Energy Auditing and Conservation for Educational Buildings: a Case Study on Princess Sumaya University for Technology

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Abstract
This paper introduces shortcut and effective approaches for energy auditing and conservation for educational buildings with application to Princess Sumaya University for Technology. The building electricity is significantly covered by a photovoltaic system, which is included in the building assessments and solutions. The short and simplified computations of the Normalized Performance Indicator of the building have shown fair performance, but some conservation opportunities are still possible. Two feasible energy conservation approaches are presented; the first is by optimization of the operating times of 357 air conditioners in the building using a Genetic Algorithm optimizer. Rigorous effort was done to get an accurate relationship between the comfortable time spans and the average temperatures to ensure the users’ convenience with considering their willingness to exceed the pre-selected optimized time span. Nineteen scenarios over 6 months have attained an average saving of 12.5%, which leads to a payback period of 9.27 years. The second approach is by ThermaCote® building insulation, which attains 38% cost savings with a combined payback period of 19.16 years, including external replacement. Although the existing photovoltaic system supplies a considerable free energy proportion and reduces the billing cost, the proposed two methods have improved the normalized performance indicator from the “fair” range in the existing situation to the “good” range.

Keywords Energy auditing · Normalized performance indicator · Energy conservation · Genetic algorithm · Optimization · ThermaCote®

Abbreviations

ACs Air conditioners
CDD Cooling degree days
GA Genetic algorithms
HDD Heating degree days
NPI Normalized performance indicators
PSUT Princess Sumaya University for Technology

Symbols

\( C_i \) Cost function
\( H_i \) Operating hours

\( H_{ACs size} \) Operating hours of a group of ACs of a unified size
\( H_{total} \) Summation of total operating hours

\( \alpha_i, \beta_i, \gamma_i \) Parameters of the cost functions

Introduction

Background and Motivation

Energy auditing has increasingly become one of the leading services provided by energy companies to the consumers in order to evaluate strategic efficiency improvements and identify considerable energy savings (Yang and Yu 2015). Globally, this can be also very useful from many well-known important perspectives: (1) lower cost of consumption for the consumers or the owners of the buildings, (2) cleaner environment due to reduction in emissions of conventional generation, and (3) improved transmission capacities in the grid due to lowered transmitted power to the consumers. One of the main challenges is to have accurate data sets through understanding of the facility; identifying problems
of excess energy consumption, if any; and formulating a suitable and logical solution. Energy auditing can be comprehensive, targeted, or preliminary (Beggs 2002). Applying direct comprehensive energy auditing can be too detailed, expensive, and time consuming (Kreith and Goswami 2008). Preliminary energy audits are crucial in order to identify the essential problems regarding energy consumption in the building energy and suggest practical solutions and this can be usually done without the need to undergo detailed energy audits (Beggs 2002). From intensive readings in this field of study, the processes of energy auditing and conservation reports have become deeply understood, which can be summarized as shown in Fig. 1. This figure shows the simplified or preliminary strategy of auditing using normalized performance indicator (NPI). The NPI is a unified approach for building assessment according to its type (educational, commercial, industrial...etc.). It avoids using the direct numeric value of energy consumption, as similar types of buildings may have different users or occupants, may have different floor areas, or may have different weather conditions. The proposed method of NPI is a unified number range that indicates poor, fair, or good performance of similar types of buildings but having different conditions.

It is better to elaborate on the background of the topic of energy auditing and conservation and their cognitive domains to recognize their multidisciplinary nature and outcomes. Figure 2 shows the multidisciplinary tendency of the paper topic with emphasis on some useful outcomes of this research and its positive impact on the economy and environment. The research in energy auditing and conservation may be initiated by a center in one engineering discipline with interdisciplinary collaborations with other programs, but the research outcomes and usefulness go beyond the boarders of any one of these disciplines alone.

Students and researchers in the above educational programs should upgrade their knowledge in the overlapping

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Fig. 1 The proposed research methodology

[Diagram showing the proposed research methodology with steps such as Site Visits, Data Collection, and Analysis, Building Performance Evaluating and Delivering the Audit Report, and decision points for Poor NPI, Fair NPI, and Good NPI leading to different outcomes like Masssive energy savings must be achieved, Considerable energy savings are still doable, and Some energy savings methods still seem to be possible.]
region between those disciplines in order to attain the dual advantage of inexpensive methodology and the corresponding reasonably acceptable results for both energy auditing and energy saving solutions. It is necessary to revise the methodologies published for the aims of building energy auditing and conservation, which are discussed in the next subsection.

Related Work

The variety of some recent published articles on different buildings confirms the interdisciplinary nature of this research area in demanding different disciplines of engineering and artificial intelligence (Veiga et al. 2021). The literature has shown variety of auditing methods and energy conservation approaches with emphasis on novel concepts and building characteristics. Al-Saadi (2021) have diagnosed the building’s operation deficiency via multi-phase energy audits and have suggested pragmatic retrofitting strategies. Rodriguez et al. (2021) have rather focused on the uncertainty in audit estimations; which has been handled via the Morris method of sensitivity analysis. Al-janabi et al. (2019) have presented novel information concerning the computational and modeling capabilities of two—widely used—building performance simulators. Osorio et al. (2022) have presented the direction of research followed by two private higher education institutes in Columbia for carbon neutrality. It has been concluded that higher education institutes not only can contribute to carbon neutrality but also can ensure sufficient cultural awareness of sustainability for their graduates. Nadimuthu and Victor (2021) have improved the energy efficiency of medicine manufacturing unit via a smart energy management system. Ascione et al. (2017) have presented retrofitting of energy in educational buildings with application to Italian universities. The energy retrofit measures have taken into account all levers of energy efficiency in buildings, such as building envelopes and photovoltaic generation. Multi-objective genetic algorithms have been used as an optimizer to select optimal packages of energy retrofit measures by minimizing thermal energy demand for space heating and coupled with EnergyPlus software for transient building energy simulations. Foroughi et al. (2021) proposed an optimization model using genetic algorithms (GA), which is coupled with the EnergyPlus software package in order to obtain the optimum window-to-wall ratio (WWR), aspect ratio, and window locations in commercial buildings in the USA. Wang et al. (2017) have proposed a MILP (mixed integer linear programming)-based approach to schedule a group of interruptible air-conditioning loads in order to relieve the uncertainties of some stochastic variables, such as wind power and ambient temperatures, which eventually improve the wind power utilization and reduce the operational costs. Belany et al. (2021) have dealt with the possible lighting retrofit and with directed economic analysis for the sake of increasing the energy efficiency of buildings by LED lighting systems. The accuracy of the retrofitted lighting systems has been validated. López-Ochoa et al. (2019) have explored the possible improvement solutions for some educational buildings in Spain with the aid of some reported Technical Building Codes published by the Spanish Ministry of Development. Twelve proposals have been presented for realizing nearly zero-energy educational buildings. More sophisticated audits are doable by regression and uncertainty analytics, which have shown accurate performance for modeling or prediction of building energy consumption (Mottahedia et al. 2015). Conventional regression modeling for building energy estimation has been investigated via three models with data classifications for performance improvements (Ridwana et al. 2020). A detailed review of uncertainty analysis in building energy assessment has been published (Tian et al. 2018). The review concludes with some possible future directions for a more suitable and rigorous uncertainty analysis of building energy. Lucchi (2018) has critically reviewed the visualization method that uses infrared thermography as applications of auditing the building energy consumption, where the applications have presented standard and detailed energy audits through detection of excessive heat walls and testing building insulations. Energy audit for a University building has been reported in Leiva et al. (2018), which has been done by investigating the influences of the individual loads on the total consumption without proposing energy conservation solutions. Lucchi
and Delera (2020) have presented an educational experience of social housing in the San Siro neighborhood in Milan, for refurbishment and improvements of buildings’ sustainability, users’ comfort, and energy efficiencies. The wide range of understandable knowledge of the local situation in terms of the economy and society of that area stimulate the selection

. Castrillón-Mendoza et al. (2020) have described the implementation of a photovoltaic (PV) system at the building of Autónoma of Occidente University by investigating the system outcomes through the building energy consumption post PV installation. It is now clearly realized that the literature has shown a wide-range, cumulative, and appreciated effort that lead to affirmative advancements in the field of building energy auditing and conservation by a combination of simple, multidisciplinary, and complicated methods. However, educational buildings still lack detailed and systematic studies, the scientific contribution of this paper is described in the next subsection. There are common bottlenecks in implementing promising energy auditing methods in educational buildings, such as lack of data, financial barriers, and traditional cultural awareness. However, the proposed method in our paper is as simple as it can be conducted by engineering B.Sc. level of students to evaluate the building performance and suggest potential energy savings, thereby avoiding detailed or expensive energy audits that involve, for instance, computational fluid dynamics (CFD) simulations or infrared thermography extensive accurate diagnosis and assessments.

The Paper Contributions

This paper presents a simplified and validated approach for energy auditing that can be followed by engineers and new graduates of engineering with a thorough understanding of the concept. This proposed preliminary auditing, which is based on NPI, is effective to diagnose the main issues that cause excess energy consumption in the building and it has not been considered in many papers. To the best of the authors’ knowledge and comprehension, it is highly desirable to present a low-cost and direct methodology for energy auditing and conservation for educational buildings with the available data and resources, which eliminates the necessity of having expensive and complex simulation packages to simulate the energy flows, or requires major changes in the building. Therefore, the main novel contributions of this article are:

1. A simple and cost-effective method for energy auditing has been conducted on the building of Princess Sumaya University for Technology. The method is based on calculating the Normalized performance indicators (Beggs 2002). The novelty of the contribution is that of the method has been simple enough to be applied by undergraduate engineering students to their University building. This is uncommon in the literature, in which the audits are mostly based on complex energy simulations and expensive software packages that are commonly used by utilities of energy auditing. The NPI computational model of the building has been developed via MATLAB software and Excel formulas that use the monthly electricity bills of 2019 and other relevant data such as the cooling degree days (CDD) and heating degree days (HDD) of the building. It is intended to use the bills of 2019 although other more recent bills are available because that year is the latest year where the building was full of students and their professors before the COVID-19 crises that motivate distance teaching and learning. Overall, the building NPI, with the inclusion of the installed PV system, is found to be within the fair range. Nevertheless, the building still has some remaining opportunities for energy savings. The building per se is still inherently inefficient because it has been just partially supplied by the external free renewable source (The PV system) of energy, but without genuine improvements in the building energy per se, and this motivates the 2nd contribution.

2. Two proposed techniques for energy conservation are suggested based on the analysis of the aforementioned NPI computational model and those energy conservation techniques have made significant improvements in the building energy savings over the existing energy situation of the building. One method is based on using a GA optimizer for optimizing the ACs’ operating hours within the working day time window and grouping the ACs according to their sizes. By studying the financial consequences of the practical implementation of the ACs’ optimizer in the building, it has been found that the system is economically viable with around 9.27 years payback period of the proposed practical control circuitry. The second energy conservation, which saves around 38% of the consumed energy, is by building envelop based on ThermaCote® insulation, with an estimated overall payback period of 19 years, including external replacement. The improvements in the energy consumption have been confirmed by the NPI computation after application of those methods, the NPI has shown that both methods are capable to transfer the NPI from the “fair” range to the “good” range, which indicates genuine improvement in the building energy performance.

The rest of the paper is organized as follows: “Materials and Methods” presents the building description and the
required weather data the monthly energy consumption data. “The Building Performance Indication via NPI” presents the NPI calculations, “Proposed Techniques for Improvements in the Building Energy Consumption” illustrates the two proposed techniques for energy savings with their payback periods for practical installation, and finally, “Conclusions” states the conclusions and future recommendations.

**Materials and Methods**

The case under study is Princess Sumaya University for Technology (PSUT) located at Amman in Jordan, where preliminary energy auditing has been conducted, which is dedicated to the whole building performance assessment. The PSUT building facility is shown in Fig. 3, which has six main buildings: King Abdullah II School of Engineering, King Hussein School of Computer Science, King Talal School of Business Technology, King Abdullah I School of Graduate Studies and Scientific Research, Deanship of Admission and Registration, Presidency of the University, Deanship of Students’ Affairs, and Al-Hassan Library. Some of these buildings are attached to each other, which gives the possibility of feeding those connected buildings from one meter.

The electrical energy bills for the year 2019 have been provided by the Financial Department at the University. The monthly bills for the fuel and electricity have been intentionally adopted for building assessment because they clarify the most recent informative data before the COVID-19 crises, which led to online teaching and learning in 2020 and 2021 and no significant energy consumption in the PSUT building. Because some of these buildings are physically connected, the total number of meters in the building is only four, which supply the whole University campus with electrical energy. Two of the total meters are connected to the PV system as energy supplied to the grid was present in some of their bills. The university has been thus treated as one facility as some individual meters cover more than one building. The analysis requires the energy consumed from the grid as it reflects the loads; therefore, summation of this energy from the four meters data was done for each month as shown in Table 1.

Energy auditing requires studying the total consumption of the building. Consequently, the energy produced by the PV system is needed in order to know the actual electrical energy consumption of the building which reflects the actual loads. The data set for PV energy contributions has been provided and is shown in Table 2.

The NPI is calculated by the net energy consumed by the building from the grid and the total gross one, which is consumed by the building that includes the PV. Thereby, the calculated NPIs in both cases altogether have avoided a likely misleading picture for building performance and diagnosis if only one of them is considered. As a result, the field can be opened for many alternative methods for inherent improvements of the building towards lower net energy consumption rather than just supplying partially with PV or other renewable resources, which has no ingrained effect on the building consumption. The total electrical energy consumed can be calculated using the energy produced by the PV system and the electrical energy bills simply as follows:
1. Find the sum of the energy consumed from the grid (kWh) from the provided bills.

2. Find the sum of the energy delivered to the grid (kWh) from the provided bills.

3. Energy consumed from the PV system
   \[ \text{Energy consumed from the PV system} = \text{Energy produced by the PV} - \text{energy delivered to the grid} \]  

4. Total energy consumed
   \[ \text{Total energy consumed} = \text{Energy consumed from the PV} + \text{energy consumed from the grid} \]  

The steps described above have been done for all months. It is specified on the bills that the tariff for the university is “Governmental”, this corresponds to the Regular Subscribers Tariff, which is an increasing block tariff as shown in Table 3.

Another approach to find the tariff is by using the billed energy consumption and the total cost to take all costs into account, from the bills available, as follows:

\[
\text{Tariff} \left( \frac{\text{JOD}}{\text{kWh}} \right) = \frac{\text{Total cost (JOD)}}{\text{Billed energy consumption (kWh)}} \rightarrow \text{factor} 
\]

(3)

The tariff using this equation has been calculated. Then, the cost of the billed energy has been calculated using both tariffs; the factor and table, to check which one is more consistent with the cost on the bills since the cost may be affected by a certain block more than the other. The most accurate tariff is chosen for the study. The energy from all sources should be considered; therefore, the fuel energy is essential for the study. Five fuel bills were provided that show the fuel consumption in liters and equivalent cost. This data is shown in Table 4. According to reference Kolb and Siegemund (2017), 1 L of diesel fuel contains 10 kWh of energy. Therefore, the energy consumption of the fuel was calculated as follows:

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**Table 1** Energy consumed— from grid

| Meter number | 20166001920 | 20164004411 | 20164004217 | 20166001926 | Total/month |
|--------------|-------------|-------------|-------------|-------------|-------------|
| January      | 13452       | 5223        | 7626        | 7309        | 26301       |
| February     | 6941        | 4777        | 6698        | 6552        | 18416       |
| March        | 9402        | 11263       | 5581        | 5642        | 26246       |
| April        | 3922        | 5861        | 5047        | 5206        | 9783        |
| May          | 4125        | 5271        | 4812        | 1028        | 15236       |
| June         | 336         | 5110        | 2186        | 2874        | 10506       |
| July         | 205         | 3129        | 1824        | 5199        | 10357       |
| August       | 4017        | 6529        | 6224        | 2555        | 15308       |
| September    | 5563        | 7862        | 2895        | 3452        | 19772       |
| October      | 104         | 4219        | 6243        | 4573        | 15139       |
| November     | 3280        | 5893        | 5046        | 5796        | 20015       |
| December     | 5288        | 5261        | 5066        | 8319        | 23934       |
| Total/meter  | 52618       | 70398       | 54201       | 33796       | 211013      |

**Table 2** PV system generation data

| Date/time     | Generated energy (kWh) |
|---------------|------------------------|
| 1/1/2019 0:00 | 53537.29               |
| 2/1/2019 0:00 | 54007.45               |
| 3/1/2019 0:00 | 71397.69               |
| 4/1/2019 0:00 | 86611.81               |
| 5/1/2019 0:00 | 102526.48              |
| 6/1/2019 0:00 | 104017.23              |
| 7/1/2019 0:00 | 109760.07              |
| 8/1/2019 0:00 | 101538.43              |
| 9/1/2019 0:00 | 88804.79               |
| 10/1/2019 0:00| 76059.23               |
| 11/1/2019 0:00| 63441.44               |
| 12/1/2019 0:00| 45421.31               |
| Total         | 957123.26              |

**Table 3** Tariff structure

| Consumption (kWh) | Lower bound | Upper bound | Tariff (JOD/kWh) |
|-------------------|-------------|-------------|-----------------|
| 1                 | 160         |             | 0.04            |
| 161               | 300         |             | 0.09            |
| 301               | 500         |             | 0.109           |
| 501               | 600         |             | 0.145           |
| 601               | 750         |             | 0.169           |
| 751               | 1000        |             | 0.19            |
| 1001              | –           |             | 0.256           |
Table 4 The fuel bills

| Bill number | Quantity (liter) | Cost (Fils/Liter) | Fuel cost (JOD) | Building(s) | Date       |
|-------------|-----------------|-------------------|----------------|-------------|------------|
| 1           | 15000           | 567               | 8505           | Multiple    | 14/1/2019  |
| 2           | 12000           | 567               | 6804           | Multiple    | 11/2/2019  |
| 3           | 11060           | 607               | 6713.42        | Multiple    | 7/3/2019   |
| 4           | 4975            | 617               | 3069.575       | IT          | 22/4/2019  |
| 5           | 11734           | 602               | 7063.868       | Multiple    | 24/11/2019 |
| **Total**   | **54769**       | **-**             | **32155.863**  | **-**       | **-**      |

\[
\text{Diesel energy (kWh)} = \text{Diesel (liter)} \times 10 \left(\frac{\text{kWh/Litre}}{\text{Litre}}\right) \tag{4}
\]

The building energy data has been summarized as two pie charts in Fig. 4a and b.

Unfortunately, the detailed equipment utilization is not provided for technical reasons; however, it is not quite necessary for NPI calculation and/or suggesting new energy-saving techniques. The equipment utilization is requested in case of detailed and comprehensive energy audits, which is intended in our study. In our study, it has intended to use simplified auditing techniques to prove the ability of engineering students to conduct such audits without expensive or complicated computations and provision of enormous data.

The Building Performance Indication via NPI

This is the analysis technique used to evaluate the energy consumption of the university. Based on the book followed in Beggs (2002), if the building is air-conditioned, then the energy consumed for space cooling should be calculated, corrected, and then used to find the NPI of the building. However, in this study, the energy consumed for space heating has been also calculated and corrected to achieve more accurate results since it is estimated to be approximately 32.5% of the total energy consumed, that is, the diesel fuel energy over the total energy. The building efficiency is assessed in the following subsection.

NPI Calculations

The process of calculating the NPI is clarified through the work-flow diagram shown in Fig. 5, where step 1 is for the Corrected space cooling energy consumption, step 2 is for Corrected space heating energy consumption, step 3 is for the Corrected total energy consumption, and finally step 4 is for calculating the NPI. The NPI method is detailed in the text (Beggs 2002).

NPI Input Data

The data inputs needed for the NPI calculation are the total energy consumed, degree-day data, the total AC energy consumed, the hours of use in the building, the exposure
coefficient, and the total floor area. These requirements are briefly explained in the following subsections.

**The Total Energy Consumed in the Building**

It is calculated using the electrical energy from the bills and PV system as already explained, and the energy from the fuel. Both energy sources are expressed in the same unit, kWh. The energy of the fuel is multiplied by 0.75 since this is the proportion of the fuel used for space heating (Beggs 2002).

**Degree days**

The cooling and heating degree days, CDD and HDD, respectively, are needed to find the standard and actual CDD and HDD to calculate the weather coefficients.

**Standard CDD and HDD** The average CDD and HDD have been downloaded from the widely used website reference (BizEE website 2022) for the base temperature 18 °C. The average is based on the past 5 years; 2016–2020 with an average uncertainty of 0.208% for both CDD and HDD. This average is used as the standard CDD and HDD of the building.

**Actual CDD and HDD** The daily CDD and HDD for the year 2019 were also downloaded from the same widely used reference (BizEE website 2022), for the same base temperature of 18 °C, and have an average uncertainty of 0.0657%. Then, the CDD and HDD of the weekends, Fridays and Saturdays, and the holidays based on PSUT’s academic calendar for the year 2019 have been excluded in calculating the actual CDD and HDD for the building.

This data was downloaded from the station Amman Airport, JO (35.99E, 31.97N) since it was the closest to PSUT’s location which is (35.88E, 32.02N). The base was chosen to be 18 °C for two reasons:

1. The work reported in (Almuhtady et al. 2019) explains that this base is usually used for the past 30 years based on Jordan’s climate.
2. According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers ASHRAE 55, the indoor comfort temperature is around 22 or 23 °C, which is consistent with the chosen base taking the indoor heat sources and Jordan’s climate into consideration, refer to the reference (ASHRAE. 2017).

To ensure logical results, the CDD data was also downloaded for base temperatures 15.5 °C and 20 °C, which gave much higher and lower values compared with base 18 °C, respectively.

**Total air conditioner AC energy consumed**

**Air Conditioner AC Data** The sizes of the air conditioners present in PSUT along with the number of each size were provided as shown in Table 5. It shows that the total AC power for PSUT 578.5 kW.

**AC energy consumed for cooling and heating** The total AC energy consumed can be estimated by either assuming a percentage of the total energy based on a study already done on a similar building with a similar climate, or by calculating an approximate based on relevant data. The second approach was done as follows: Using the daily actual degree days DD data, the number of days per month for which the DD is more than 1.5 was calculated in order to exclude days with DD of 0.1. Then, the sum of CDD days for each month was found to know how many days cooling is needed each month. Similarly, the HDD days per month were found. The number of operating hours of ACs is influenced by many factors, such as weather temperature, users’ willingness, and comfort. However, the total operational hours can be reasonably assumed to be linked with either the CDD or a forecasted dry-bulb temperature in order to optimally decide the most economical operating hours for each size of the ACs.

The number of hours per day for which the AC is on for both cooling and heating was assumed with the best reasoning known.

The total power of all AC sizes has been calculated; assuming 1 kW/1 ton is drawn as a rule of thumb. Therefore, using these 3 parameters, the consumption was calculated through Eqs. (17)–(18):

\[
\frac{AC \ consumption \ (kWh)}{Month} = \frac{Total \ AC \ power \ (kW)}{Month} \times \frac{Relevant \ days}{Month} \times \frac{Assumed \ hours}{Day} \quad (5)
\]

\[
Annual \ AC \ consumption \ (kWh) = \sum_{Month} \frac{AC \ consumption}{Month} \times \text{of \ the \ relevant \ months} \quad (6)
\]

Since we are dealing with an educational building, it can be reasonable to estimate ACs operating hours per working day. The assumptions are mentioned in Table 6.

**Hours of Use**

The standard hours of use per year are 4250 (Beggs 2002) to be able to compare the NPI with the yardsticks. The actual hours of use per year were calculated by assuming 8 working hours per day, excluding the weekends; Fridays and Saturdays, and the holidays based on PSUT’s academic calendar of 2019. Similarly, the days of use have been calculated.

**Total Area**

The area of each floor for all buildings of PSUT was provided. The net internal area for each floor for all buildings has been added to find the total floor area of the building, which is needed for the NPI. The average area for each building was found by finding the average of all floors for each building. Then, the total ground area by finding the summation of the average area for all buildings. Also, the total floor area is approximately found using the following relation:

\[
\text{Total \ floor \ area} \ (m^2) = \text{Total \ ground \ area} \ (m^2) \times \text{Number \ of \ floors} \quad (7)
\]

**NPI Results**

The NPI has been calculated for different cases in order to find the most logical and accurate result. Figures 6 and 7 show the input and output as depicted from the developed NPI excel calculator sheet, respectively.

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**Table 5** AC data provided. Rule of thumb: 1 ton consumes 1 kW

| Number | Size (ton) | Power (kW) |
|--------|-----------|------------|
| The PSUT building ACs | 96 | 1 | 96 |
| | 90 | 1.5 | 135 |
| | 160 | 2 | 320 |
| | 11 | 2.5 | 27.5 |
| Total | 357 | – | 578.5 |

**Table 6** AC hours/day assumptions

| Season | Hours/day — total energy consumed (PV + electricity bills) | Hours/day — energy consumed from grid only (electricity bills) |
|--------|-----------------------------------------------------------|---------------------------------------------------------------|
| Cooling [May–Oct] | 6 | 2 |
| Heating [Nov–April] | 2 | 2 |
Proposed Techniques for Improvements in the Building Energy Consumption

In this section, the energy conservation methods for building consumption improvements are introduced. Although the building energy is largely covered by the PV system, especially in the summer season, it has been found that the building is inherently still not efficient and some energy conservation strategies must be applied to reduce its gross energy consumption. The PV system acts like an external free source and has no ingrained effect on the building consumption. To avoid any possible misleading pictures on the building efficiency, two energy conservation principles have been proposed, one is based on GA to optimally schedule the operating time span for all air conditioners according to the forecasted temperature or the predicted CDD from historical data. The reason for selecting air conditioners’ circuit rather than lighting or computer can be justified through basic inspection of the rating of the devices in the building, which obviously has shown that the air conditioners are the highest energy-consuming devices in the building. The time windows of operation for each size-grouped air conditioners are decided in advance with free desire of the users to switch on/off. The assumptions have included many operating optimal scenarios produced by GA that have been compared with other hypothetical scenarios with average cost savings of around 12.5% of the total cost per year with 9.27 years payback period. The second method is by proposing a building envelop of ThermaCote® that attains further 38% cost savings per year with a combined payback period of 19.16 years. It is noticed that the latter can be relatively longer to recover; however, this payback period is combined after the applications of the PV system and the GA air-conditioning optimizer, and even so, it can be comparable to other buildings with other energy investment projects for other buildings (Zhang et al. 2021). Overall, this is certainly useful environmentally and economically with reasonably acceptable payback periods for educational buildings due to their sustainability for several decades to come. The next subsections describe the proposed energy conservation with their investment analysis.
The Genetic Algorithm Optimizer

Genetic Algorithm is a well-known meta-heuristic optimization technique that represents a class of artificial intelligence. Because it was inspired by the Darwinian theorem, it follows the mechanism of natural selection, but in a mathematical and iterative fashion. The surviving parameters produce the best fit which evolves towards the global optimal solution by three main actions: reproduction, crossover, and mutation, which are applied in each generation of parameters. Every action has specific settings in order to obtain—or accelerate—the solution. It has been shown that GA is a rigorous optimization technique that is capable of resolving many highly complex and practical optimization problems, such as parameter identification of coal mills (Guo et al. 2014) and modeling energy-efficient supercritical power plants (Mohamed et al. 2011). The simplified schematic for GA is shown in Fig. 8. The idea is mathematically based on the fact that there are infinitely set of operating hours of the AC groups that could satisfy the consumers, according to the daily expected average temperature, with different costs of consumption; nevertheless, there is an optimal choice among all these sets that make the cost minimum which corresponds to minimum energy consumption.

The objective function to be minimized for a unified size group of ACs is assumed to be a quadratic cost function and the optimization problem can be mathematically described through Eqs. (7)–(10)

\[ C_i = \sum_{n=1}^{1.5, 2, 2.5} a_i + \beta_i + H_i + \gamma_i + H_i^2 \]  
(8)

Subject to the following equality and inequality constraints

\[ H_{\text{min}} \leq H_i \leq H_{\text{max}} \]  
(9)

\[ \sum H_i = H_{\text{total}} \]  
(10)

where \( H_i \) is the scheduled operating hours for a group of ACs that have the same size; these scheduled hours are to be optimally found by GA to minimize the total cost \( C_i \) of electricity. The coefficients \( a_i, \beta_i, \gamma_i \) are simply determined by a curve fitting tool either in MATLAB or Microsoft excel. The curves are built by the relationship of the CDD or average temperature with the operating hours of a group of ACs. \( H_{\text{total}} \) has been considered equality constraint, which is the summation of total operating hours for the groups of ACs predetermined either by the forecasted average temperature or the CDD on a working day. It can be alternatively represented by the operating hours of the ACs in the offices, the classrooms, and the stadiums. The inequality constraints are adjusted to fit the working day hours to allow maximum flexibility for the AC user. After using determining the coefficients of the cost function of each group, they have been recognized by the GA optimizer as an M-File representing the objective function. Many scenarios were tested; nonetheless, the most satisfactory results are obtained with population-type double vector, population size of 50, heuristic crossover, Gaussian mutation function, and mutation rate of 0.1.

Sizes, Quantities, and Rooms of Air conditioners

In the data collection phase of the audit, it has been given that there are 4 AC sizes, distributed in 4 types of rooms as in Table 7.

The power of each size is calculated using Eq. (11), assuming that (1 ton = 1kW):

\[ \text{Power [kW]} = \text{size [ton]} \times \text{quantity} \]  
(12)
In order to optimize the system, the number of operating hours for each size of the 4 AC sizes must be bounded. The bounding criterion is decided according to the daily average temperature in summer, in which the maximum daily average temperature corresponds to the full working-day hours and the minimum average temperature corresponds to the minimum hours, which are selected to be two hours for the offices and classrooms. The number of operating hours boundaries for each room type have been assumed logically depending on the occupancy trends for each room type in PSUT, two cases were studied as follows:

1) The first case was that all air conditioner sizes had the same lower and upper bounds which are 2–7 h/day.
2) The second case was to keep the first 3 sizes with the same 2–7 h/day boundary and reduce the boundary of the 4th size to 0–3 h/day.

The lower and upper bounds are assumed according to the most guessed users’ activity during the daily working hours of the building. The credit hours of the largest air conditioners are actually low even on the hottest days because they are installed in auditoriums and corridors where the occupancy rate is very low, especially the auditoriums where the activities are only the invited talks and non-scheduled lectures that may happen once every week throughout the academic year. In addition, the two assumed cases have been extensively tested for many simulation scenarios for the proposed automatic energy conservation via GA and the results were more consistent when applying the constraints in case 2. It also is important to mention that, the automation of the proposed design of the practical control system, which is described in the next subsection, allows flexibility of the user to exceed the time span decided by the GA optimizer if needed or even switch off the AC, but the GA optimizer controls the ACs operation hours instructively and automatically. Therefore, the savings can be economically viable as average cost savings after many days of operation of this optimal strategy in comparison to other hypothetical cases on the same number of days where the GA optimizer and the proposed smart system do not work.

A curve fitting tool has been used to develop the cost equations for each AC size so we have four quadratic cost equations representing the time-span of the operating hours of each grouped size. The daily data of the cooling degree days of Amman between May and October is obtained. Considering 18 °C as the base temperature, the maximum and minimum number of operating hours assumed for PSUT which are equal to 24 and 6 hr./day, respectively. The 0 h/day is assigned to the base temperature, i.e., where no cooling is needed. It is logical to relate the daily operating hours to the forecasted daily average temperature using historical data, which was calculated using the CDD as follows:

$$\text{Average temperature} = \text{Base temperature} + \text{CDD}$$  \hfill (13)  

Note that the minimum CDD is 1.5 DD even if smaller CDD are available because this is the minimum CDD value to consider cooling on that day. The next subsection shows the practical automation system, cost savings associated with GA, and the payback period.

### The Proposed Practical GA Optimizer

The Genetic Algorithm method is a proposed energy conservation system that needs a reasonably acceptable budget to implement. The practical implementation of the Genetic Algorithm method of optimizing the number of daily operating hours for each size of the air-conditioning system is done using a smart system which is responsible for all the air conditioners in PSUT. This computerized smart system should be connected to all the air conditioner switches in the facility. Figure 9 depicts the proposed practical automation system for more economical operation of the ACs. In order to do this, the following components are needed:

1. Centralized smart computer (1 item).
2. Thermostats—one for each air conditioner (357 items).
3. Timer switches—one for each air conditioner (357 items).
4. D/A converters or Arduino—one for each air conditioner group with the same size (4 items).

To implement this system, specialists in the field of smart systems are needed. Also, a long time and a budget are needed in order to purchase these components. As mentioned earlier in the abstract, in some cases, the user’s remote control may bypass this automation circuitry to switch ON/OFF the AC in his/her room; however, such

### Table 7 Air conditioner data for PSUT

| Room type                                      | Size [ton] | Quantity | Power [kW] |
|-----------------------------------------------|------------|----------|------------|
| Offices                                       | 1          | 96       | 96         |
| Classroom                                     | 1.5        | 90       | 135        |
| Bigger rooms, auditoriums, and corridors 1    | 2          | 160      | 320        |
| Bigger rooms, auditoriums, and corridors 2    | 2.5        | 11       | 27.5       |

The Bounds of Operating Hours and Practical Correlations

In order to optimize the system, the number of operating hours for each size of the 4 AC sizes must be bounded. The bounding criterion is decided according to the daily average temperature in summer, in which the maximum daily average temperature corresponds to the full working-day hours and the minimum average temperature corresponds to the minimum hours, which are selected to be two hours for the offices and classrooms. The number of operating hours boundaries for each room type have been assumed logically depending on the occupancy trends for each room type in PSUT, two cases were studied as follows:

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To implement this system, specialists in the field of smart systems are needed. Also, a long time and a budget are needed in order to purchase these components. As mentioned earlier in the abstract, in some cases, the user’s remote control may bypass this automation circuitry to switch ON/OFF the AC in his/her room; however, such
cases are not dominant, and therefore, they have trivial effects on the overall intelligent decision for this large number of ACs because of the following reasons:

1) The operating hours are decided overall by the GA optimizer for the large number of ACs within boundaries of practical time spans that are rooted in the average temperature and the CDD; therefore, any slight mismatches result in near-optimal decisions, which is also economical. If the mismatch is due to switching off, then that can be more optimal, if it is due to exceeding some few time spans, then it is a near-optimal decision.

Table 8 The control system components, quantity for each component, and price

| Component                  | Quantity | Price [JOD/unit] |
|---------------------------|----------|-----------------|
| Centralized smart computer| 1        | 2800            |
| Thermostats               | 357      | 15x357          |
| Timer switches            | 357      | 20 x357         |
| D/A converters/Arduino    | 4        | 44 x4           |
| Installation              | –        | 1000            |
| Total cost (investment)   |          | 16471           |

Table 9 Savings percentage in comparison to other hypothetical cases

| Assumption | Total operating hours (hours/day) | Savings percentage (%) |
|------------|----------------------------------|------------------------|
| 1 (maximum CDD) | 24                           | 0                      |
| 2          | 23                               | 0.003                  |
| 3          | 22                               | 8.14                   |
| 4          | 21                               | 5.85                   |
| 5          | 20                               | 9.92                   |
| 6          | 19                               | 18.08                  |
| 7          | 18                               | 18.98                  |
| 8          | 17                               | 21.16                  |
| 9          | 16                               | 5.255                  |
| 10         | 15                               | 4.16                   |
| 11         | 14                               | 14.97                  |
| 12         | 13                               | 13.94                  |
| 13         | 12                               | 12.74                  |
| 14         | 11                               | 26.94                  |
| 15         | 10                               | 23.81                  |
| 16         | 9                                | 28.34                  |
| 17         | 8                                | 13.20                  |
| 18         | 7                                | 11.66                  |
| 19 (minimum CDD)         | 6                                | 0                      |
| Average     |                                 | 12.5 %                 |
The proposed controller has been designed and tested in the worst cases, in which all ACs are turned ON and compared against many hypothetical cases with considerable average cost savings. Therefore, the success of this strategy is clarified by the fact that the cost savings are calculated over many days of operation, not necessarily per-day cost saving.

In the suggested design, 357 timer switches are used, one for each AC, or an advanced multiple-device programmable timer switches may be used, with less number of required items. The time span for each grouped size ACs is calculated as follows

\[ \text{Time span for each size} = \text{No. of ACs} \times \text{optimal daily hours from the GA} \]  

(14)

It is also expected that the practical installation should reveal some needs for calibrations either on the data inputs or the scheduling limits; however, the overall investment, cost savings, apparatus used, and payback period is comparable with the calculated one in the next subsection.

The Controller Economic Analysis

An economic analysis is done to ensure the feasibility of the proposed control system. Table 8 summarizes the components needed, quantity of each component, and estimated prices. The prices are estimated by surfing many national and international websites for marketing embedded systems, but the prices are mentioned in JOD. This strategy of ACs control is designed for cooling purposes. Thus, the assumption for the air-conditioning usage period is from May to October. Many hypothetical assumptions have been assumed (Table 9).

These hypothetical cases are calculated to take advantage of the average cost savings, in order to compare with the optimal near-optimal decisions of the GA controller and it is not recommended to mention the details of all of them here; however, one sample achieved saving in someday is mentioned in Table 10.

The GA method resulted in 12.5% average savings if used in PSUT which are obtained theoretically as shown in Tables 9 and 8; 19 assumptions of different total operating hours have been studied to calculate the most realistic average savings of the GA tool which appears to be 12.5%. The two extreme cases which are the minimum and maximum operating hours which result in 0 savings were taken into consideration when calculating the average savings. The total energy costs before implementing the GA and after the GA with the corresponding savings in JOD are mentioned in Table 11.

Thus, the payback period is calculated using the investment cost and saved cost as follows:

\[ \text{Payback period} = \frac{\text{Investment cost}}{\text{Saved cost}} = 9.27 \text{ years} \]  

(15)

To conclude the analysis, the results above ensure that implementing this control system is feasible and
beneficial for PSUT as it returns its initial cost approximately 9.3 years after the installation, which is acceptable for an educational building. This is the worst payback period due to the largest number of components used; it may range from 5 to 9 years if other approaches are chosen.

**Improvement Reflected on the NPI**

The NPI has been improved since the GA results in 12.5% decrease in energy used for cooling. It was calculated as already explained, but with the following changes since the reduction is only in the cooling energy:

\[
\text{AC energy used for cooling \ post GA} = \text{AC energy used for cooling} \times 0.875
\]

\[
\text{The total electrical energy \ post GA} = \text{The total electrical energy} - (0.125 \times \text{AC energy used for cooling})
\]

The NPI is reduced to 3.59% and is equal to 339.82 kWh/m², which is still in the “fair” range. This is shown in Figs. 10 and 11.

The Building Insulation Method

Proper building insulation reduces both the energy and NPI by 38% according to the product data sheet and presentations of ThermaCote® (ThermaCote® website 2022). Thermacote® Insulation of buildings is a high-performance paint ceramic heat-resistant material that leads to significant energy savings for the building (ThermaCote® website 2022). Hence the actual NPI reaches the “good” range for either case of total energy consumed by the building or excluding the energy shared by the PV system, as shown in Table 12 and Fig. 12. It has saved 301141.16 kWh for the assumed case.

**Economic Analysis Results of the Proposed Energy Conservation Methods**

The results of the economic analysis are shown in Table 13. It is stated that the ThermaCote® product is guaranteed for life for indoor applications, and 10 years for outdoor use (ThermaCote® website 2022). If the total energy is considered, case 1, the payback is 2.89 years which implies the recommendation...
is feasible. However, this is not the actual cost since the energy covered by the PV system is for free now, so this only means that if the insulation was improved before installing the PV system it would have been feasible.

Two scenarios were studied where only the energy from the grid is considered:

1. Using the same investment cost and this gives a payback period of 12.89 years. It is greater than 10 years; however, the insulation is internal and external, so it can be considered feasible. However, to ensure that, maintenance of the external coating should be considered for a longer lifetime.

2. Using the following investment cost:

\[
New\ ThermaCote\ cost = Old\ ThermaCote\ cost + \frac{Old\ Thermacote\ cost}{2}
\]  

That is, the investment cost is 50% higher when assuming the external insulation is replaced which accounts for the worst case of maintenance. This case has shown a lifetime of 20 years, so a payback of 19.33 years is feasible and saves 26451.18 JOD annually. The cost-saving opportunities due to the load shifting concept may exist if the tariff depends on the time, peak, night, or day, or if a penalty on the maximum demand exists. However, this is not applicable for this study since the tariff structure

---

### Table 12 Insulation energy reductions

| Energy consumption case | Electrical energy (kWh) | Fuel energy (kWh) | Total energy (kWh) | Post-insulation total energy (kWh) | Saved energy (kWh) | NPI - pre insulation (kWh/m²) | New NPI—post insulation (kWh/m²) |
|-------------------------|-------------------------|------------------|-------------------|----------------------------------|------------------|-------------------------------|-------------------------------|
| 1 Total energy considered | 1134149.008            | 547690           | 1681839          | 1042740.18                      | 639098.82        | 352.46                        | 218.52                        |
| 2 Only energy from grid considered | 244786.73             | 547690           | 792476.73        | 491335.57                       | 301141.16        | 170.14                        | 105.48                        |

---

Fig. 12 Improvements before and after insulation

---

![Pre and Post-Insulation energy consumption](image1)

![Pre and Post Insulation Normalized Performance Indicators](image2)
is the Regular Subscribers’ tariff which is an increasing block tariff. Consequently, there are no cost-saving opportunities depending on this concept.

### Summary of Combined Improvements

The cost reductions for the GA control and insulation improvements are summarized in Table 14, along with the reduction caused by installing both recommendations.

The payback period if both improvements are done together can also be calculated using Table 14 as follows:

\[
\text{Combined Investment Cost (JOD)} = \text{GA cost} + \text{Insulation cost}
\]

\[
\text{Payback} = \frac{\text{Investment}}{\text{Annual saved cost}} = \frac{528001}{27551.96} = 19.16\,\text{years}
\]

The total energy consumed is considered—improvements

Table 13 Insulation economic analysis

| Energy case       | Electricity cost (JOD) | fuel cost (JOD) | Total cost (JOD) | ThermaCote® cost (JOD) | Annual saved cost (JOD) | Payback |
|-------------------|------------------------|-----------------|------------------|------------------------|------------------------|---------|
| 1 Total energy    | 277949.68              | 32155.9         | 310105.54        | 341020                 | 117840.10              | 2.89    |
| 2 Only energy from grid | 37452.50              | 32155.9         | 69608.37         | 341020                 | 26451.18               | 12.89   |

\[
\text{Combined Annual Saved Cost (JOD)} = \text{Initial cost} - \text{Post GA & insulation cost}
\]

\[
\text{Combined Annual Saved Cost (JOD)} = 69608.37 - 42056.40 = 27551.96
\]

Table 14 Improvement summary over one year of typical actual energy consumption of 2019

| Data                         | Initial | Post GA control | Post insulation | Post GA control and insulation |
|------------------------------|---------|-----------------|-----------------|--------------------------------|
| NPI (kWh/m²)                 | 352.46  | 339.82          | 218.52          | 210.69                         |
| Percentage reduction in NPI (%) | 0   | 3.58            | 38              | 40.22                          |
| Final total energy (kWh)     | 1681839 | 1641922.50      | 1042740.18      | 1017991.95                     |
| Percentage reduction in energy (%) | 0   | 2.37            | 38              | 39.47                          |
| Final total energy cost (JOD) | 69608.37 | 67832.90        | 43157.19        | 42056.40                       |
| Percentage reduction in cost (%) | 0   | 2.55            | 38              | 39.58                          |

| Remarks - case studied       | Output - ThermaCote Insulation |
|------------------------------|--------------------------------|
| AC Consumption               | Space cooling energy consumption (kWh) | Space heating energy consumption (kWh) | CDD Weather Coeff | HDD Weather Coeff | Corrected space cooling energy consumption (kWh) | Corrected space heating energy consumption (kWh) | Corrected heating energy consumption (kWh) | Non-cooling/heat (kWh) | Corrected total energy consumption (kWh) | Hours of use coeff | Normalized annual energy consumption (kWh) | NPI (kWh/m²) |
| Only energy from grid is considered | 43757.74 | 330713.89 | 1.961507 | 1.3629773 | 85831.12 | 450755.52 | 116863.9482 | 653450.5793 | 2.414773 | 1577934.6 | 105.49 |
| Total energy is considered   | 197985.84 | 332148.57 | 1.961507 | 1.3629773 | 388350.6 | 452710.96 | 512605.775 | 1353667.334 | 2.414773 | 3268799 | 218.5297 |

\[
\text{Combined Investment Cost (JOD)} = \text{GA cost} + \text{Insulation cost}
\]

\[
\text{Combined Investment Cost (JOD)} = 16471 + 511530 = 528001
\]

\[
\text{Payback} = \frac{\text{Investment}}{\text{Annual saved cost}} = \frac{528001}{27551.96} = 19.16\,\text{years}
\]

(20)
for many coming decades. The return cycle could be much lower if the PV contribution is not considered; however, it is intended to include the PV contribution as free energy and consider the cost of electricity from the grid, which results in this payback period. As might be a subject of interest to some researchers, the reduction in carbon emission from the contribution of the solar PV system may be mentioned. From the website (Boston Solar Website 2022) as a typical generalized example of the solar PV system may be mentioned. From the website (Boston Solar Website 2022) as a typical generalized example of the solar PV system may be mentioned. From the website (Boston Solar Website 2022) as a typical generalized example of the basic calculation, 1 kWh electricity from solar is equivalent to 0.846 lbs reduction in CO₂ emission or 0.383 kg. By referring to Table 2, 957123.26 kWh is the total annual PV generation from the data of 2019, the year just before the corona crises, which is equivalent to a carbon reduction of 366578.2 kg.

### Conclusions

In this paper, a simplified energy audit has been conducted on the PSUT building, which has targeted the whole building consumption with suggested improvements to the AC system.

The following points present the concluding remarks and findings from the data and results:

- The energy consumed by the PSUT building has been partially covered by a PV system since 2016.
- Energy audits of the building have been conducted via the NPI method, with monthly energy bills of 2019, including the share of the PV system, with the result of fair building performance.
- The reason for choosing the 2019 bills is that it is the last year where it was full of students, professors, and employees, before the COVID-19 crisis that stimulates online classes with no significant energy consumption.
- Although the NPI has shown fair-range performance, two proposed energy conservation methods are proposed, one on optimizing the ACs’ operation times by GA, and the other by building insulation with high-performance ceramic material manufactured by Thermacote.
- The relevant payback periods are calculated and discussed for guaranteed and economically viable performance.
- These approaches have successfully reduced the cost and energy by 12.5 % in the summer and the NPI by 3.59 % in comparison to hypothetical and actual cases. In addition, building insulation developed by a recognized company has been suggested, which has resulted in 38% savings and energy, NPI, and total cost. Both methods cause approximately 40% savings.
- The proposed methods have driven the NPI from the “fair” range to the “good” range according to international standards.

The proposed methods have been evaluated based on the real data of the Jordan climate and the accurate energy consumption of the building, which considers the data of gas and power consumption in addition to the PV power share. This method is much simpler than other detailed energy audits and solutions and comparable in accuracies and outcomes. Other characteristics are best assumed from our experience of the building and search skills, such as the constraints imposed on the working hours of the ACs and the estimated prices for the appliances of the control strategy of ACs. However, every study needs some
potential data besides some sort of logical assumptions so that the study can be realized.

Future recommendations can be stated as follows: The Genetic Algorithm method can be extended for heating purposes during winter alongside the current usage of cooling purposes controlling the operating hours using different codes of GA to account for HDD instead of CDD. This eventually results in further billing cuts. The paper has included the full data and information so that it can be additionally regarded as an educational guide to other future researchers worldwide to conduct such simplified audits, subject to data availability in the building facility or facilities they aim to improve. Further explanations could be published as a critical review article to discuss, for instance, how the proposed NPI method is simple and to what extent other methods are expensive and complicated. The implication of more accurate consumption of the ACs seems to be possible by smart energy meters. Despite the satisfactory performance of the GA optimizer, swarm optimizers may have faster capability for producing the solutions. More walk-through audits could be made to test the building via infrared thermography and thermal examination of the building’s proposed insulator if it is approved and installed. LED lighting replacement with a recent lighting system is another possible future feasibility study. Sophisticated studies can be also suggested to account for emission reduction from building insulation and smart control of air conditioners. Finally, since the PV system covers the highest proportion of energy of 78% of the building consumption, the solar PV system may need extensive studies to be conducted as optimization problems, such as maximum power point tracking (MPPT) and/or Operating and Maintenance Standard Operating Procedures (O&M SOPs). However, the last point requires enormous data and significant amount of research work.

Data Availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of Interest The authors declare no competing interests.

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