INTERNATIONAL JOURNAL OF OPTIMIZATION IN CIVIL ENGINEERING
Int. J. Optim. Civil Eng., 2021; 11(4): 563-579

IMPLEMENTATION OF SMART TEMPERATURE MONITORING AND CONTROLLING SYSTEM IN URBAN PUBLIC SPACES

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ABSTRACT

Optimization of public space energy consumption can basically improve the savings and the ratio of energy consumption and resources entirely. In this regard any methodology and system to shorten the redundant use of energy in different spots of the public space and to distribute energy based on significance of each zone will contribute in the task. This study has sought to develop a prototype of a multi-function smart system to monitor and control the use of energy in a space in terms of temperature, brightness and ventilation based on the significance of each zone according to the traffic calculated during time periods. Although in the current prototype there has not yet been photovoltaics embedded in the device, it has been accounted for in software section.

The monitoring system performs to monitor and store temperature, light intensity, CO_2 concentration, and traffic at each zone while control system acts based on the zone significance and mechanism used in each energy consuming device including heaters, coolers, lights, etc. Findings on pilot scale shows that optimization of energy usage by such a system can drastically reduce space energy consumption while the optimal configuration of the multi-function system depends on the space conditions. Space conditions include climatic, area, etc. Although zero-energy building require further researches to be realized and utilized, this system can be perceived as first steps toward this goal.

Keywords: energy; comfort indices; temperature; smartness; building automation.

Received: 4 July 2021; Accepted: 22 October 2021

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1. INTRODUCTION

Energy sources are not infinite. Forecasts show that crude oil can only be exploited by 2070. Also, the use of fossil energy sources usually results in harmful environmental impacts, which in turn lead to greenhouse effects and climate change. In addition, security issues necessitates energy storage, smart energy management, and the use of internal resources (Lund, 2018). On the other hand, the advent of modern technologies has led cities to move towards smartness.

By definition, smart city means integrating the physical, digital, and human systems into an artificial environment designed to provide citizens with a sustainable, prosperous and inclusive future. (Kaika & Swyngedouw, 2002; Papa & Fistola, 2016)

In a very simple way, the smart city is intended to deal with or mitigate, through the highest efficiency and resource optimization, the problems generated by rapid urbanization and population growth, such as energy supply, waste management, and mobility. Many classifications of smart-city intervention are as can be found in the literature, as in the study performed by Chourabi et al. (Caragliu & Del Bo, 2012; Certomà, 2015; Chourabi et al., 2012; Shwayri, 2013).

Cities' energy requirements are complex and abundant. In consequence, modern cities should improve present systems and implement new solutions in a coordinated way and through an optimal approach, by profiting from the synergies among all these energy solutions.

1.1 Energy oriented smart-cities

Taking action to reduce the waste of energy is essential for the purpose of increasing the smartness of cities. Moreover, in smart cities, energy community paradigm can produce also structural benefits in terms of reducing peak demand during the day and performing load shifting in the electric system.

What is more, the subject of energy efficiency, for some time has been at the center of the strategies and policies being developed by European cities, also in order to respond to the pressing demands from the European Union in recent years. (Batty et al., 2012; Corsini et al., 2016; Dinçer, 2018; Vanolo, 2014)

In fact the subject of energy, broken down into its various parts, (reducing emissions, using alternative sources, efficiency of distribution networks, and so on) has for some years now been at the centre of the agenda of the EU, which has fixed the strategies related to energy efficiency with a deadline of 2020. (Battarra, 2015; Giffinger et al., 2007)

The precondition for implementing a smart city is smart energy management and optimal consumption. Given that smart cities often rely on technology, it is expected that a smart city will have a direct relationship with the smart management of primary energy sources. In the case of a smart structure, energy management requires a systematic and continuous effort to promote energy within the organization efficiently (Trianni et al., 2019). Therefore, realizing smart urban space is not only about upgrading its technology and knowledge, but also about providing the infrastructure for optimal energy consumption and management. The smart city, and in particular smart energy, provides a platform for monitoring and control, and energy management in general, to be made more accessible to officials, and even consumers (Kitchin et al., 2015). When residents' comfort criteria and their actual requirements are clearly identified based on smart and modern mechanisms, energy production and supply management can certainly be done by carefully measuring these needs. Not only does this drastically reduce energy consumption, but also provides a mechanism for achieving smart city and building automation.

Energy resource management should be performed as a function of production and demand (Trianni et al., 2019). So energy management will be difficult and even impossible until the energy consumption pattern is substantially improved. Therefore, in order to achieve the ideal energy management in a multifaceted system such as smart city, we need to identify and examine most of the energy elements as well as implicit dependence between them. Full modeling is also required to validate current and advanced systems (Petritoli et al., 2019). Although many models are currently used for different urban purposes, they are only used for specific purposes and for the management of individual systems. This represents a major restriction on the management of smart city systems because these models ignore the linkages between them and do not take into account their combined performance.

Building automation and real-time control systems have been proven effective in significantly increasing energy savings in the built environment (Marinakis et al., 2013). Integration of distributed renewable energy resources, combined with energy storage systems, can support buildings to consume energy more efficiently and reduce their dependency on the electrical grid. However, energy storage devices must be controlled properly, storing energy when it is most e-cient to generate it and releasing it when the energy supply systems are less efficient. Adequate control strategies for heating ventilation and air conditioning (HVAC) can increase energy savings in buildings and reduce CO 2 emissions as well as the cost of the energy that the buildings consume. Some advanced control systems such as Model-Predictive Control (MPC) (Richalet et al., 1978) are often too costly to be implemented in small residential buildings because they require identifying the dynamic model of the system they control (Prívara et al., 2013). Furthermore, any building retro fit and/or system upgrade would require model-based controllers to be redesigned, or at least recalibrated.

Given the increasing presence of sensors in HVAC systems (Park & Nagy, 2018), and new advances in cloud computing for HVAC control, there is an increasing amount of historical sensor data that can be used to optimize HVAC operations (Yu et al., 2016). Liu and Henze reduced the energy costs of a passive thermal storage inventory (Liu & Henze, 2007).

It is noteworthy that this is a nascent research field with most contributions having been published after 2013. Yang et al. proved RL to be an effective algorithm for optimal energy control in low energy buildings (Yang et al., 2015).

Urieli and Stone, and Ruelens et al. applied different algorithms to control a heat pump with a setback strategy and an auxiliary heater for optimal energy conservation and comfort maximization (Ruelens et al., 2015).

More recently, Mocanu et al. proposed a deep reinforcement learning controller to minimize the cost of consuming electricity by some electrical loads that could be found in a building (Mocanu et al., 2019).

Despite these advances, most of these contributions use very simplified building energy models, or are difficult to reproduce. As a consequence, there is a need to bridge high performance building energy simulation models.

Energy consumption optimization and overcoming challenges in a building requires precise consideration of automation and smartization. Comfort indices in a smart building, including temperature, relative humidity, gas concentration, and even light intensity parameters are monitored and controlled automatically in an optimized manner. The common tasks performed in smart buildings to save energy are usually as follows:

- Optimized power switching
- Adjusting air and water temperature on desired values
- Narrowing energy request

The proposed method in this study modifies the consumption pattern by managing and applying the principle of intelligent space. In other words, the smart elements in this design, along with the continuous and efficient management of urban space are used within the context of a smart city to provide intelligent monitoring and controlling energy consumption. This is a positive step towards the implementation of Sustainable Development Goals, since it enhances the quality of the environment and by reducing fossil fuel consumption, optimizing energy consumption pattern, and smartizing current buildings.

2. METHODS

The present study aims to investigate and present a feasibility model for implementing smart city mechanisms and providing a compact energy management software. The proposed system (Fig. 1) utilizes a real-time system (control and monitoring system) to increase efficiency and intelligence of energy management process. To achieve this purpose, a central electronic board should be used to make communication between multipurpose sensors to check electric current consumption, indoor and outdoor temperature, CO_2 gas density, traffic, and controllers to control heat generation, and ventilation. The research scheme could be presented in three sections as follows:

- Hardware and software implementation: Implementing monitoring and controlling elements
- Identification: Data logging on energy parameters (consumption and production), desired comfort factors (light, temperature, etc.) using software before and after the implementation of the automatic control section
- Analysis: Analyzing statistical data based on standard comfort indices at certain time points and evaluation of the effect of intelligent and automated system

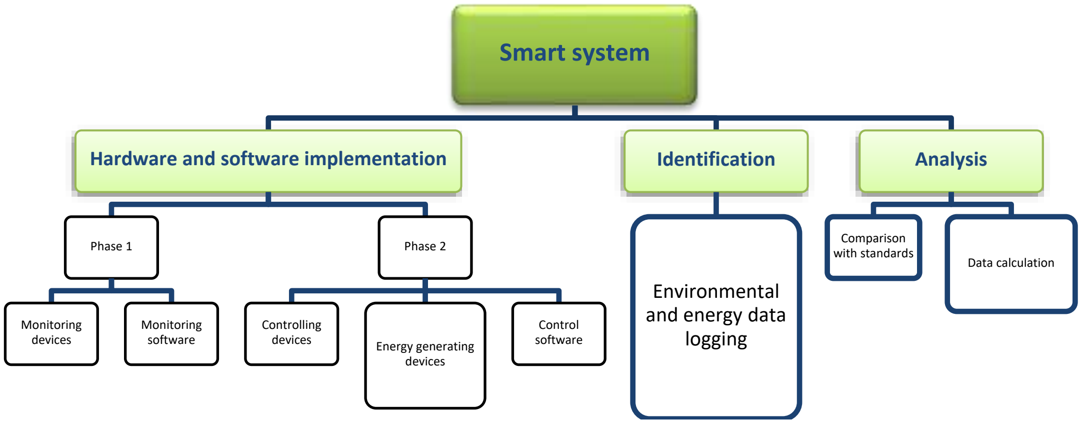

Figure 1. Research scheme

2.1 Software and hardware implementation steps

The implementation of the technical sector will initially take its experimental steps on a small manageable scale for a certain period of time. The technical part of the work will be performed in two phases. The first phase, as outlined in the design steps, is devoted to data collection and energy data collection such as consuming power. The second phase involves the control system implementation, temperature adjusting by heating/cooling system, and ventilation. Following details are outlined according to each phase:

A.Phase 1

1- Evaluating different equipment and mechanisms for environmental data logging

2- Hardware implementation for long-term environmental data logging

B. Phase 2

1- Evaluating different controlling equipment and mechanisms

2- Hardware implementation for ling-term environmental data controlling

3- Comparison of environmental and consuming data based on time and location

4- Optimization of the system according to final analysis of data

The purpose of technical phase is to optimize energy consumption by adjusting comfort indices (temperature, CO_2, light intensity, …) based on the critical need for each location and time. The logical relationship and schematic view of the proposed system are depicted in Fig. 2 and Fig. 3.

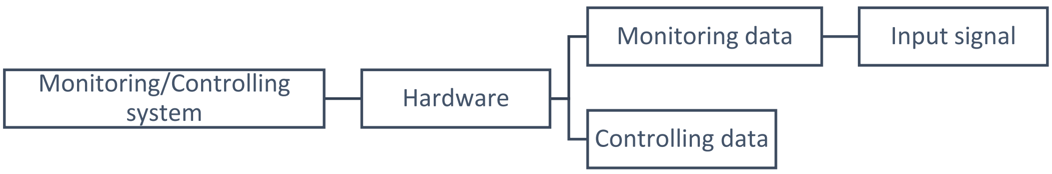

Figure 2. The logical relationship between elements in the proposed system

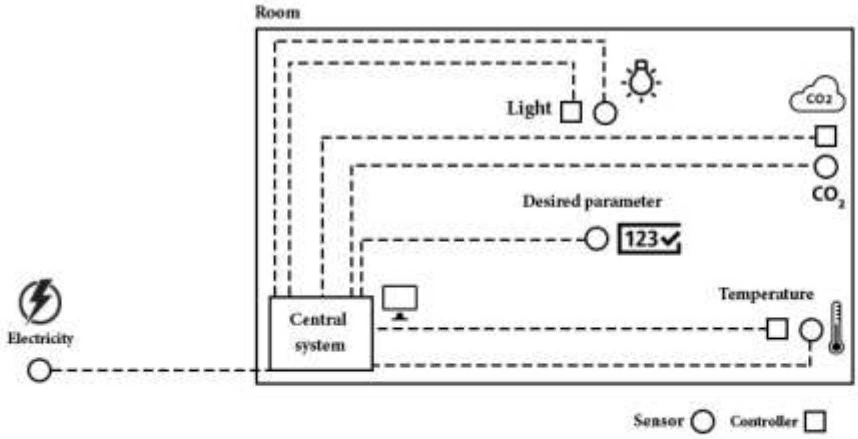

Figure 3. Schematic view of the proposed system in a residential room

Monitoring and controlling systems are explained here separately:

2.2 Monitoring system

Monitoring is performed based on input parameters in 3 sections. These parameters are explained more in Table 1.

Table 1: Groups of parameters to be monitored in the proposed system

Monitor data	Parameters	Description
Desired parameters	Standard/User defined values	These parameters are usually defined based on standard values or user preferences for comfort indices, energy consumption, CO_2 concentration, etc.
Consumption	Electricity	Energy consumption data which is mainly related to electricity power here as a considerable part of devices use electricity as energy source.
Environmental factors	CO_2 concentration, Traffic rate, Temperature, Light intensity	Environmental data including temperature, light intensity, CO_2 concentration, and traffic rate are logged. Traffic rate is accounted for as an index of location importance.

2.3 Controlling system

Controlling process is performed based on collected data using motoring system. It is intended to perform the process for each environmental factor according to the importance of each location detected by traffic rate data. In fact controlling process reduces the wasting of the energy by concentrating energy consumption for high importance locations.

Controlling procedure is performed in a closed loop to be checked intermittently and adjusted based on feedback data, for heating/cooling, ventilation, and lighting devices. Details are provided in Table 2.

Table 2: Groups of parameters to be controlled in the proposed system

Control data	Mechanism	Description
Temperature	Switch	Controlling plan is performed based on heating/cooling devices used. It is done by setting the temperature or switching on/off intermittently.
	Setting heating/cooling device temperature	
CO_2 concentration	Switch	Controlling plan is performed by switching on/off or setting the speed of the ventilation fan.
	Ventilation rate	
Light	Switch	Controlling plan is performed by switching on/off the required number of lights or setting the intensity of the current lights.
	Potentiometer	

2.4 Control approach

The control algorithm compares the current values versus desired values in a real-time manner to apply the required changes in each devices. The general relationship between each stage in control scheme is depicted in Fig. 4.

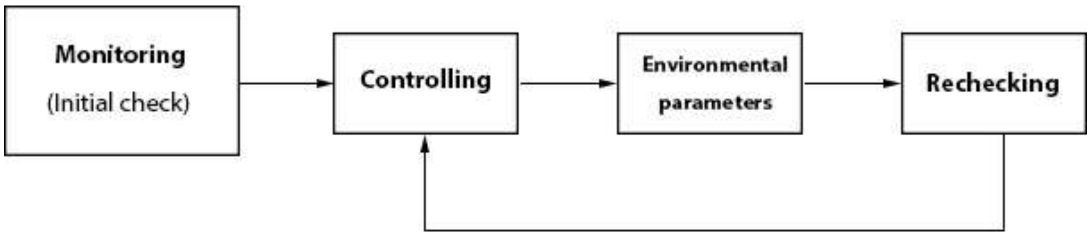

Figure 4. Control algorithm used in the proposed system

The details about control algorithm is explained for comfort parameters in the following sections. t_R is the interval for checking the parameters intermittently in each section.

2.4.1 CO_2 control algorithm

The simple diagram in Fig. 5 demonstrates the algorithm used for setting CO_2 on the required value.

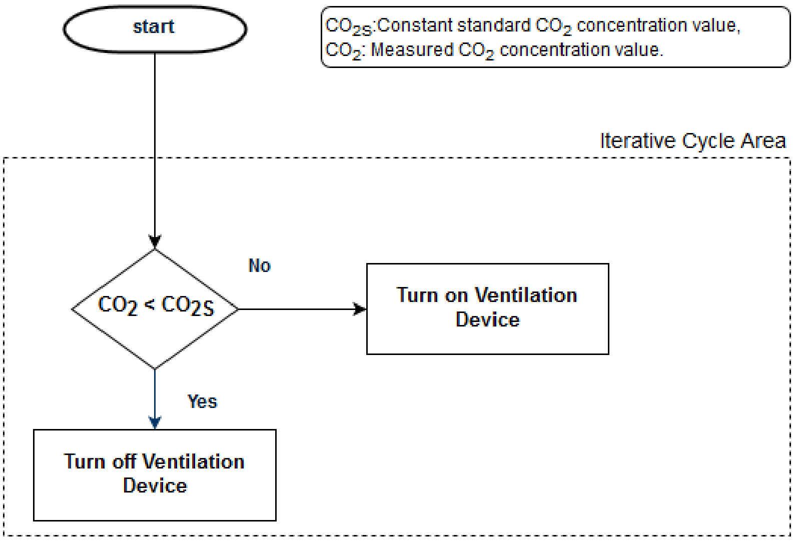

Figure 5. The simple algorithm used for controlling CO_2 concentration

2.4.2. Energy consumption control algorithm based on traffic

This algorithm (Fig. 6) is used to check traffic and set heating and lighting systems based on its rate. In the first cycle, checking time (t_C) is set on 0.

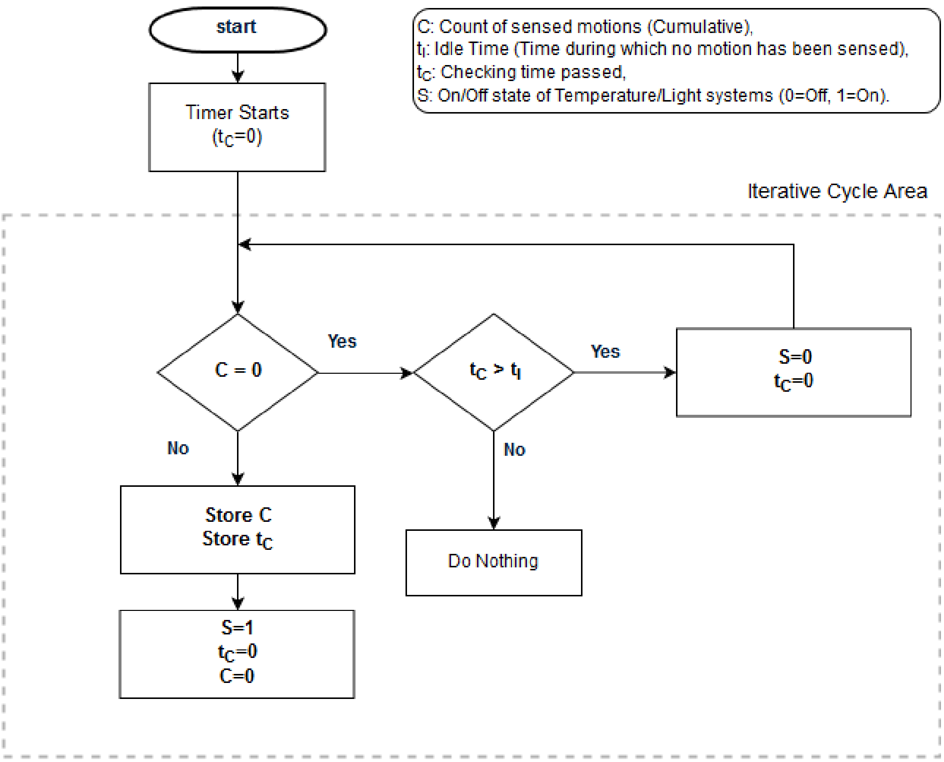

Figure 6. Temperature and lighting system control algorithm based on traffic (t_R)

2.4.3 Temperature control algorithm

Temperature control algorithm is used to set the temperature between T_{min} and T_{max} according to Fig. 7.

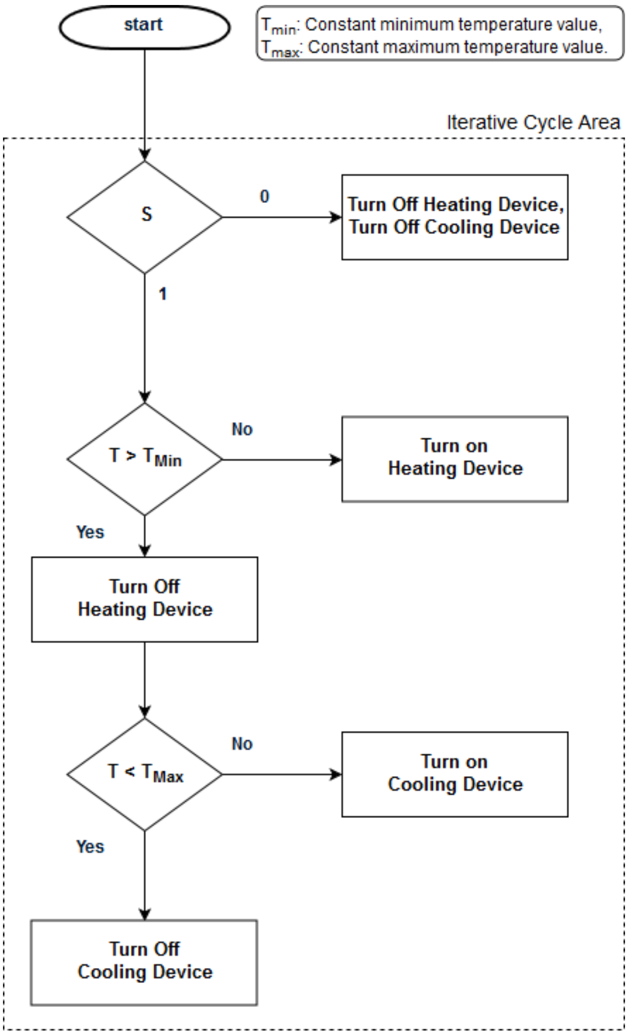

Figure 7. Algorithm used for temperature control

2.4.4 Lighting control algorithm

Lighting control algorithm is demonstrated in Fig. 8. Lighting control algorithm is used to set the light intensity between I_{min} and I_{max}.

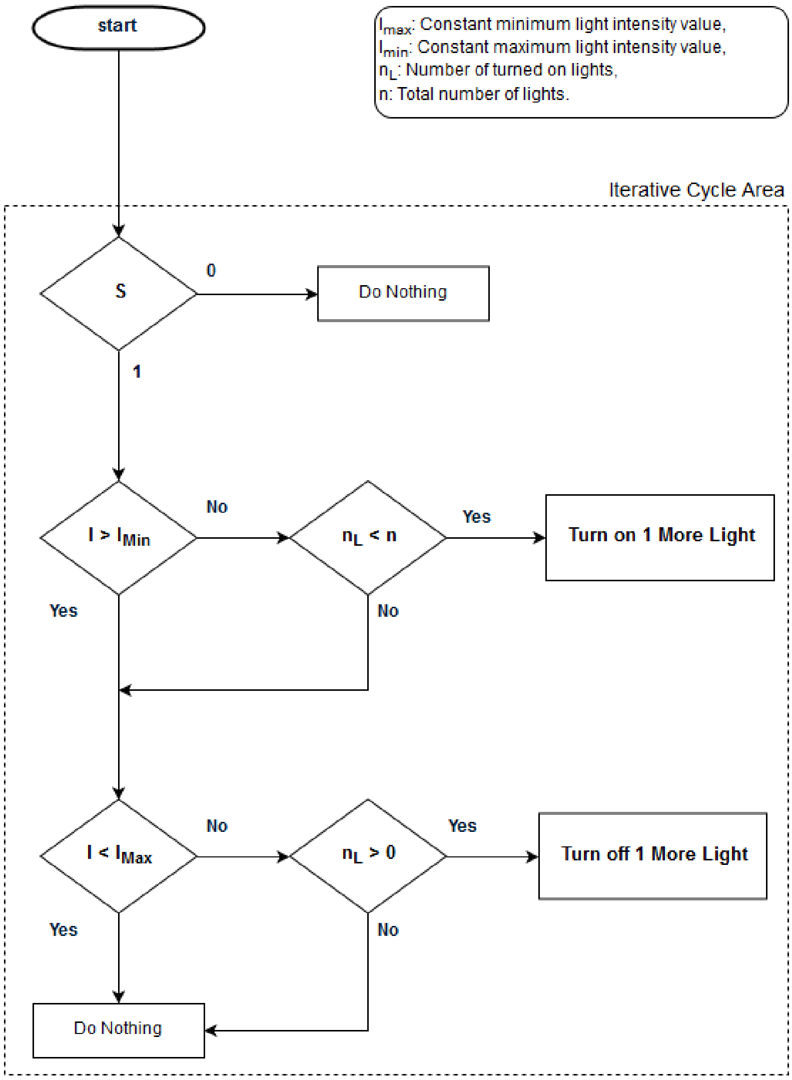

Figure 8. Algorithm used for lighting system

2.5 Software structure

Proposed software is planned to monitor and control environmental and consumption parameters based on algorithms in certain locations. Location is referred to as any spot defined distinctly to monitor and control environmental and consumption parameters independently.

2.5.1 Environmental parameters

This section of software refers to monitoring and controlling features (Fig. 9).

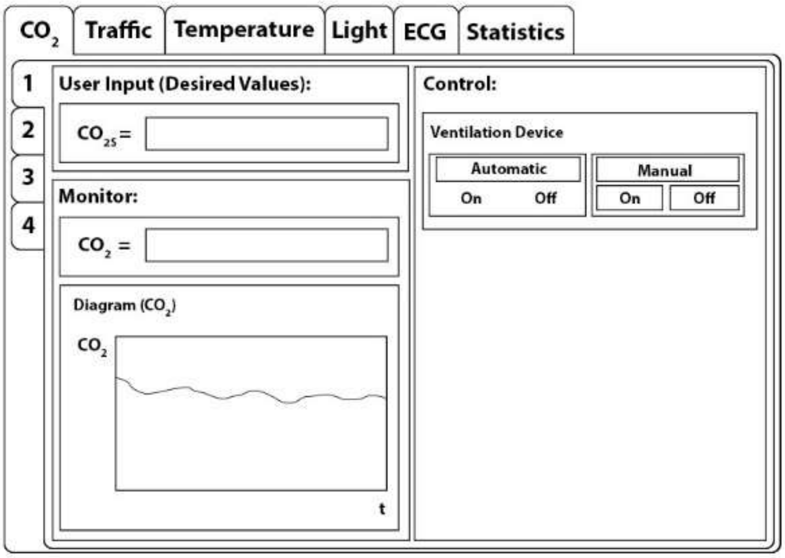

Figure 9. Proposed software: Monitoring and controlling section for environmental parameters

2.5.2 Consumption/generation

The consumption/generation section indicates parameters related to consuming and generation of energy (just in the case of using photovoltaic electricity generators) (Fig. 10). In Fig. 10, I_{EC} refers to consumed electrical current, E_{EC} refers to consumed electrical energy. I_G refers to generated electrical current, and E_G refers to generated electrical energy.

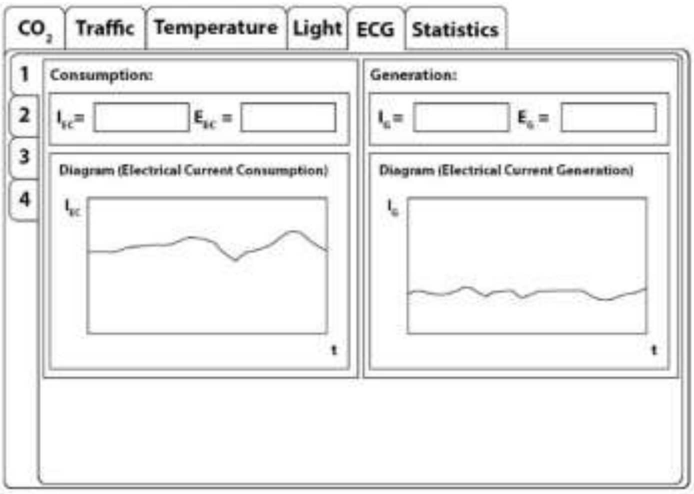

Figure 10. Proposed software: Monitoring and controlling section for consumption/generation

2.5.3 Statistics

Consumption and generation parameters, traffic, ventilation device activity duration, heating/cooling device activity duration, number of active lamps, CO_2 concentration, and light intensity are all indicated for annually, monthly, daily, and hourly (Fig. 11). Therefore conservative value of electrical energy could be evaluated before and after system implementation using standard indices (Jung et al., 2019) (R_C,E_C):

$$\mathrm{E_C} = \mathrm{E_{CC}} - \mathrm{E_{SSC}} \tag{1}$$

$$\mathrm{R_C} = \frac{\mathrm{E_C}}{\mathrm{E_{CC}}} \tag{2}$$

where E_{SSC}[1] and E_{CC}[2] are consumed electrical energy before and after implementation of the system respectively.

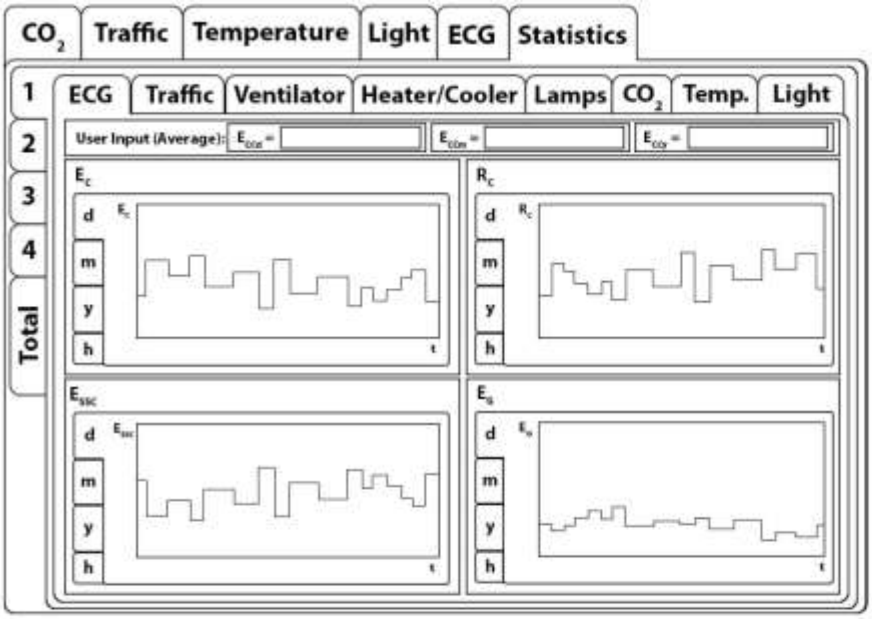

Figure 11. Proposed software: Statistics

3. RESULTS AND DISCUSSION

In the current research, a study has been performed on temperature according to the proposed method. Therefore data logging and control processes have been included in the whole procedure.

First of all, the location has been divided to certain zones. This is done according to heating/cooling device mechanism. The pilot location in the current study has been divided into 4 zones. Then traffic parameter has been considered to be checked continuously to estimate the usage of each zone. The measured traffic value and rate has also been used as an indicator of importance for each place.

[1]Smart System Energy Consumption
[2]Common Energy Consumption

Since the energy source of heating/cooling device has been electricity, only electrical energy has been accounted for. The required traffic data for measuring temperature in each 4 zone is illustrated as charts in Fig. 12, while measured environmental temperature value for these zones are depicted in Fig. 13 for 24 hours.

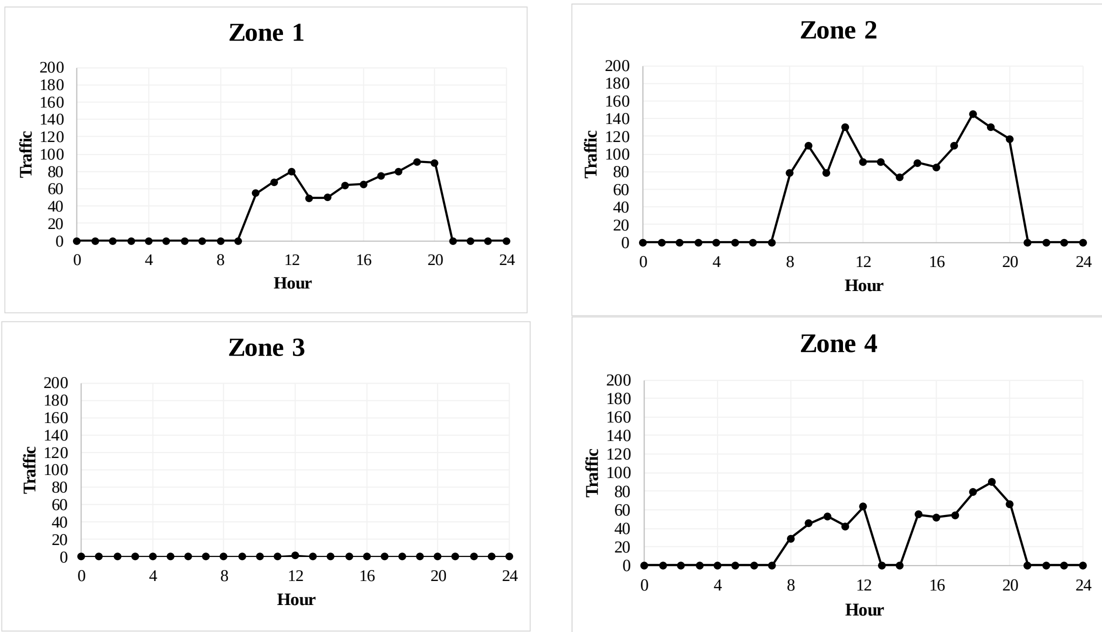

Figure 12. Measured traffic in 4 zones during 24 hours

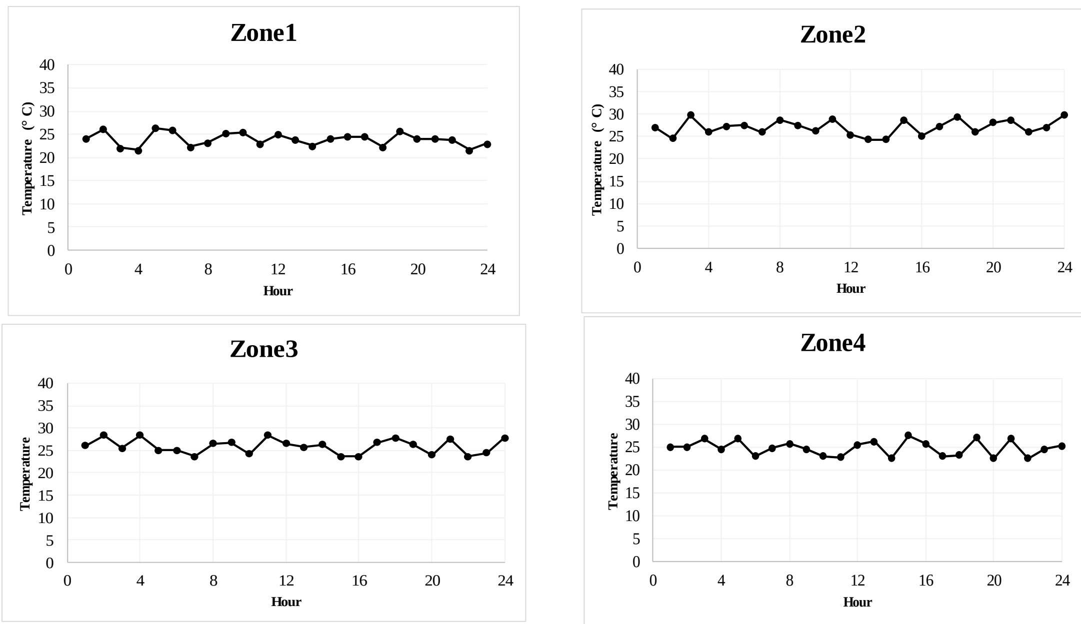

Figure 13. Measured temperature data in 4 zones during 24 hours

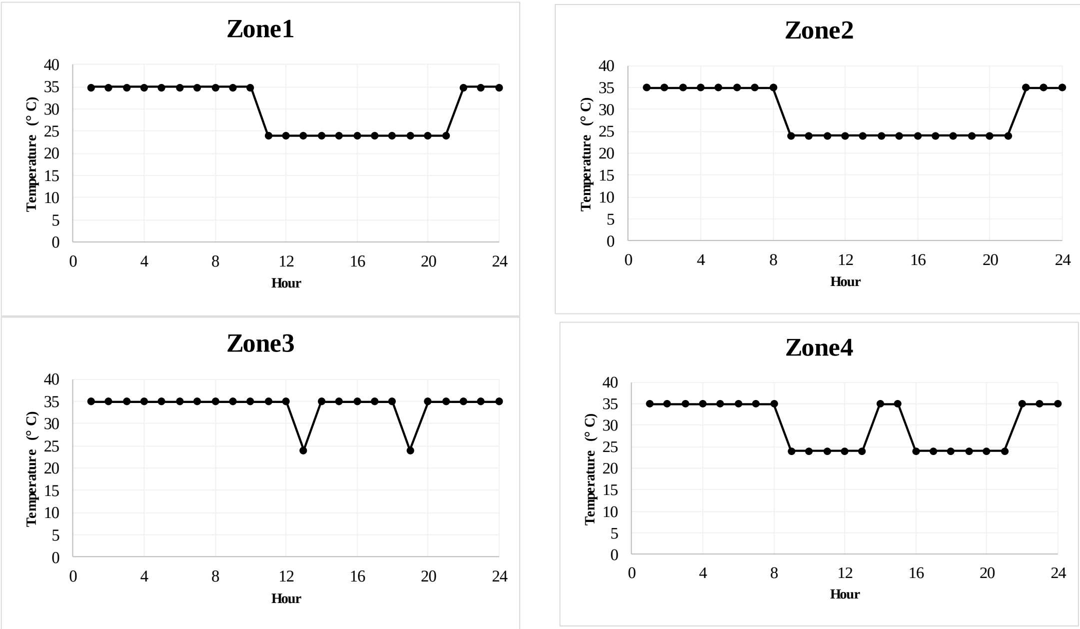

Figure 14. Measured temperature after activating control mechanism

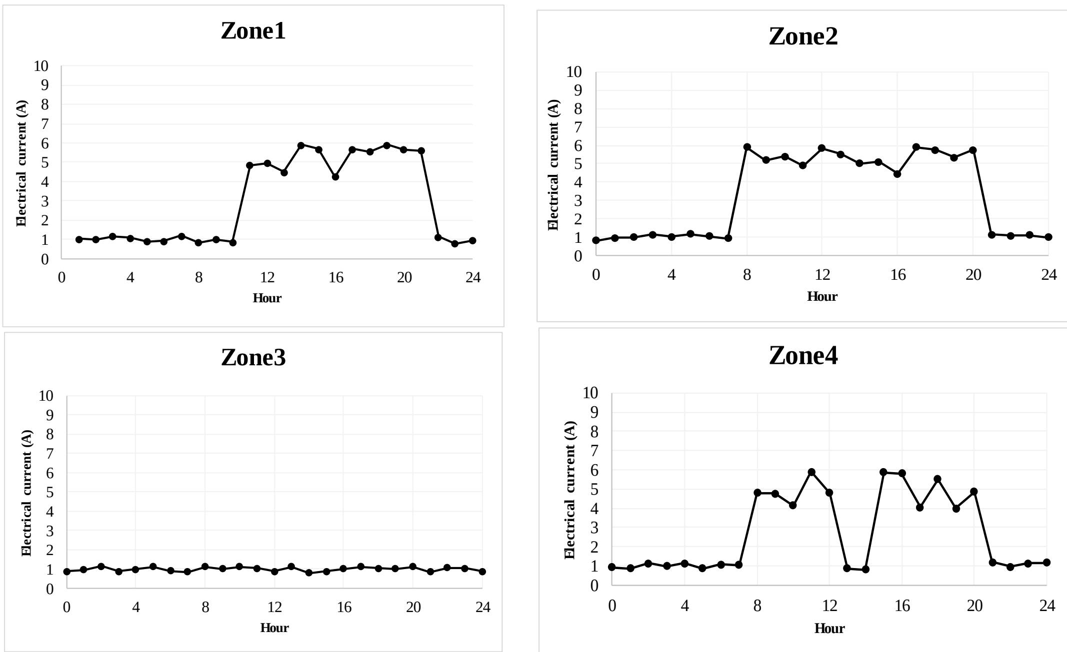

Figure 15. Electrical current consumption in 4 zones, before and after control system activation

Temperature has been controlled according to the importance of each zone after the implementation of controlling system (Fig. 14). In fact temperature has been set based on the requirement of each zone. The same fact is visible for the energy consumption according to Fig. 15 as electrical current indicates the value of electrical energy consumption. According to Fig. 12, the most important zone is considered to be zone 2 while the least important one is zone 3 based on traffic value. The control scheme for temperature is then planned based on traffic index for each zone. Energy consumption is evaluated for the proposed control mechanism before and after control system activation as total value in Fig. 16. The reduction in energy consumption is clearly visible as claimed before in Fig. 16.

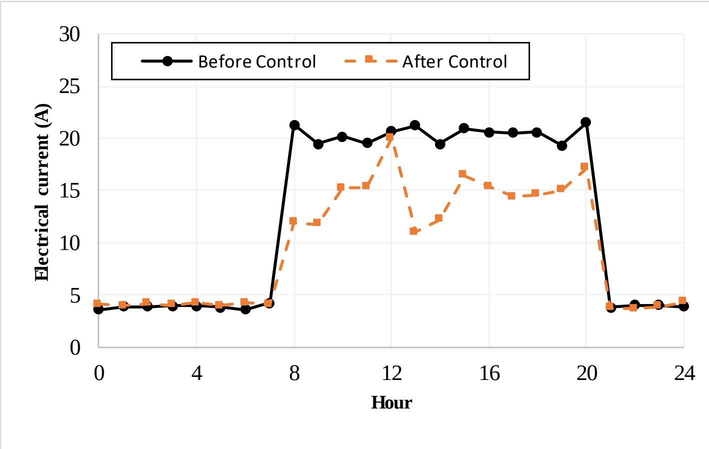

Figure 16. Total measured electrical current, before and after activating control system

4. CONCLUSION

A monitoring/controlling energy consumption optimizing system for comfort parameters was proposed while it has been tested practically for temperature as a case study in results section. Configuration of designed software structure has been demonstrated and the performance of proposed approach is verified for temperature controlling purpose. It is expected that proposed concept can be used efficiently as a smart multi-purpose tool to optimize energy consumption, control comfort indices, and provide public healthy spaces. It is also expected to provide different solutions for clean energy generation after equipping the system with generative elements such as photovoltaic components, to improve energy management tasks.

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