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Intelligent Energy Management Analysis for Thermal Comfort in Commercial Complexes

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ABSTRACT

Commercial complexes, as energetic and large energy consumers, are of great importance. With the increasing trend of energy and environmental concerns, smart energy management has been proposed as a key solution to improve energy efficiency and reduce energy-related costs in commercial complexes. In this regard, the use of innovative technologies and intelligent methods for optimal energy management, energy consumption reduction, and improvement of thermal comfort in these complexes is of particular importance. This research examines the importance and effects of smart energy management on thermal comfort in commercial complexes. In this analysis, smart energy management methods including the use of smart systems, utilization of renewable energy sources, and energy consumption management are investigated. Moreover, the impacts of these methods on energy consumption reduction, reduction of energy costs, and enhancement of comfort and thermal convenience in commercial complexes are examined. The results of this analysis indicate that implementing smart energy management in commercial complexes can lead to improved energy performance, reduced energy costs, and increased comfort and thermal convenience.

1. Introduction

Today, environmental pollution and global warming resulting from the consumption of fossil fuels, the increase in energy carrier prices, and the reduction of energy resources for humans have become problematic. Calculating the CO2 emissions from buildings, which constitute 50% of the total carbon dioxide emissions, has changed the approach to construction towards energy consumption reduction. [1] Significant energy savings can apparently be achieved through architectural design and implementation of a series of measures. [2] The demand for energy is increasing every day. This requires progress in all fields for every nation. Moreover, modern power systems are facing challenges such as environmental problems, the need for reliability, increasing social and industrial demand, and so on. All these needs cannot be addressed solely by universal distribution networks. Microgrid is an important technology that can meet these needs.

In a commercial building, the production and quality of people's lives depend on the level of comfort in it. Visual comfort and warmth are the main factors of comfort [3]. These are provided by lighting and air conditioning systems. The higher the level of comfort, the higher the energy consumption. Nowadays, energy shortage makes it necessary to balance energy consumption and customer comfort. Limited energy resources, problems caused by the indiscriminate use of fossil fuels, and international commitments to reduce carbon dioxide emissions oblige countries to reduce and save energy. About 200 million barrels of crude oil are used annually for heating in commercial, residential, and office buildings, and if energy consumption is optimized, 10% of energy can be saved [4]. Approximately 20 million barrels of crude oil are saved annually. The resilience of buildings against energy consumption plays a significant role in energy efficiency, considering that administrative service complexes are spaces continuously utilized by users throughout the year, with high working hours during day and night as well as in different seasons, always requiring attention in terms of cooling and heating, and creating favorable conditions in the indoor environment of the building is very important. Therefore, a unique and practical optimization plan, both in terms of comfort and environmental impact, is considerable. The energy value consumed improperly in the country is over 18 billion dollars annually, and by properly managing energy, while ensuring essential needs, substantial energy savings can be achieved in buildings that are highly energy-consuming and inefficient. This also minimizes overall energy consumption. Stored energy can be used for essential needs later [5-7].

A smart energy control system in commercial buildings can fulfill several objectives, such as reducing total energy consumption, optimal and efficient energy use, ensuring essential needs, and minimizing energy waste. The continuation of this research is as follows: first, it demonstrates the overall system layout. Then, it explains the microgrid, which includes renewable energy sources such as photovoltaic arrays (solar power generation) and wind power generation, and a battery energy storage system for storing the remaining energy. It then presents an idea about smart energy management implemented in a commercial building. Finally, there is a conclusion.

2. Thermal Comfort

Thermal comfort can be defined as the mental state that expresses satisfaction with the environmental temperature; thermal comfort cannot be defined under absolute conditions and is always different for each individual. The instrument for measuring the level of thermal comfort in buildings is the Fanger tool in which the Predicted Mean Vote (PMV) is calculated by researchers based on six parameters: air temperature, mean radiant temperature, air velocity, relative humidity, and metabolic rate, and it should be maintained within the range of -0.5 to 0.5 according to ASHRAE standard, so that the level of dissatisfaction with thermal conditions (PPD) by residents is not more than 10 [8]. The relationship between thermal insulation and thermal comfort in interior daylighting is also affected by temperature differences, as the greater the temperature difference, the less the thermal comfort becomes. Conversely, as the temperature difference between the first and last floors increases, it creates multiple layers of thermal insulation, each of which transfers accumulated heat to adjacent spaces and removes those spaces from the thermal comfort range. Therefore, reducing thermal insulation can lead to thermal comfort.

3. Clean Energy Generation System

A microgrid usually consists of a local collection of distributed generation, energy storage systems, and loads (thermal and electric) that can be connected to the grid and operated in island mode. Microgrids will have many benefits for both consumers and power generating companies. From the consumer's point of view, microgrids have the capability to simultaneously provide electricity and heat, increase reliability, reduce greenhouse gas emissions, and improve quality. From the power companies' point of view, employing microgrids has the potential to reduce peak demand and therefore reduce the need for developing transmission lines. Additionally, it will help eliminate peak consumption points, thus reducing grid losses [9]. The commercial building in question is supplied with a microgrid that utilizes renewable energy sources. This makes the building self-sufficient. In this case, renewable energy sources used include PV arrays and wind turbines that are environmentally friendly and do not pollute the environment. Energy produced during off-peak hours is stored by a battery energy storage system. The stored energy can be used later. The microgrid is placed near controllable loads, increasing reliability and reducing transmission losses. The microgrid can be disconnected from the energy generation source when necessary, or connected to it [10]. As a result, energy exchange between the grid and the microgrid becomes possible. Additionally, if there is an issue with the energy source, the microgrid can supply its own loads as an independent network. The control system for smart buildings uses a multi-purpose smart technology. This includes multi-layer factors for control. Desired factors include visual and thermal comfort. Therefore, the fundamental loads are the HVAC and lighting systems, which respectively provide visual and thermal comfort throughout the building. By using multi-layer agents in the control system to provide customer comfort, energy consumption is minimized.

3-1- The generation of wind

Wind energy is obtained through wind turbines, which is an important renewable energy. The energy obtained from wind turbines is in accordance with equation (1):

$$Pm=Cp(½\rho Au3)=CpPw$$

Where Cp is the wind turbine performance constant, A is the cross-sectional area of the enclosed air in square meters, ρ is the air density in kg/m^3, and u is the wind speed in m/s.

3-2- Solar Energy

Photovoltaic (PV) energy can be considered as an effective and readily available source [11, 12], abundantly found, without impacting the environment or causing electricity pollution, it can produce direct current. PV system is stationary and silent, it has no moving parts and consequently has lower operational and maintenance costs. To supply ac loads, a solar module includes PV arrays for production, a control unit to track the production voltage stage, a DC/AC converter, an isolation transformer to ensure that DC does not enter the network, an output filter to limit the entry of current harmonics into the network, and more. The Phase Locked Loop (PLL) method is used for synchronization with the grid. The specifications equation of PV arrays is also used for modeling.

4. Smart Control System

Modern control technologies provide more power, efficiency, and flexibility to the system, expressing the concept of a smart network. The concept of a smart network is a new technology that enables customer participation. This ensures the quality and reliability of energy. The increasing demand for energy production requires decentralized control due to changing market activities and more complex distribution systems. Therefore, controlling the network through a central system is a problem. Smart control system technology provides secure and reliable system operations. The smart building energy management system also performs the same function. The energy management system in a commercial building aims to improve the building environment and minimize energy consumption [13].

The smart control system described in this article is a multi-layered control system consisting of 4 interfaces. An interface can be software or a physical entity. Here, a smart control system based on agents is designed for energy management in a smart commercial building. The interfaces include a switch interface, a central control interface, local control interfaces, and loads interfaces.

5. Production and consumption in smart energy networks

The discussion on energy as one of the very important issues in today's world has transcended economic, welfare, and scientific aspects and has not been limited to the boundaries of the world of politics and war between countries. The survival or destruction of societies depends on their access to energy resources, and their security and stability. Given that the architecture and foundation of power grids have not undergone a revolutionary and significant change since their inception at the beginning of the twentieth century until the last few decades [14]. The lack of measurement, monitoring, data exchange, and intelligent control equipment is keenly felt in various parts of these networks. To overcome these network problems, SG networks have been introduced. SG networks have a two-way communication infrastructure between the supplier and the consumer. This infrastructure enables the consumer to take action in the best possible time in terms of cost or maximum network consumption change in their consumption patterns by developing distributed generation, MSG networks were introduced, and in this type of network, various types of distributed generation systems are used in combination with each other. Consumers are also in effective and two-way communication with MSG networks. With the emergence of MSG networks and the possibility of close interaction between the consumer and the consumer network, they play an important role in the network and smart buildings were created. A smart building is able to optimize energy resources and systems based on defined internal programs and the external state of the building to achieve maximum energy optimization.

Table 1: Variables of smart energy production in commercial buildings

Number	Name of Variable
1	Outdoor air quality
2	Interior and exterior light intensity of the building
3	Amount of power allocated for lighting systems
4	Amount of power allocated for ventilation systems
5	Maximum demand time signal
6	Power consumption of non-displaceable loads in time
7	Power consumption of transferable loads in time
8	Power required to achieve desired conditions for building users

5-1- Lighting Control

Inadequate lighting can have adverse effects on health. Therefore, proper lighting should be provided inside the building to ensure visual comfort [15]. As a result, artificial lighting is necessary to ensure visual comfort in smart commercial buildings. To ensure proper visual comfort, a fuzzy control system is used for appropriate lighting.

Numerous solar concentrators and highly efficient light couplers are essential for sufficient sunlight collection for indoor illumination. To save power consumption on electrical lighting, daylight can be provided for the interior of a building via sunlight focused by a solar concentrator and guided by a bundle of optical fibers. Active daylighting system with a solar concentrator requires a precise sun-tracking system to achieve high optical efficiency for daylight collection and distribution.

5-2- Active Daylighting System with Single-Axis Tracking System.

Active daylighting systems attached to single-axis trackers only have a single degree of rotational freedom to track the sun. It usually tracks the change of sun position due to the hour angle, but it is not designed to follow the seasonal change of the earth's equatorial plane with respect to the sun position [16]. This active daylighting system is an intermediate solution, which is simpler than the dual-axis tracking system but more complicated than passive daylighting system.

5-2-1- Linear Fresnel.

Ullah and Shin proposed a new method for the linear Fresnel lens as shown in Figure 1 [17] . At the capturing stage, daylight was uniformly distributed to increase the efficiency of the system, and direct sunlight was focused via the linear Fresnel lens. The focused sunlight then went into and out of a collimating lens of which the collimated sunlight was guided by the optical fibers. Achieving a high concentration of light with the linear Fresnel lens was essential; hence, a popular nonimaging optical component called the trough compound parabolic concentrator (CPC) was introduced just before the optical fibers [17]. Also, silica optical fibers (SOFs) placed before plastic optical fibers (POFs) were used to distribute sunlight to each floor with small losses and less heat. Most existing linear Fresnel daylighting systems have some difficulties such as low accuracy in design, installation, and routing of hardware [18]. Tripanagnostopoulos et al. also discussed the application of a linear Fresnel lens to control the illumination of a building interior space due to its ability to segregate the beam and the diffuse solar radiation [19].

5-2-2- Parabolic Trough.

Ullah and Shin proposed an approach of an active daylighting system by using a parabolic trough where sunlight was captured by the parabolic trough, focused towards a parabolic reflector, and directed into a multistory building through the optical fibers (POFs) [17]. Similar to the linear Fresnel system, to attain a very high concentration of light with the parabolic trough, a trough CPC was introduced before the optical fibers as shown in Figure 2 [17]. The advantage of their proposed system is just like that of the linear Fresnel system: it is expandable and simply requires a tracking module having one axis. POFs are ideal in daylighting systems as they are low-cost, bendable, durable, and suitable for complicated wiring in buildings. The disadvantage of their proposed system is that the uniformity of light inside the building is not yet achievable and SOFs are quite costly.

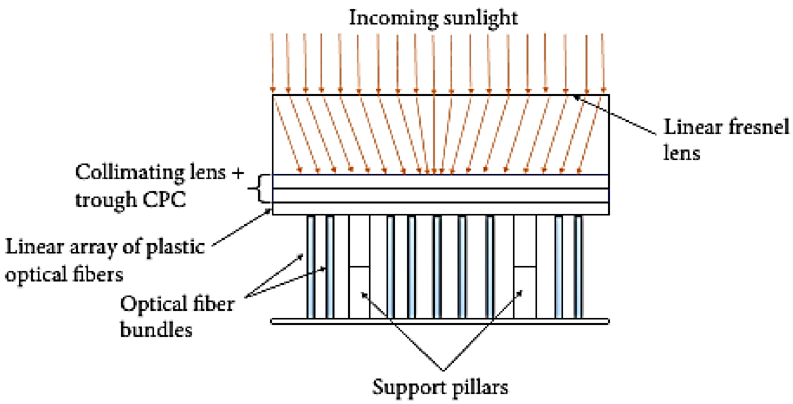

Figure 1: Front view of the physical layout of linear Fresnel lens daylighting system by introducing the trough compound parabolic concentrator (CPC) before the optical fibers (source: adapted from [17]).

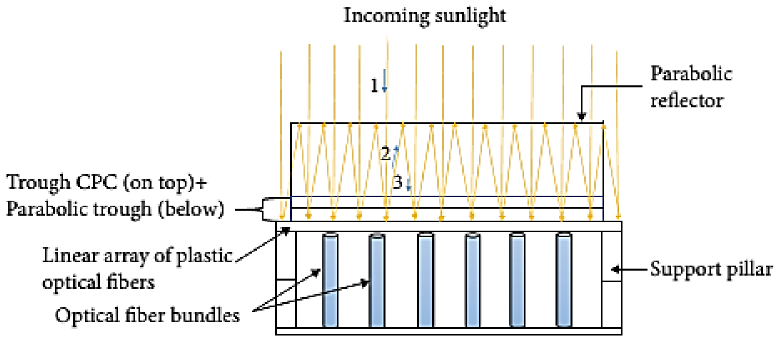

Figure 2: Front view of the physical layout of parabolic trough daylighting system by introducing the trough compound parabolic concentrator (CPC) before the optical fibers (source: adapted from [17]).

6. Energy management using smart control system

The aim of designing a control system for energy management in smart buildings is to minimize energy consumption and ensure customer comfort. Therefore, a smart control system is used here as detailed below. Energy demand in all areas is increasing every day. However, conventional methods of production cannot meet all the needs. This is why renewable energy sources can be introduced in this field. Insufficient energy to meet the increasing demand for energy may affect the performance of essential loads, such as those present in commercial buildings, as these loads always require a continuous power supply [19, 20].

Due to the scarcity of energy resources to meet the increasing demand for energy, proper energy management is necessary. This involves designing a smart control system focused on the proper use of energy in a smart commercial building. The primary goal of energy management is not only to minimize energy consumption, but also to ensure customer comfort. The implemented smart energy management system utilizes fuzzy controllers for essential loads. For continuous power supply, distributed generation using renewable sources is essential to provide local energy as needed, making the building more self-reliant. Photovoltaic arrays are used here as a renewable energy source [21].

Essential loads in commercial buildings include lighting and air conditioning systems that provide visual and thermal comfort inside the building, ultimately ensuring improved quality of life and productivity in the building environment. Non-essential loads in the building, such as pool pumps, fountain pumps, and decorative lights, reduce overall energy consumption inside the building. The stored energy can be used for essential loads when needed, ensuring visual and thermal comfort. This forms the basis of the control system design. The energy management system designed here manages non-essential loads to minimize energy consumption in the building [22]. It prioritizes essential loads by providing continuous power sources and manages non-essential loads by toggling them on and off using load agents, ultimately reducing overall energy consumption in the building.

7. Energy Optimization by Essential Loads (Lighting and Air Conditioning Systems)

Renewable energy sources have been used to supply energy for loads in the building, making the building more self-reliant. Fuzzy controllers have been used for the optimal use of energy by essential loads (lighting and air conditioning systems). They accurately select temperature and light levels according to the set parameters, which can be adjusted by the customer. Fuzzy logic controllers select temperature and light levels based on the customer-set values [23]. If the energy requirement of essential loads cannot be met solely by microgrids, non-essential loads such as pool pumps, fountain pumps, and decorative lights are properly managed so that the stored energy can be used by essential loads. Proper control of non-essential loads is achieved by generating suitable control signals for circuit breakers that connect the loads. At each stage, non-essential loads are intelligently controlled to minimize energy consumption. If the energy requirement cannot be met even after load management, the public grid is used to supply energy and ensure comfort.

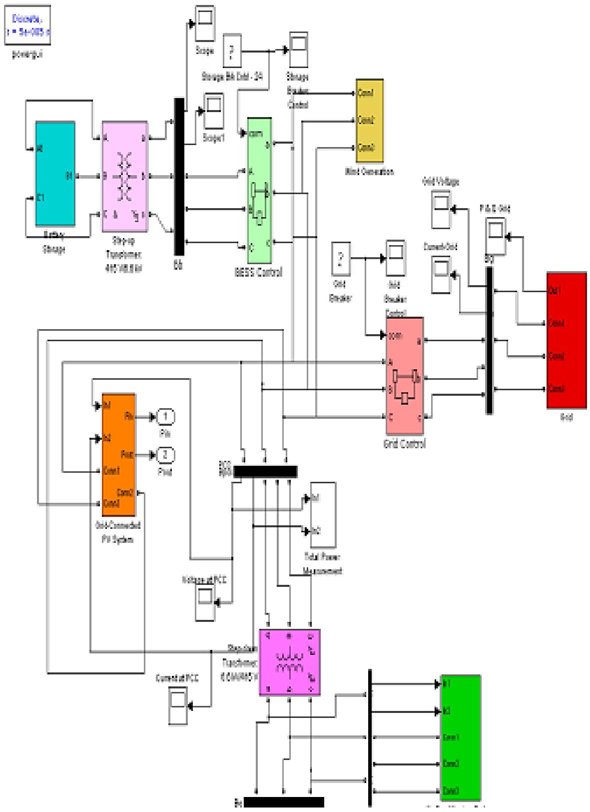

Figure 3: Energy Management System of a Commercial Building

As shown in Figure 2, the use of fuzzy controllers minimizes the energy consumption of lighting and air conditioning by selecting the appropriate levels of brightness and temperature according to customer preferences. Proper energy management is carried out by the control system. Genetic algorithms optimize the values of temperature and brightness, which minimizes overall energy consumption, as revealed.

8. Conclusion

In the smart energy management system presented in this article, environmental friendliness is ensured through microgrid technologies. The smart control system performs its task as evident from the results. Energy consumption in the building is minimized through proper control of storage, non-essential loads, and the grid. Customer comfort, as indicated by a comfort factor greater than 0.9, is achieved. Therefore, smart energy management in commercial complexes can lead to reduced energy consumption, lower energy-related costs, and improved thermal comfort. The use of innovative technologies and intelligent methods for optimal energy management can improve energy efficiency and reduce negative environmental impacts. Therefore, attention to smart energy management in commercial complexes not only reduces energy costs but also enhances living and working conditions in these environments.

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