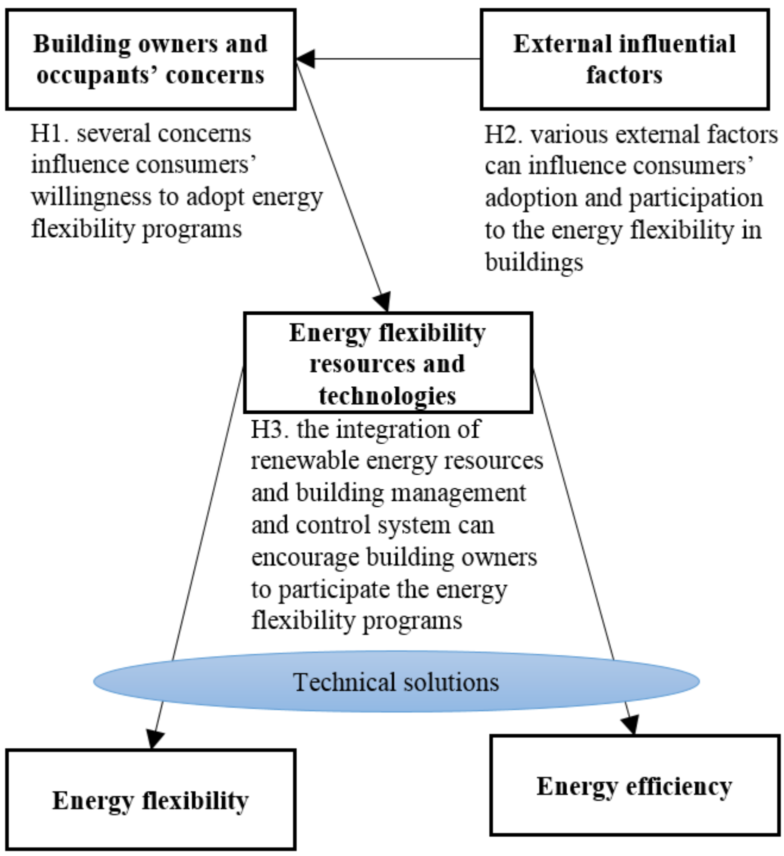


**Fig. 2 Conumer central energy flexibility in office buildings.**

consumers' concerns. Meanwhile, there is conflict of interest between building owners/managers and occupants due to different preferences and consideration. For instance, although building owners/manager and occupants both concern security and privacy, but building owners/managers concern more business operations and profit, while occupants give importance to indoor comfort, ease-of-use of technology, security and privacy (shown in Fig. 1).

Incentives, regulations and information are external factors that influence consumers' technology adoption and program participation. The amount of received energy-related information (e.g. governmental subsidy for energy technology) positively impacts consumers' technology adoption.

This paper also finds that buildings that have installed building management and control system or distributed energy resources are more willing to provide energy flexibility to gird compared to other types of building, because they do not need to invest new or more energy flexibility resources.

The framework (shown in Fig. 2) presents the relationships between consumers, external influential factors, and energy flexibility resources and technologies in the office building energy flexibility. For example, building owners/managers consider occupants comfort when adopting building technologies. This paper also argues that building automation is a cost-effective solution, and can potentially provide flexibility without compromising indoor comfort in the office buildings.

This paper mainly discusses the consumers (office building owners/managers and occupants) in the energy flexibility. Due to specific focus in this paper, this paper suggests the followings discussed in the future research:

- In-depth discussion regarding external factors' impact (e.g. incentives, regulation implemented by government and utilities) on energy flexibility in office buildings.
- Other challenges caused by building automation to the business processes during the participation of energy flexibility programs.
- Other factors (e.g. building structure, ownership) affecting indoor comfort of office building.
- Consumers' concerns and motivation to adopt a specific distributed energy resources or technology (e.g. EVs, building automation system) in the office buildings.

## 4. Conclusions

Each office building has a unique characteristic. Thus, this paper presents that various aspects—social, technical and business needs to be considered in building energy flexibility.

General issues presented in this paper include grid demand, energy waste in office buildings and high electricity consumption. This paper also finds differences regarding the roles, interests and behaviors between building owners/managers and occupants in relation to energy flexibility. Specifically, business profit concerns by building owners/managers and occupants' comfort needs affect the participation of energy flexibility programs in office buildings. Information sharing and incentives from utilities and regulators can change consumer behaviors.

In addition, integrated building management and automation system can satisfy the need and interest of both parties (managers, occupants) while improving energy efficiency and providing opportunities for energy flexibility in office buildings. Lastly, industries and scholars who are engaged in energy flexibility in office buildings can test and validate the hypotheses presented in this paper and develop consumer central solutions for energy flexibility in office buildings based on the results.

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