Air Conditioning Consumption Optimization Based on CO2 Concentration Level

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***Abstract*—Nowadays, energy consumption increasing is a big concern for many countries around the world. Disadvantages and consequences of fossil fuels for the environment caused a lot of efforts to invest in renewable energy resources and programs to optimize energy consumption. All types of buildings are the major consumers of electric power. Therefore, buildings can be considered as good options for implementing optimization algorithms, assuming that they are equipped to required infrastructures. Air conditioners are flexible loads that can be directly controlled by optimization programs. This paper presents a particle swarm optimization algorithm to minimize the power consumption of the air conditioners based on the carbon dioxide concentration level. The algorithm considers the thermal comfort of users with defining restrictions. The case study of the paper proposes two scenarios with real monitored data of a building. The result of the paper shows the obtained results of the algorithm and makes the comparison of two scenarios.**

***Index Terms*—Optimization, PSO, Buildings, CO2.**

I. Introduction

THE increments of electrical power consumption become a big threat to the global society around the world. The fossil fuels usage has been caused many problems and consequences on the environment [1], such as climatic phenomena and the changing in temperature characteristics, that they are directly related to the power consumption [2]. Also, greenhouse and traffic on the roads emissions also contribute to this problem with raising the CO2 levels hence the earth surface temperature [3]. Therefore, it is very important to manage these problems in order to maintain our planet and our future.

However, the statistic of energy consumption shown that residential buildings consume quite a large percent of the global produced energy around the world. Energy consumption for residential buildings represents the second largest increase in energy consumption [4]. For instance, in China in 2015, 19.93% of the country's total energy consumption is consumed by residential building [5]. Also Globally, public and residential buildings account for 20.1% of the total delivered energy consumed[6].

From this information the building energy consumption reduction is an important thing to think, therefore some countries have proposed goals and policies for zero energy buildings [7] which are reducing the consumption, increase the renewable energy usage and improve the efficiency[6].

The building's energy consumption is not a constant value and it is depending on many variables (weather, date, community). Some studies showed that the most percentage of the energy is consumed by air-conditioners (AC) systems and they estimate that percentage between 20% to 40 % [8], and this percentage could reach to 50% of building energy [9][10], so AC can be a good trace to choose for optimization and reduced the energy consumption in the building [11]. However, the AC power consumption has a direct effect on the thermal comfort of users and modifications in the AC power consumption can be led to the inconvenience of the users. Therefore, it is important to consider user comfort and preferences in optimization purposes.

In order to find out optimum solution for energy consumption, it is important to choose optimization algorithms which are varied in a wide range.

Intelligent systems field is very suitable to solve the optimization problems since it has a great variety of diversity to find the optimum solution, but also these problems can be solved by deterministic, stochastic or heuristic algorithms. The right choice will help to get the best solutions.

Heuristic methods are currently the main part of optimization algorithms, and they often inspired by nature with multiple interacting factors. such as Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) and so many other algorithms. Both GA and PSO algorithms are getting used greatly and give a very good result [12]. On other hands, it is important for the quality of any optimization process that the data should be trusted, therefore the building or the facilities should equip with automation infrastructure to measure data. Supervisory Control and Data Acquisition (SCADA) system can be the best choice for that task [13].

In this work, the used optimization algorithm is PSO which become a better-developed optimization algorithm, in recent years. It searches the optimal solution through continuous iteration, and it finally employs the size of the value of the objective function, or the function to be optimized, in order to evaluate the quality of the solution [14].

However, the optimization of AC power consumption is not a new topic. Many researchers did a lot of studies about that. Some of them present a management system for AC using data mining framework and based on a combination of unsupervised

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and supervised learning techniques [15]. Other studied the controlling of AC regarding humidity using A hybrid genetic algorithm and particle swarm optimization algorithm (GA-PSO) [16]. Also, there is a study that uses a prediction model by Neural Networks, and then use the model as a function of Genetic Algorithm to search for optimal values to get a minimum power [17].

This paper proposes a methodology to optimize the (AC) consumption in an office room based on CO2 levels, with using PSO algorithm. The used dataset in this paper is the real data which are monitored by existing equipment in the building.

After this section, the methodology is explained in Section II. The case study is demonstrated in Section III and the obtained results will be compared in section IV. Finally, Section VI describes the main conclusions of the work.

II. Methodology Description

This section presents the optimization algorithm which is implemented to minimize the power consumption of the ACs based on CO2 concentration level in office rooms. The increment of CO2 in any closed environment can be considered as an inconvenience factor for the users. When the carbon dioxide concentration goes up, temperature also goes up. Appropriately, the AC should work in cooling mode to make the CO2 concentration balanced in houses or office rooms. However, the excessive use of ACs can be led to electricity cost increment and the other consequences. In addition to CO2 concentration control, and power consumption minimization, the temperature comfort of the user should be maintained. It means that the present algorithms follow objectives in different directions. Fig. 1 shows the steps of the present optimization algorithm.

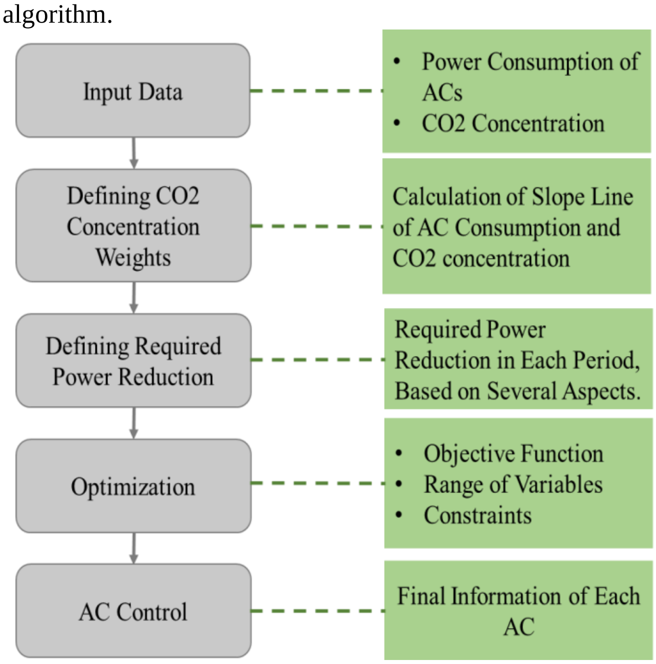

Fig. 1. Flowchart of the methodology.

As can be seen in Fig. 1, the first step is importing the input data that in this algorithm the required input data are the power consumption of the ACs and the CO2 concentration in each room. After that, the CO2 variation weight should be calculated according to the following formulation:

$$CO2\_W_{(r,t)} = ABS\left(\frac{CO2_{(r,t)} - CO2_{(r,t-1)}}{P\_AC\_act_{(r,t)} - P\_AC\_act_{(r,t-1)}}\right) \quad (1)$$

CO2_W is a numerical value that shows the weight of CO2 concentration variation in each room. *CO2* shows the real amount of *CO2* based on time and place. *P_AC_act* is the abbreviation of the actual power consumption of each *AC*. It should be noted that *r* and *t* are the numbers of room and period respectively. It should be mentioned that the number of rooms and ACs are equal. It is expected that the low values of *CO2_W* in any room and any period mean to reduce the power consumption of ACs. In the periods and rooms that the CO2_W is high, the algorithm should keep the ACs ON.

There is a specific required power reduction in each period that can be assigned based on several aspects such as electricity price, power generation, user preferences, etc. After providing all required parameters, the objective function and its following constraints should be defined. In this methodology, the comfort of the users has been considered with related constraints.

The present methodology is implemented in Rstudio® software which is a free open source and enterprise-ready professional software for doing the work better and faster (www.rstudio.com). This optimization algorithm is solved by the PSO algorithm and is implemented by an internal function in MetaheuristicOPT package. MetaheuricticOPT package contains the implantation of several heuristic algorithms that genetic algorithm and PSO are its most known algorithms.

Equation (2) presents the objective function of the problem:

Minimize Objective Function:

$$\sum_{t=1}^{T}\sum_{r=1}^{R} CO2\_W_{(r,t)} \times P\_AC_{(r,t)} \quad (2)$$

As it is presented in (1), *CO2_W* is the weight of CO2 concentration variation based on variation which is the slope line of AC power consumption and CO2 concentration. *P_AC* is the decision variable of the algorithm that shows the power consumption that should be reduced from each AC in each period. It should be noted that *T* is the maximum number of periods and *R* is the maximum number of rooms with considering that each room contains one AC. Equation (3) shows the required power reduction of the algorithm that should be reduced in each period.

$$\sum_{r=1}^{R} P\_AC_{(r,t)} \geq ReqRed_{(t)};\ \forall\ 1 \leq t \leq T \quad (3)$$

ReqRed is the abbreviation Required power Reduction in each period. In order to consider the user comfort, the algorithm limits the total power reduction of each AC during all periods by (4) to prevent excessive power reduction.

$$\sum_{t=1}^{T} P\_AC_{(r,t)} \leq \sum_{t=1}^{T} PRL_{(r,t)} \times P\_AC\_act_{(r,t)};\ \forall\ 1 \leq r \leq R \quad (4)$$

PRL stands for Power Reduction Limit that can be changed at different times and devices. PRL does not let the algorithm to reduce power consumption more than the user preferences.

III. Case Study

In order to test and validate the present methodology in real life, an office building has been considered for present case study. The building is located at ISEP Campus, in Porto, Portugal. Figure 2 presents the map of the building.

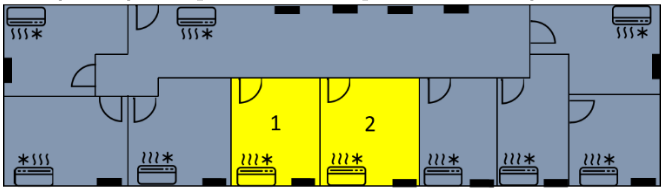

Fig. 2. Map of the building in present case study.

As it can be seen in Figure 2, the building contains 10 ACs, however, the present case study focuses on two ACs in two distinct room which are highlighted in yellow.

This building is equipped with a SCADA system for controlling and monitoring several environmental parameters as well as energy consumption and production. In the SCADA model, there are three distributed based Programmable Logic Controller (PLCs) and one main PLC, which are employed to control and record the data. Each distributed based PLC is responsible for a group of offices, and the main PLC is responsible to acquire data from the other PLC in order to store in the database, and also to provide a webpage for monitoring the parameters of the building. More detailed information about the present SCADA system can be found in [11]. In each office of this building, there are a group of sensors connected to the related PLC. The sensors are CO2, air quality, humidity, temperature, light intensity, movements and presence of each office users. All these data are transmitted to the PLC through several communication protocols, such as serial and Ethernet interface. Also, there are several energy meters in the building that monitor the real-time consumption of lighting system, sockets, and ACs. All these data are acquired from the SCADA model in 1 second time interval, and they are stored in the database with 10 seconds interval. Therefore, the user is able to mine the data from a minimum interval of 10 seconds.

In this case study, the real data has been acquired from the related database with 1-hour time interval to optimize the power consumption of the two ACs in 4 working hours a day.

Fig. 3 shows the power consumption of the AC and CO2 concentration in room number 1:

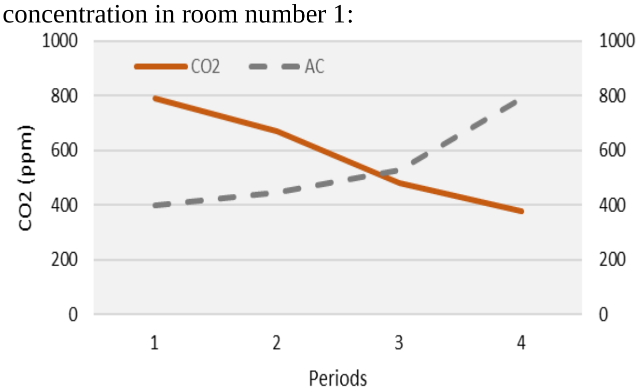

Fig. 3. CO2 concentration and Power Consumption of AC in room 1.

As it can be seen in Fig. 3, the increment of power consumption of the ACs. Have been caused the decreasing in CO2 concentration.

Fig. 4 shows the power consumption of the ACs and CO2 concentration in room number 2.

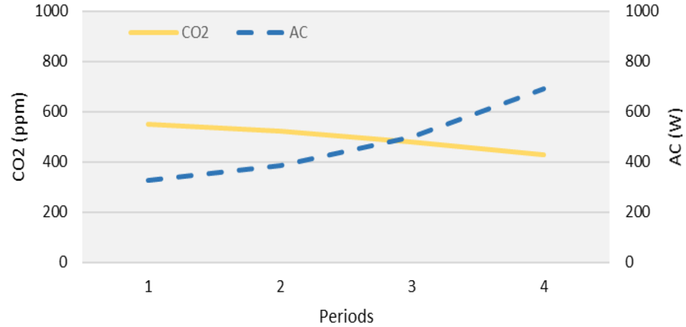

Fig. 4. CO2 concentration and Power Consumption of AC in room 2.

It is clear in Fig. 4 that while the power consumption of AC has been increased the CO2 concentration has been dropped.

The scatter chart in Fig. 5 presents the relationship between AC power consumption and CO2 concentration in 4 points.

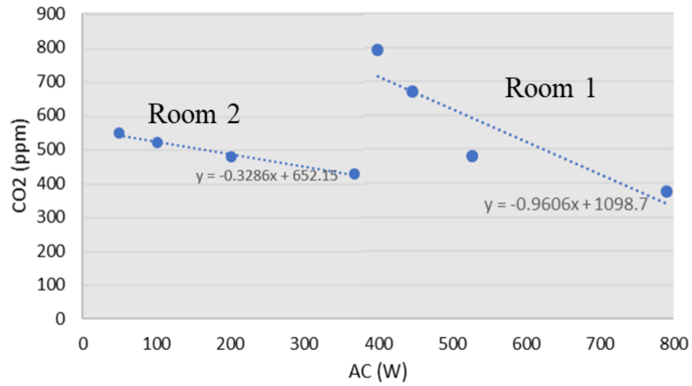

Fig. 5. Relationship between CO2 concentration and AC power consumption.

The related formulation is shown in Fig. 5 shows the slope line of whole periods. However, the individual slop for every two periods should be calculated by the algorithm.

Two scenarios are considered for this study. Scenario A considers (4) for the user comforts and scenario B ignores the impact of (4) by using PRR equal to 1. Table I shows the PRR in each scenario.

TABLE I. PPR in Each Scenario.

	Scenario A	Scenario B
PRR	0.7	1

It should be noted that the CO2_W, actual power consumption, and required power reduction in both scenarios are equal. Table II shows the CO2_W and required power reduction in each period.

TABLE II. Used Input Data In Each Period.

	CO2_W (AC1)	CO2_W (AC2)	ReqRed (W)
1st Period	0.25	0.05	300
2nd Period	0.23	0.03	300
3rd Period	0.03	0.02	500
4th Period	0.03	0.01	700

Scenario A

This scenario presents the implementation of the algorithm with all existing constraint. The power consumption of the ACs should be minimized based on CO2_W, while the user comfort should be maintained by (4). PRL has been defined in (4) to limit the power reduction of each AC in all periods. For instance, in this scenario, the user prefers to offer 70% of the available power of its device, so, the PRL should be assigned equal to 0.7. It means that the required power reduction of the algorithm should be met. Although, the total power reduction of each AC should not exceed 70% of nominal power consumption. The other initial used data in this scenario can be seen in Table II and Fig. 3.

Scenario B

This scenario optimizes the power consumption of the ACs based on CO2 concentration level, however, there is no limitation for total power consumption of ACs. This scenario considers the amount of required power reduction and CO2 concentration without considering the thermal comfort of the user. It means that the (4) has been ignored in this scenario to check the impact of this constraint. The initially used data in this scenario can be seen in Table II, and Fig. 4.

IV. Results

This section presents the obtained results of two proposed scenarios. Scenario A has been implemented to minimize the power consumption of the ACs, based on the slope line of CO2 concentration and AC power consumption. In each period, the specific amount of power has been reduced, however, the ACs have been limited to avoid excessive power reduction with defining PRL parameter in comfort constraints. Fig. 6 presents the obtained results of scenario A implementation.

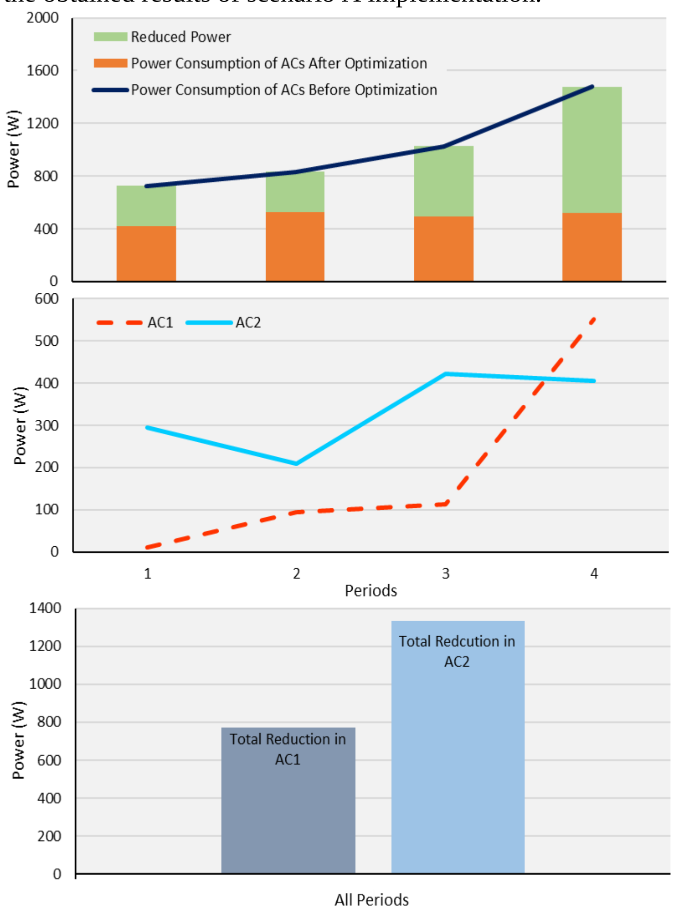

Fig. 6. Obtained results of scenario A.

As it can be seen in Fig. 6_A, the required power reduction has been approximately achieved by the algorithm. The power consumption of the ACs before optimization and after optimization has been shown in Fig. 6_A. According to Table II, the CO2_W of AC number 1 in period 1 and period 2 are equal to 0.25, and 0.23 respectively. Fig.6_B shows that AC number 1 in two first periods has the power reduction equal to 11 and 94 respectively. It shows that in the periods that CO2_W is high, the algorithm has been avoided to reduce power from AC number 1. In Fig. 6_C, the total power reduction of each AC during all periods can be seen. It is clear that AC number 2 has more power reduction based on its CO2_W.

Scenario B has been implemented to only reduce the desired power reduction of the algorithm based on the slope line of CO2 concentration and AC power consumption. The defined comfort constraint is ignored in this scenario. It can be interpreted that the PRL is equal to 1 in this scenario. Fig. 7 shows the obtained results of scenario B implementation.

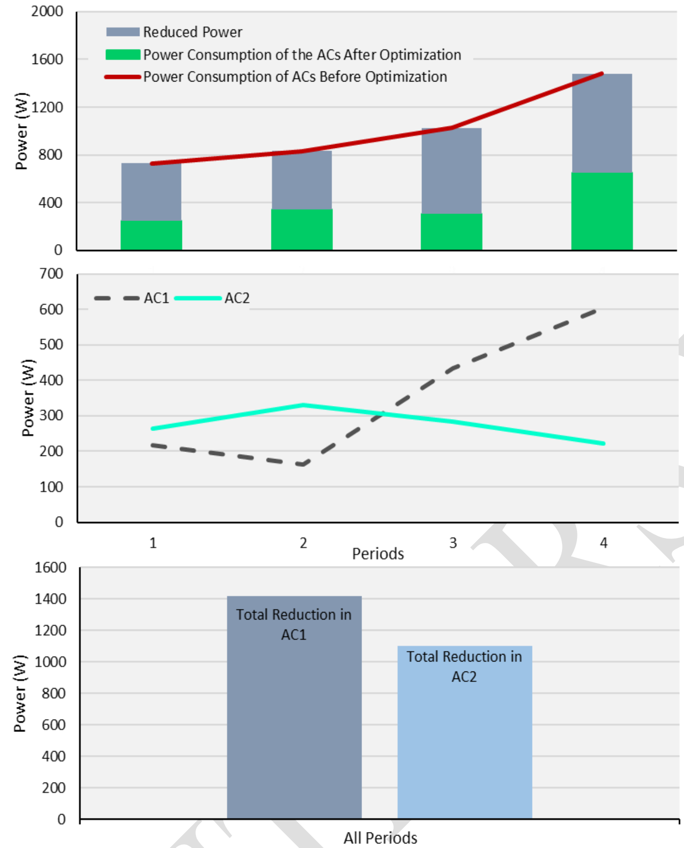

Fig. 7. Obtained results of scenario B.

According to Fig. 7_A, the required power reduction of the algorithm has been met. The reduced value is more than the desired one, however, the (3) justifies this matter. The power consumption of the ACs before and after optimization can be seen in Fig. 7_A.

Fig. 7_C shows the total power reduction of each AC during all periods without any restrictions. The AC number 1 in the first period and the second period has lower power reduction, but in third and fourth period AC number 1 has more contribution in achieving desired power reduction, since the CO2_W of both ACs are approximately equal.

Fig. 8 is prepared to show the comparison of the obtained results of scenario A and scenario B.

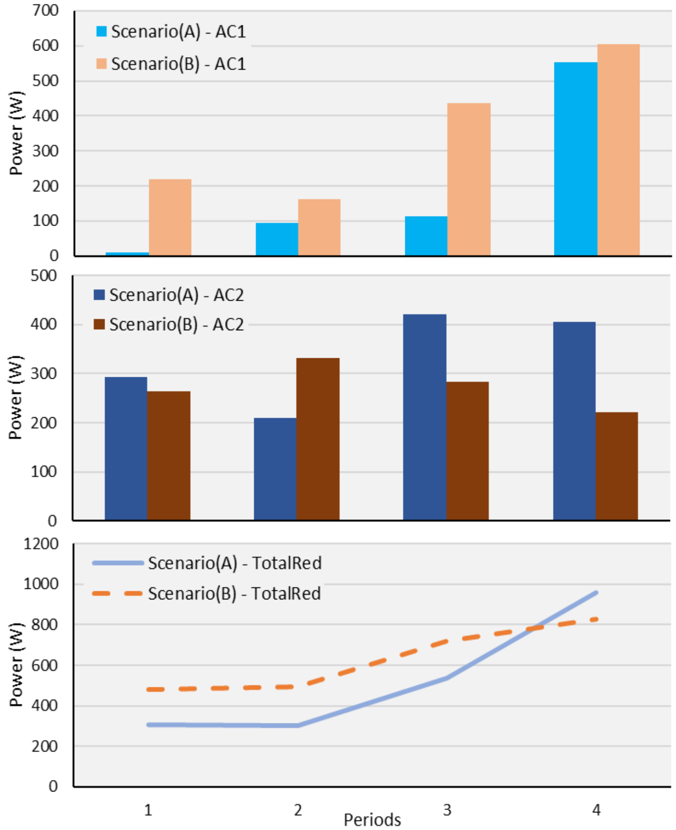

Fig. 8. Comparison of scenario A and scenario B.

It can be seen in Fig.8_A that AC number 1 in scenario A has lower power reduction, based on its CO2_W and comfort constraint. According to Fig. 8_B, the power reduction of AC number 2 has been decreased in scenario B since the AC number 1 has more contribution in scenario B. However, it is obvious in Fig. 8_C that the total reduced power has been increased in scenario B that shows the absence of PRL in comfort constraint.

V. Conclusions

The energy consumption increasing around the world has become a big concern for countries. All types of building are known as major consumers of energy. Optimization algorithms with different methods have been applied in various aspects to reduce electricity consumption.

This paper presented one particle swarm optimization algorithm in order to reduce the power consumption of the ACs, based on CO2 concentration levels. The desired power reduction has been considered for each period of algorithm implementation, and this desired value should be reduced in low CO2 concentration levels. In order to respect the user comforts, one restriction has been considered to limit the power consumption of ACs more than enough and avoided the excessive power reduction from devices. The case study of the paper presented two scenarios with real data of an office building to compare the impact of comfort constraint. The obtained results of the paper proposed that in the periods that the CO2 concentration has been measured as a high value, the algorithm avoided to turn off the ACs. In another hand, in the periods that the CO2 concentration level is low, the algorithm took advantages to reduce the power consumption of the ACs. The obtained results showed that the comfort constraints cause the lower power reduction from ACs to maintain the thermal comfort of users.

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