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Using Genetic Algorithm Optimization for University Buildings Timetable Scheduling Based on Energy Efficiency: A Case Study of the Electrical Engineering Department, Assiut University

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***Abstract*— Higher education administrators must actively develop their management strategies to lower building energy usage, as it is challenging to get students to adopt energy-saving behaviors due to their limited responsibilities. The increasing number of students, the variety of teaching processes, the lack of adequate educational facilities in some areas, limited availability of classrooms, and the scheduling preferences of lecturers and students are essential factors that affect schedule management. Programming for preparing academic timetables has become particularly difficult in recent years. The goal of this paper is to use the academic timetable as an effective tool to improve electrical energy consumption and to align students' activities during their time in university buildings with energy efficiency. The goals of an optimum timetable can be achieved through three directions: human preferences, time slots, and space characteristics. This work uses a genetic algorithm to generate an optimum university schedule that considers building energy efficiency. The suggested technique simulates the schedule of a university teaching building in the Electrical Engineering Department at Assiut University, Assiut, Egypt, for the academic year 2023/2024. The optimized timetable shows a reduction in energy consumption of teaching spaces by approximately 20.6%. Moreover, it helps improve student and teacher activities during working hours through the design and operational management of teaching spaces**

Keywords-University course timetable; building energy efficiency; Genetic algorithm

List of Nomenclature

E	Energy consumption
t	Operating time
M	Total Number of courses
C	Classrooms
W	Weekdays
L	Time slots
K	Teachers
S	Classes
G	Number of students in a course
V	Number of seats in a classroom
O	Penalty coefficient Vector or matrix
P	Power rating
x	Device
X	Total Number of devices
F	Number of frequency courses at week
FF	Fitness function
A	Occupancy level matrix for each course at different time slots
A_{lm}	Number of students in time slot l for course m.
O_m	Penalty coefficient associated with course m.
h_m	The weight or reward for course m based on its preference

I. Introduction

A university building uses 1.5 times more energy per unit area compared to other public structures [1]. Most of the energy consumption and carbon emissions in university buildings are attributed to teaching facilities, where instructors and students frequently reside for extended periods [2]. Consequently, for university teaching buildings to become carbon neutral, energy conservation must be prioritized. Both technical and management solutions are available for reducing energy consumption in university buildings [3]. However, due to their high cost, technical solutions are often difficult to implement on a large scale [4]. Therefore, management methods are more suitable for university instructional buildings [5]. Accordingly, administrators must enforce the use of management-based solutions. A classroom's energy usage may fluctuate over time due to variations in indoor and outdoor climates [6]. Additionally, classrooms of different sizes consume varying

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amounts of energy. By optimizing the course schedule, the energy consumption of a teaching building can be effectively managed. Furthermore, scheduling classes in rooms that match the student population and classroom capacity can lead to energy savings of about 4.0% [7]. Calculating a building's energy usage is essential for developing an optimization model for university course schedules aimed at reducing energy consumption. Common techniques used to estimate building energy consumption include white, black, and gray box models [8, 9]. These models calculate

Building energy consumption can be calculated more accurately using detailed methods compared to simplified approaches, which only require unit power ratings and operating hours obtained through field surveys. These models take into account external factors, such as weather, and internal characteristics of the building. While each method has its strengths and weaknesses, the simplified method is sufficient for creating energy-saving course schedules in real-life applications. It is quicker and easier to use, relying on bottom-up surveys of energy-consuming items to calculate their usage [7].

University timetabling belongs to a class of problems known as non-deterministic polynomial combinatorial optimization problem [10]. These problems are complex due to the need to satisfy all specified hard and soft constraints. Hard constraints are rules that must never be violated, while soft constraints represent preferences that can be overlooked without significant consequences [11].

Over the years, many algorithms have been proposed to solve university timetabling issues. Optimizing the teaching schedule with respect to energy efficiency is critical. For example, Song et al. [7] developed an energy-saving course timetable technique that achieved a 4% reduction in energy consumption during both the heating and cooling seasons. Similarly, Jafarinejad et al. [4] introduced a bi-level energy-efficient timetable optimization method using a model predictive controller, which reduced energy consumption by 1.3%, and increased energy-saving potential from 11.65% to 19% when incorporated with the controller.

Fathi et al. [12] also optimized the course schedule, considering factors such as energy consumption, student preferences, educational constraints, professor schedules, class sizes, and shared resources. Their findings showed that heating energy usage could be reduced by 12% with optimal scheduling, compared to traditional methods. Sethanan et al. [13] resolved a similar issue at a Thai university, improving energy efficiency by scheduling classroom occupancy. Their algorithm achieved a relative improvement of 7.12–28.59% over the previous schedule for the academic years 2006–2012.

Common heuristic algorithms used for university timetabling include tabu search (TS) [14], simulated annealing (SA) [15], particle swarm optimization (PSO) [16], bee mating [17], and hybrid algorithms [18–20]. Among these, the genetic algorithm (GA) is one of the most popular due to its high computational parallelism and efficiency. GA iterates over a population to find the best solution by optimizing parameters.

Khonggamnerd and Innet [21] used a GA to create a university course schedule that adhered to strict guidelines while still producing a viable solution. Similarly, Hossain et al. [16] introduced a novel approach based on Particle Swarm Optimization (PSO) to tackle issues with university course timetabling. The results demonstrated the effectiveness of their method, surpassing traditional techniques in performance. To further optimize course scheduling, Kohshori et al. [22] developed a multi-group hybrid GA, which integrated local search, SA, TS, and fuzzy search techniques. The outcomes of the experiments suggested that the suggested GA yielded encouraging outcomes when applied to extensive timetabling issues.

In this paper, Assiut university, faculty of engineering, Electrical department's course timetable is optimized in the period from February to May 2024 to reduce the energy consumption of teaching buildings. The objectives of this research can be stated as follows:

- Calculation of energy consumption in classrooms and laboratories based on rating of loads and operation hours due to non-optimized table.
- Creating an optimal course timetable using GA to minimize energy consumption of the teaching building and ensuring student comfort. The solution also considers hard and soft constraints.
- Calculation the impact of the optimized course timetable on energy consumption of the teaching buildings.

II. Optimum Timetable Parameters

A. Classrooms Energy Consumption

Classrooms at electrical department, Assiut university can divide into three partitions: small classrooms, large classrooms, and laboratories. The electrical loads are led, and florescent lamps, fans, air conditioning, LCD monitors, and projectors. Calculation of energy consumption is based on bottom-up surveys of energy-consuming devices and operating hours due to courses timetable schedules. It depends on summation of power rating for all devices at classroom and multiply with operating time which is extracted from timetable schedule. The total amount of energy consumed in a classroom can be calculated by (1).

$$E(c) = \sum_{x=1}^{X} (P_{cx} * t_{cx}) \quad (1)$$

Where E (c) is energy consumption in classroom © at operating time (t) and P is rating power of device (**x**) in classroom (c) where $\boldsymbol{X}$ is the total number of devices in the classroom.

B. Course Timetable Constraints

This research aims to reduce energy consumption by reallocating students in classrooms based on fitness function. The fitness function of course timetabling is to minimize energy use in classrooms, while satisfying hard constraints and soft constraints

An acceptable course schedule must meet the following hard constraints:

- A teacher is assigned to teach only one course at a time.
- A class is scheduled for no more than one course at any given time.
- A classroom is allocated for only one course at a time.
- The number of seats in a classroom must be at least equal to the number of students enrolled in the course.
- Each course must meet its required frequency of sessions per week.

The mathematical equations describing each constraint are given by (2-6) [23].

$$\sum_{m\in M} y_{m,c,w,l,k} \le 1 \quad \forall k \in K, \forall w \in W, \forall l \in L, \forall c \in C \tag{2}$$

$$\sum_{m\in M} y_{m,c,w,l,s} \le 1 \quad \forall s \in S, \forall w \in W, \forall l \in L, \forall c \in C \tag{3}$$

$$\sum_{m\in M} y_{m,c,w,l} \le 1 \quad \forall c \in C, \forall w \in W, \forall l \in L \tag{4}$$

$$G{*}y_{m,c,w,l} \le V \ \forall m \in M, \forall c \in C, \forall l \in L \tag{5}$$

$$\sum w \in W, s \in S, c \in C \quad y_{m,c,w,s,k} = F \ \forall c\in C \tag{6}$$

Here, $\boldsymbol{y_{m,c,w,l,k}}$ is a binary variable that is 1 if course **m** is assigned to classroom **c**, on day **w**, during time slot **l**, with teacher **k** assigned to it, and 0 otherwise. F is assigned to the number of frequency courses at week, **G** denotes the number of students in course **m**, **V** denotes the number of seats in the classroom c, $m \in M$ represents the course, $c \in C$ represents the classroom, $w \in W$ represents the weekday, $l \in L$ represents the time slot, $k \in K$ represents the teacher, and $s \in S$ represents the classes.

Moreover, an acceptable course schedule should meet all the following soft constraints. Soft constraints can be violated, they are not required, but their fulfillment is critical to produce a good quality timetable and is used to measure the quality of the solution. Every violation denotes a penalty for the solution that is added to the cost. Soft constraints can be represented as the following:

- Minimizing distance between classrooms location.
- No one must stay in the classroom for one hour continually after finishing lecture.
- Maximizing classroom utilization, minimizing evening classes, and minimizing waiting time between classes.
- There are no classes at peak time.
- The number of empty seats should be minimized.

C. Fitness Function

The used time schedule fitness function determines which solutions are better by giving them a score based on how well they meet the goals. Our goal is to achieve the following four objectives:

1. **Minimize Energy Consumption:** Schedule courses in a way that reduces overall electricity usage by optimizing the use of lighting, air conditioning, and other energy-consuming equipment in classrooms.

$$f_1 = \min \sum_{x=1}^{X} (P_{cx} * t_{cx}) \tag{7}$$

2. **Maximize Scheduling Preferences:** Ensure that courses are scheduled on the preferred days, sessions, and hours as much as possible.

$$f_2 = \sum_{m=1}^{M} \sum_{l=1}^{L} A_{lm} * O_m \tag{8}$$

A**:** Matrix representing the number of students or the occupancy level for each course at different time slots, where A_{lm} is the number of students in time slot l for course m.

O**:** Vector or matrix containing penalty values associated with scheduling courses at undesirable times, where O_m is the penalty coefficient associated with course m.

3. **Minimize Undesirable Scheduling:** Avoid assigning courses at unwanted times.

$$F_3 = \sum_{m\in M} [\sum_{m=1}^{M} \sum_{l=1}^{L} y_{mcl} * G_{cl} * D_{mcl} * h_m] \tag{9}$$

M **:** The set of indices for courses that have specified preferences (i.e., not NaN).

y_{mcl} **:** An indicator function that is 1 if course **m** is assigned to classroom c and time slot l, and 0 otherwise.

G_{cl} **:** The number of students in classroom **c** and time slot $\boldsymbol{l}$.

D_{mcl}**:** A mask indicating the degree to which the assignment of course m to classroom c and time slot l matches the preferences.

h_m**:** The weight or reward for course m based on its preference.

4. **Maximize Classroom Utilization:** Assign courses to the largest possible classrooms.

$$f_4 = \sum_{c\in C} empty\_space_c \tag{10}$$

$empty\_space_c$**:** represents the unused capacity of classroom. It is calculated as the difference between the classroom's capacity and the number of students assigned to it.

$$\boldsymbol{FF = f_1 - f_2 + f_3 - f_4} \tag{11}$$

III. Optimization Algorithm

As an optimization method to investigate an energy-efficient course timetable, this research employs GA. GA starts with a set of random solutions and each solution is called a chromosome. The chromosome consists of several genes which are values corresponding to certain properties in the solution. The genes can then be used to control the fitness of the chromosome. Based on the chromosomes' fitness, a new off string is created by crossing. These off springs are then randomly mutated to create a bigger search space. When an offspring matches a specified fitness condition, this means an acceptable solution has been found and the algorithm terminates. There are two main stages in the genetic algorithm: selection and crossover [24]. The proposed algorithm can be presented as follows:

- Collect all information about electric engineering department (number of students, number of classes, number of all stuff …ets).
- Convert information to a decimal coding scheme, with each teacher's timetable represented as a chromosome.
- Convert traditional timetable for every course to chromosome contain all information in genes (teacher, class, day, slots, power consumption)
- Make overlap matrix which is a square matrix where each element (i, j) represents whether two courses i and j

conflict with each other based on given conditions. If there is a conflict, the matrix element is set to 0; otherwise, it is set to 1. The overlap matrix ensures that there are no scheduling conflicts between courses and instructors for each class and time slot. It identifies potential overlaps by checking that no two courses are assigned to the same instructor or occur simultaneously for the same batch of students.

- Scheduling and allocation of course times and venues based on classroom capacity, student enrollment numbers, designated time slots, and the energy consumption of each lecture. This approach aims to develop an optimal timetable that maximizes efficiency and minimizes energy usage.

The flowchart represents the proposed algorithm shown in Fig. 1.

IV. Results and Discussions

A. Electrical Department Building

There are 70 seats in classrooms 1, 2,3,4,19,20,21,22, 100 seats in classrooms 11,12, 140 seats in classrooms 6,7,8, 200 seats in large classrooms 23,24,25 and {5,9,10,13,14,15,16,17,18,26,27,28} laboratories classrooms at three levels: communications & electronics section, power & machine section, and computer science & control section. $S = \{1, \cdots, 29\}$, $M = \{1, \cdots, 51\}$, $K = \{1, \cdots,73\}$, $W = \{1, \cdots,5\}$, and $L = \{1, \cdots,10\}$. There are 3 classes for the first-level, 7 classes for second level, 2 classes for power & machine section, 1 class for communications & electronics section, 2 classes for computer science & control section for third level, 3 classes for power & machine section, 1 class for communications & electronics section, 2 classes for computer science & control section for fourth level.

B. Traditional Schedule Timetable

Four levels are studied in electrical department building and divided into three sections in third and four levels: communications & electronics section, power & machine section, and computer science & control section. There are 28 classrooms, 51 courses (M) per semester, 73 lecturers (K), and 29 classes (S). The electric load in each classroom is presented in table I.

First level students' study five courses, second level students' study eight courses, third level students' study five courses in the power & machine section, four courses in the computer science & control section, and five courses in the communications & electronics section. Fourth level students' study four courses in the power & machine section, six courses in the computer science & control section, and four courses in the communications & electronics section.

C. Optimization Results and Discussions

The optimization approach is flexible and can be adapted to different universities or contexts with varying energy needs. Adjusting input parameters allows application in diverse institutions, but further studies are needed to validate its generalizability. The result of the proposed algorithm is optimized electric department building timetable schedule.

Daily energy consumption is calculated based on bottom-up surveys of energy-consuming and optimized timetable schedule by GA. The results are presented by Fig. 2 and table II.

The percentage reduction in energy consumption is calculated by (12). The results show that percentage reduction is 20.6% through the semester studied.

The timetable schedule for Wednesday before optimization (B) and after optimization (A) is presented by table III. This table shows the difference in occupancy distribution for the classroom schedule before and after optimization, considering only one day per week, which is the day with the highest electricity consumption.

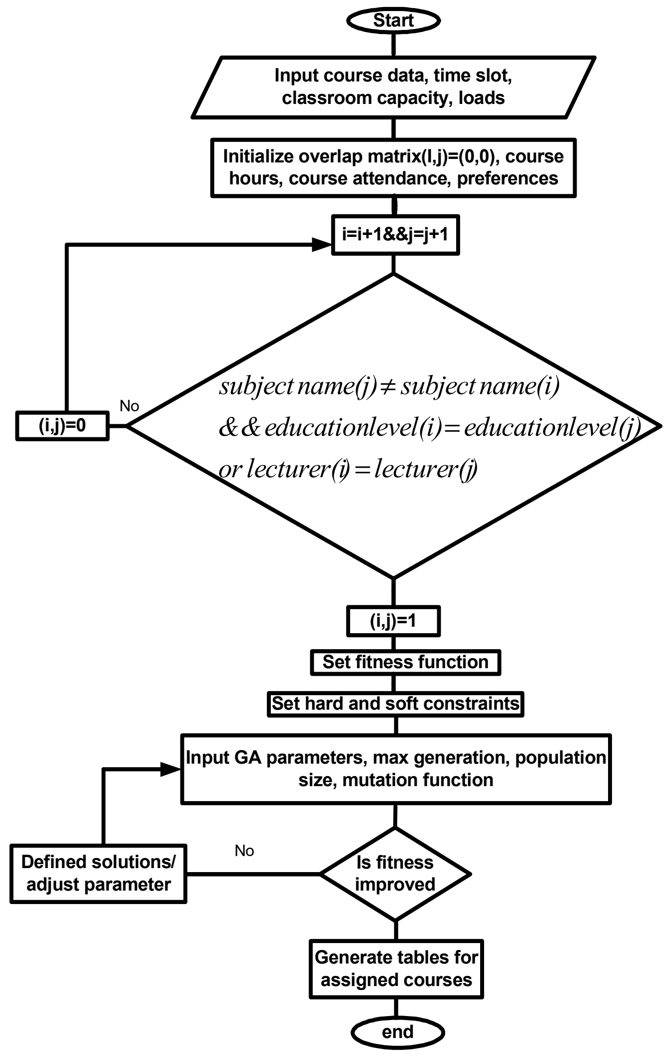

Fig. 1. Proposed Algorithm flowchart

$$\text{Percentage Reduction} = \frac{\textit{energy cons.before optimization} - \textit{energy cons. after optimization}}{\textit{Total energy cons. before optimization}} * \mathbf{100} \qquad \mathbf{(12)}$$

TABLE I. CLASSROOM LOADING

Classroom	Power consumption	Classroom	Power consumption	Classroom	Power consumption
ID1	6801W	ID11	7255 W	ID21	6952 W
ID2	6801 W	ID12	1062 W	ID22	6952 W
ID3	6801 W	ID13	1062 W	ID23	26483W
ID4	7255 W	ID14	1062 W	ID24	30980W
ID5	6649 W	ID15	1593 W	ID25	30980W
ID6	908 W	ID16	1593 W	ID26	12770W
ID7	908 W	ID17	1668 W	ID27	3818W
ID8	1000 W	ID18	7636 W	ID28	3818W
ID9	1000 W	ID19	6952 W		
ID10	1000 W	ID20	6952 W		

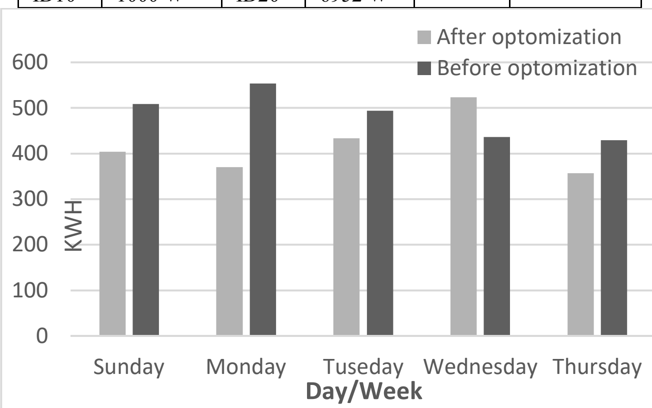

Fig. 2 Daily Energy Consumption Based on Non-Optimized and Optimized Timetable

V. CONCLUSION

The proposed algorithm is developed using a genetic algorithm to create an optimized academic electric department building timetable schedule that achieves hard and soft constraint leading to minimizing energy consumption. This algorithm is applied to Assiut university, electric department as a case study through the period from February to May 2024. The reduction in energy consumption is calculated with non-optimized and with optimized timetable schedule. The result shows 20.6% reduction in energy consumption in electric department building.

TABLE II. DAILY ENERGY CONSUMPTION BASED ON NON-OPTIMIZED AND OPTIMIZED TIMETABLE

Day	Sunday	Monday	Tuesday	Wednesday	Thursday
Energy before Optimization (kwh)	525.742	433.278	639.629	878.991	513.017
Energy after Optimization (kwh)	344.732	344.56	499.523	717.508	468.24

TABLE III. TIMETABLE SCHEDULE ON WEDNESDAY BEFORE AND AFTER OPTIMIZATION

Time slots / classrooms	**8:9AM**		**9:10AM**		**10:11 AM**		**11:12 AM**		**12:1 PM**		**1:2 PM**		**2:3 PM**		**3:4 PM**		**5:6 PM**		**5:6 PM**	
	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A
ID1	•		•		•		•		•		•		•		•		•			
ID 2	•		•		•		•		•	•	•	•								
ID 3					•		•	•	•	•	•	•	•	•	•		•		•	
ID 4	•		•		•		•		•		•									
ID 5	•	•	•	•				•	•	•	•			•		•		•		•
ID 6	•		•	•		•	•	•	•	•		•		•		•		•		
ID 7		•				•		•		•		•		•		•				
ID 8	•		•	•		•	•	•	•	•		•		•		•		•		
ID 9	•																			
ID 10																				
ID 11										•		•	•		•	•		•		
ID 12	•		•			•		•	•		•				•		•		•	
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ID 20	•		•			•		•	•		•		•		•					
ID 21	•		•				•		•				•		•					
ID 22	•		•		•		•		•	•	•	•	•	•	•	•	•	•		•
ID 23		•		•	•		•					•		•	•		•			
ID 24	•		•		•	•	•	•		•		•		•	•	•	•	•		•

ID 25						•		•						•		•				
ID 26																				
ID 27																				
ID 28	•		•					•	•		•		•		•		•		•	

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