

Feasibility Study and Design of Smart Low-Energy Building Electrical Installations (Case Study: Isfahan University, Virtual Faculty Building)

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Abstract — Buildings, particularly office buildings, are major energy consumers and sources of CO₂ emissions, contributing to around one-third of global energy consumption. As a result, energy consumption optimization regulations and the deployment of renewable energy technology in the construction sector has the potential to significantly reduce energy consumption and carbon emissions. This paper describes a comprehensive study on the technical feasibility and design of the electrical equipment of the Isfahan University virtual faculty building project in accordance with Iran's standards and guidelines of low-energy buildings (mostly chapter 19 of the Iranian National Building Regulations). In this case study, relevant designs and calculations were presented in order to accomplish the low-energy construction goals for various portions of the project. The photovoltaic system on the roof provides a part of the building's energy, and the KNX protocol was used to operate the lighting management system, the cooling and heating systems, and to enable intelligent energy management.

As a result, the consumption of the lighting system using high-efficiency LED panels is less than 11 W/m². In order to ensure safety requirements, the main bonding system and ground electrode were designed in accordance with the site characteristics and standard criteria. Low-loss transformers are utilized to power the facility, and a soft starter, a multi-speed control, and a start-up system are used in the utility room. To achieve a minimum power factor of 0.94, a capacitor bank equipped with detuned reactors is employed for reactive power compensation. This paper focuses on the details of this design and the resulting experiences.

Index Terms: low-energy building, renewable energy, optimization of energy consumption, smart building management system.

I. INTRODUCTION

Humans' increasing reliance on energy consumption has raised a number of problems and challenges in the context of sustainable and high-quality energy supply in many countries worldwide. To address these problems and challenges, an effective policy would be to optimize energy consumption patterns and utilize new energy supply technologies, such as renewable energy technology and building management systems. Optimizing energy consumption entails selecting patterns and adopting and implementing methods and policies for correct energy consumption that are desirable from the standpoint of the national economy and ensure the continuity of energy supply and the continuation of daily activities [1].

Renewable energy has experienced significant growth in

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recent decades. Previously seen as unattainable and unconventional, contemporary technologies are now being implemented in various industries as cost-effective solutions to address problems associated with outdated fuel systems and concerns over pollution and expenses. Buildings are the most numerous energy consumers. According to Iranian Students' News Agency (ISNA), around 40% of Iran's energy is consumed within the development sector [2]. Moreover, buildings account for 30% of the worldwide energy consumption and 27% of all harmful emissions [3]. Therefore, optimizing energy consumption policies and expansion of renewable energy technology can have a critical impact on reduction in energy consumption and carbon emissions. In this regard, recent studies have investigated various aspects of low-energy buildings, or, in special cases, zero-energy ones.

A low-energy building is characterized by a design and particular specifications that empower it to supply living benchmarks and consolation with low energy consumption and carbon emissions [4]. Energy-efficient houses mostly have extraordinary designs. For example, their windows are planned to provide the foremost supply of daylight. These buildings can also benefit from intelligent lighting control, cooling and heating systems, as well as energy generation units such as solar air heating, solar water heating, active or passive solar heating to minimize the energy consumption of the building. All over the world, companies and non-profit organizations give guidelines and certifications to guarantee the energy supply to buildings and their processes and materials.

Low-energy buildings with high levels of insulation, effective heating and cooling systems, in combination with renewable energy sources decrease essentially energy demand [5]. Most of rural communities depend intensely on agriculture as their primary source of income. Energy efficiency requirements allow them to supply all benchmarks of living with negligible energy consumption and carbon emissions [6]. Urban zones are regular places with high population density. The buildings of these zones should incorporate features such as a proper thermal insulation, an appropriate control system for ventilation, a suitable size of heating and cooling systems, and the highly energy efficient doors and windows [7].

Since low-energy buildings are an appropriate solution to decrease carbon emissions, different studies have examined the impact of these buildings on a reduction in overall carbon emissions. In [8], the study examines a modern low-energy building within the Tibetan Plateau of

China, which includes a sun powered heat pump system to supply the heating load in winter. The ventilation of the doors and windows of this building is designed to provide the least heating and cooling losses, so that the temperature inside the building is not less than 18°C without utilizing the heating system. The authors claim that this building spares approximately 6 724.3 kg of CO₂ emissions each year. In [9], an idea for planning a multi-energy framework for different low-carbon scenarios in low-energy buildings is introduced. This research considers a wide extent of generation units' technologies, such as gas microturbines and solid oxide fuel cells. The authors believe that the integration of hydrogen-based innovations and storage systems are effective arrangements to substantially cut down energy consumption and carbon emissions. As mentioned earlier, the integration of renewable energy technologies with buildings can foster the accomplishment of goals of low-energy buildings. One of the innovations that are most consistent with the building division is solar systems, including photovoltaic systems integrated with the building, solar air and water heating systems, and passive solar systems.

Similar studies have investigated the utilization of these systems in completely different buildings. The authors in [10] tried to discover the foremost beneficial way to build a photovoltaic system in a residential building in Oman, taking into consideration the local climate, the average monthly energy consumption, and the rates paid by the local electricity company. The average monthly energy consumption of this building is 550 kWh. One of the aspects considered in this study is the intensity of daylight that changes throughout the year. When the intensity of radiation is at its peak and the rate of power generation is at its most noteworthy, a photovoltaic system is considered as a reasonable choice to meet the building's energy needs. In addition, photovoltaic systems, primarily known as rooftop photovoltaic systems, have already been introduced in numerous parts of the world. For most office buildings, however, the rooftop photovoltaic system alone is not sufficient to achieve a low-energy building, since the energy required by offices is normally large and the roof space is restricted. The roof space is also used for other projects. Therefore, using photovoltaic systems integrated with the building structure can be a better option. In this case, any part of the building exposed to sunlight can become a photovoltaic electricity generator, and today there is almost no limit to what this technology can offer to architects and builders [11].

The paper [12] indicates that the use of transparent amorphous silicon solar cells in a building-integrated photovoltaic system reduced energy demand by 33.3% and the use of perovskite-based cells – by 24.5%. Many other advantages of building-integrated photovoltaic systems are listed in [13] and [14]. In addition to photovoltaic systems, many other photovoltaic systems discussed earlier can effortlessly be used in buildings to meet energy demand, especially for heating, ventilation, and air conditioning (HVAC), which account for nearly half of a building's total energy consumption [15]. For example, in [16], authors evaluate the performance of a novel passive air conditioning system using solar stacks, solar water heaters, and phase change materials as a complete air cooling and water heating system in Egypt. The results of this study show that the integration of solar cell stacks and the exchange of phase-change materials with cooling towers significantly decreases the temperature of the space during the day and night. In [17], investigation focuses on the energy consumption and power generation of a heat pump system with variable refrigerant flow and integrated photovoltaic technology in a five-story residential building in Cyprus. The power consumption of the variable refrigerant flow system ranges from 14 005 to 18 710 kWh/y, and the solar power system, with a total output of 13 kWh, can generate 23 200 to 23 650 kWh/y. In fact, photovoltaic systems supply 126 to 166 percent of the annual energy needs of variable refrigerant flow systems. In addition, the installation of the photovoltaic system will reduce CO₂ emissions by approximately 14 ton/y. In [18], the study is concerned with a solar source heat pump system in a low-energy residential building in Xingying, China. This system keeps the average temperature inside the building between 16.13 and 19.61°C. Moreover, the study claims that the solar air source heat pump system can reduce energy consumption by 55.38% compared to the conventional air source heat pump systems. Another part considered in this research is smart building management systems. Recent developments in the field of the Internet of Things (IoT) have led to the development of smart buildings. Management systems based on the IoT play an important role in optimizing smart building operations. The IoT, as a key technology in smart buildings, is essential for connecting embedded objects to sensors and actuators over the internet anytime and anywhere [19]. Depending on the IoT characteristics, an IoT-based smart building management system can deliver different types of information about operational processes, indoor climate,

and user behavior to ensure energy sustainability and efficiency in buildings.

The main objective of [20] is to find key factors that provide decision-makers with an optimal set of adoption strategies for smart building management systems based on the IoT. The main results show that disaster prevention systems and energy management systems for office buildings; environmental monitoring and energy monitoring systems for smart factories are selected by the integrated decision-making model. In addition, the authors highlighted the interrelationship between laws, regulations, and ecosystem value chains for government action in this area. In general, modern building energy management systems use centralized control architectures that are incompatible with the topology of the building space. This system faces high configuration costs and difficulties in field setup, not to mention sharing information between systems. The study presented in [21] involves investigating a wireless sensor network framework and designing a network model for a smart building energy management system. Subsequently, a blockchain-based dynamic key management strategy for smart building energy management systems is proposed. Experimental results show that the proposed scheme reduces the time and space required for data storage and optimizes the control of energy management systems in smart buildings.

Commercial and administrative facilities such as universities typically have high energy consumption, as well as energy losses. This paper focuses on the feasibility study and design of the electrical installation of the virtual faculty project at the University of Isfahan. In this study, principles and criteria for the design of electrical systems in low-energy buildings are presented and proposed systems are introduced. The design of electrical installations in complex buildings requires the basic design information. These cases may include a set of design and implementation points that follow standard or well-known engineering principles. The system proposed in this paper includes a different set of smart building management systems; lighting, grounding, and equipotential bonding systems; lightning protection system, photovoltaic systems, low-voltage electrical equipment, transformers, uninterruptible power supplies, generators, capacitor banks, and more.

This study proposes an efficient lighting system evaluated with DIALux[®] software. Currently, DIALux[®] uses an algorithm that considers the light intensity

distribution curve inside the window depending on the illuminance distribution in the sky and the daylight control system [22].

II. INVESTIGATION AND FEASIBILITY STUDIES

It is difficult to fully consider the contribution of sunlight when assessing the energy consumption of building lighting annually. There is a complicated overlap between daylight and electric light and increased planning challenges for their simultaneous use. Smart use of daylight can reduce the energy consumption for lighting by more than a third [23]. With the development of the new version of DIALux-evo, it is now possible to estimate the energy-saving potential of integrated daylight and electric lighting strategies in everyday lighting plans. Various studies are concerned with the room lighting optimization using the DIALux software [24, 25].

Therefore, in the current project, it is appropriate to estimate the available electric loads (especially the lighting load) in the first step. For this purpose, building demand information such as building maximum energy demand, demand factor, simultaneity factor, and load factor were gathered by reliable surveys and valid references. In chapter 4, various parts of the building's electrical system are calculated to meet demand while being designed to meet low energy targets. In [1], the authors review the mandatory criteria in the design of buildings; in the field of external surface; in heating, cooling, ventilation, and hot water supply systems; electrical installations, and lighting system to improve the energy performance of components and equipment and reduce the need for and consumption of building energy. In this regard, three levels of quality (energy class) of the building are defined by determining the energy efficiency [31]:

- The EC building complies with national building regulations.

- Low-energy buildings (EC+)
- Buildings with very low energy consumption (EC++)

Based on about 30 face-to-face meetings held before COVID-19 between the authors and the project investors, and coordination with the architecture and engineering team and employers, it was decided that the type of design would be a low-energy configuration or in line with EC+. Below are selected papers based on this energy category. Note that EC stands for Energy Compliant. According to [32], there are the following design methods:

- Prescriptive method
- Trade-off method

- Energy Need method
- Building Energy Performance method

The first three methods suggest that the design processes of building walls, mechanical and electrical systems are independent of each other. In contrast to these three methods, energy performance requires an integrated design that can be supported by dedicated software. This paper methodology is based on the Trade-off method.

2.1. Estimating the load (demand) of the building

Electrical demand is the power displayed by a wattmeter at the peak load (Fig. 1). To design the building's electrical installations, one must first make an accurate estimate of the load to enable various calculations based on it. As a result, an explanation relevant to demand calculation methods (load estimation) is mentioned in this section, and eventually, the project demand is estimated. The determination of simultaneity factors is one of the challenges that may emerge in relation to demand estimation of large projects.

2.2. Maximum demand

Maximum demand is known as the average power consumed in a given time period (typically 15 minutes) (Fig. 2). In practice, usually the goal for demand estimation is the maximum demand rather than the maximum power [33].

2.3. Demand factor

Due to the lack of simultaneous use of all electric loads, the demand factor is multiplied by the connected power to estimate real demand. The demand factor is plant-specific. The simultaneity factor has the same concept as the demand factor, but the former is used for several loads, whereas the latter is defined for only one load:

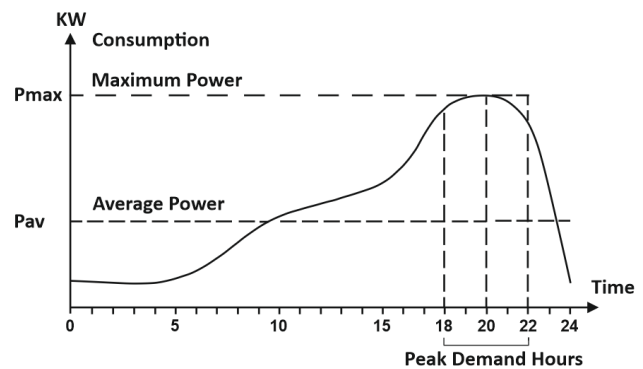


Fig. 1. Typical time variation curve of electric power.

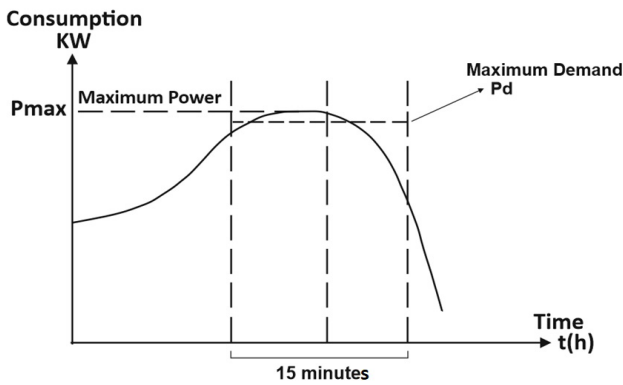


Fig. 2. Maximum demand and maximum power.

Total connected power per unit = Demand factor × Demand for one load;

Line Demand for similar loads = Power of one load × Simultaneity Factor × Number of similar loads.

For instance, if the demand of a utility room in winter and summer is 10.35 and 92.85 kW respectively, and the total installed power is 101.1 kW, then the demand factor is equal to:

For instance, if the demand of a utility room in winter and summer is 10.35 and 92.85 kW respectively, and the total installed power is 101.1 kW, then the demand factor is equal to:

$$g = \frac{92.58}{101.1} = 0.918.$$

2.4. Load factor

The load factor is defined as the average load (in kW) divided by the peak load (in kW) in a specified time period. The load factor closes to 1 indicates an optimal and economic use of the rated capacity of the equipment.

2.5. Simultaneity factor

To calculate the value of the simultaneity factor, the electrical designer requires detailed information on the project, loading conditions, future development plans, and other aspects. To calculate the maximum demand, the simultaneity factor can be taken from valid technical sources or similar projects. This study uses the simultaneity factor recommended in [34]. For different types of loads such as lighting, general socket outlets, single purpose electrical outlets, and other electrical loads, which are fed through electrical panels, suitable simultaneity factors should be applied to the total demand of all fed points (connected load) (Table 1).

Table 2 shows the simultaneity factors for switchboards based on different loads. Table 3 indicates the simultaneity factors for apartment complexes based on the number of consumers.

2.6. Total project demand

The project power demand is determined based on the power consumption of the lighting system, equipment, HVAC systems, and computers. They are presented in Table 4. Thus, the demand for this project is supposed to

Table 1. Simultaneity Factor for Final Circuits [34]

Circuit function	Diversity factor (k_s)	
Lighting	1	
Heating and air conditioning	1	
Socket-outlets	0.1 to 0.2 ⁽¹⁾	
Lifts and catering hoist ⁽²⁾	For the most powerful motor	1
	For the second most powerful motor	0.75
	For all motors	0.60

⁽¹⁾In certain cases, notably in industrial installations, this factor can be higher.

⁽²⁾The current to take into consideration is equal to the nominal current of the motor increased by a third of its starting current.

Table 2. Simultaneity Factor for Switchboards [34]

Type of load	Assumed loading factor
Distribution – 2 and 3 circuits	0.9
Distribution – 4 and 5 circuits	0.8
Distribution – 6 and 9 circuits	0.7
Distribution – 10 or more circuits	0.6
Electric actuator	0.2
Motors ≤ 100 KW	0.8
Motors > 100 KW	1.0

Table 3. Simultaneity Factor for Apartment [34]

Number of downstream consumers	Diversity Factor (k_s)
2 to 4	1
5 to 9	0.78
10 to 14	0.63
15 to 19	0.53
20 to 24	0.49
25 to 29	0.46
30 to 34	0.44
35 to 39	0.42
40 to 49	0.41
50 and more	0.38

Table 4. Power Demand of Each Section in the Project

Total area	5 892.78 m ²
Lighting system power (W) = area (m ²) × lighting power density (W/m ²)	65 kW
Equipment power in each section (W) = section area (m ²) × equipment power (W/m ²)	24 kW
HVAC power (gathered from HVAC designer report)	15 kW
Power of computers (W) = number of computers × typical power of a computer (W)	31 kW
Utility room power (gathered from utility room designer report)	200 kW
Total power demand	335 kW

be 350 kW for electrical facilities design (335 kW is rounded up to 350 kW).

2.7. Feasibility of the proposed plan

The project site is on University Street, on the west side of Isfahan (51° 39' 30"W, 32° 37' 16"N, 1599 AMSL). This building is built in 5 floors and has an area of about 7 000 m². Figure 3 depicts the geographical position and accessibility of the project site, whereas Fig. 4 shows the solar radiation situation in this location. Because of the policies of Iranian government and its International obligations, there is a strong desire to encourage the use of renewable energy sources. It is expected that the use of renewable energy sources will be the first priority in satisfying the project demand power. As Isfahan has an excellent potential with more than 300 sunny days per year, the use of solar power plants is preferable in this project.

As a result, the implementation of this project involves the use of grid-connected solar power plants and the investigation of the method of transferring their electricity. A grid-connected power plant was a candidate for a service period of 20 years, because according to the Iranian Ministry of Energy Policies, the project must supply at least 20% of its electricity consumption with renewable energies. It is important to emphasize that, according to [31], it is necessary to supply 30 kW of electricity by solar panels for this project to be classified as a low-energy building.

Given the wide range of products used in solar power plants, the project's initial costs will be around 25 000\$. If the solar power plant's output is sold to the public grid, the financial projection and return on capital will take around 5 years. The remainder of the power plant's income will be profit, according to the distribution company's 20-year

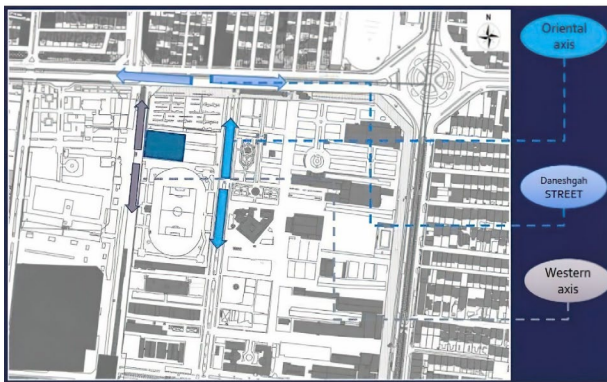


Fig. 3. Geographic location of the project.

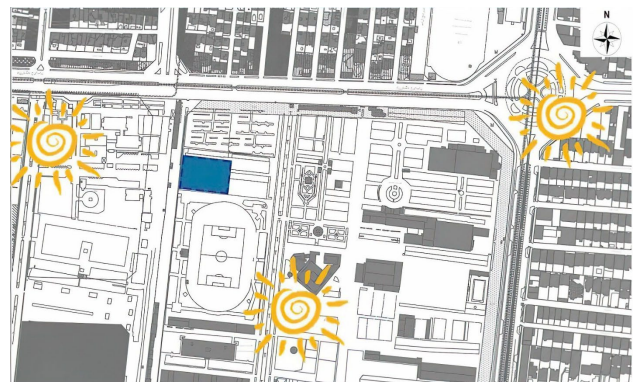


Fig. 4. The direction of sunlight in the project site.

deal.

The designs in the field of low voltage facilities and smart building control follow national building regulations [31]. There are two references to smart building management systems in this topic. The first is concerned with the control and monitoring of the cooling and heating system, and the second is for the lighting system. The building's cooling and heating can be supplied centrally or individually. Utility rooms and wall mounted gas boilers are considered as central systems, whereas heaters and coolers are considered as independent systems. All central and independent systems need appropriate control systems [31]. Each controlled space needs separate control systems to reduce the need for heating or cooling. Smart building control was also proposed for lighting system to implement a low-energy framework. The proposed solution was tested using the DIALux software. High-efficiency LED panels were used in classrooms and workplaces, which allows the goal of 11 W/m² for low-energy buildings to be achieved.

III. DESIGNING THE ELECTRICAL INSTALLATIONS OF THE BUILDING

3.1. Solar system

The sun is the most abundant source of energy on the planet. The primary applications of solar energy are divided into two groups:

1. Solar thermal systems (direct conversion of solar energy into thermal energy);
2. Photovoltaic systems (direct conversion of solar energy into electrical energy).

Photovoltaic systems have various applications due to the benefits such as long life, ability to be installed and started up in inaccessible and hilly areas, ease of maintenance, absence of reliance on the grid in remote areas, ability to be connected to the grid, and others. According to Iranian

Ministry of Energy Policies, educational institutions, government colleges, and their sub-units should be constructed providing 20% of their energy consumption with solar power plants [26].

3.1.1. Guaranteed purchase rate of solar electricity

The legal obligations of Iranian Ministry of Energy are fulfilled according to the principle of guaranteed purchase of electricity from photovoltaic power plants with an output of up to 100 kW (Table 5) (these rates refer to the study year). Undoubtedly, the new resolution proposes a price increase of 30% (1 Iranian riyal is approximately equal to 2×10^{-6} USD).

3.1.2. The requirements of renewable power plants

Designing a construction project needs to determine both its dedicated space and the route for the installation and commissioning of future renewable system circuits and associated infrastructure. The energy checklist must list separately the annual energy of the project and the annual energy that can be provided by renewable systems in the future (if expanded). The necessary studies and projections should be carried out for all the buildings to ensure that the amount of energy that can be supplied in the future does not fall below the following values [30]:

- 20 kWh/y/m² of the roof surface for one-floor buildings;
- 32 kWh/y/m² of the roof surface for buildings with more than one floor.

All relevant information must be recorded in the calculation and design notebook. In the cases where it is not possible to provide the minimum values due to special conditions caused by the construction of the building, such as shading from neighboring buildings, technical justifications must be provided, and the impossibility of using renewable energies must be clearly stated in the

Table 5. Guaranteed Electricity Purchase Rate

Generators for electricity subscribers up to the limit of branching capacity		Base rate of guaranteed electricity purchase (Riyals per kWh)
1	Wind turbine with a capacity of one megawatt or less	5 700
2	Solar With a capacity of 100 kW and less	7 000
	With a capacity of 20 kW and less	8 000

Table 6. The Minimum Annual Energy Provided by Renewable Systems (kWh/m²) [31]

Energy class	The minimum amount of annual energy provided	
	One-floor	More than one floor
Energy Compliant (EC) building	14	22.4
Low-energy building (EC+)	20	32
Very low-energy building (EC++)	28.6	45.7

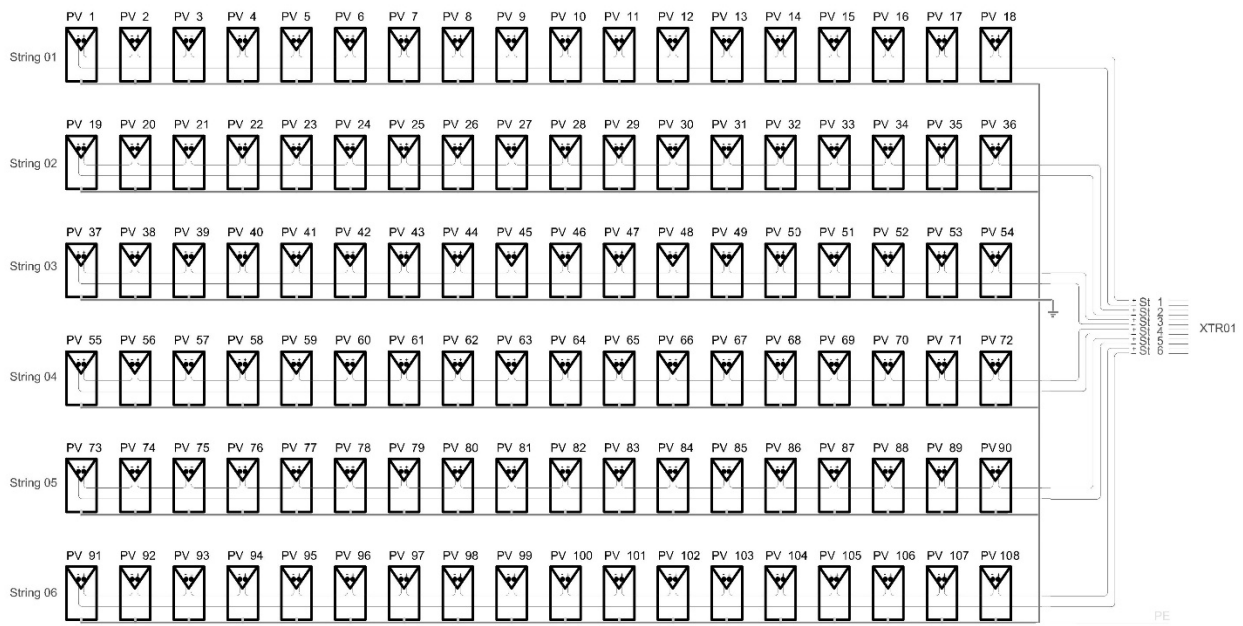


Fig. 5. The proposed power plant schismatic diagram.

building's technical documents. The suggestions for this project was to install panels on the building's roof and sidewalls, which was considered feasible given the sufficient available space on the roof.

Table 6 indicates the amount of renewable system use required for buildings according to [31], low-energy buildings, and extremely low-energy buildings. According to Table 7 and the figures given in [31], the required power of rooftop solar power plant is 30 kW approximately.

3.1.3. Photovoltaic system simulation

The PVSyst® software can be used to model a solar

power plant necessary for the project. This software can compute the system's connection to the grid, disconnection from the grid (DC grid), and construction of solar pumps. The rated power of the system with 108 modules (6 parallel strings consisting of 18 series modules according to Fig. 5) at standard test conditions is equivalent to 40 kW, which meets the calculated demand of 30 kW. This power plant's annual production rate is 79.76 MWh, and its average performance coefficient for different months is assessed to be 85.34%. Figure 6 depicts a graph of power plant production and various system losses by month. Photovoltaic array losses (energy conversion losses) and system losses (inverter, wiring, etc.) are examples of these losses.

Shading is another critical issue in the design of solar power facilities. PVSyst® software divides shading into two categories: close and far shadings. Given the proximity of Mount Sofeh to the project, the distant shadows can be modelled in Meteonorm® software and then entered into PVSyst® software. As a result, the Meteonorm® software (Fig. 7) is employed in the designs and simulations of this project. According to the calculations, 30 kW solar power plant was sufficient, but according to the available space and the possibility of installation, calculations and placement for a 40 kW power plant were suggested. Figure 8 shows the schematic diagram of the proposed solar power plant switchboard.

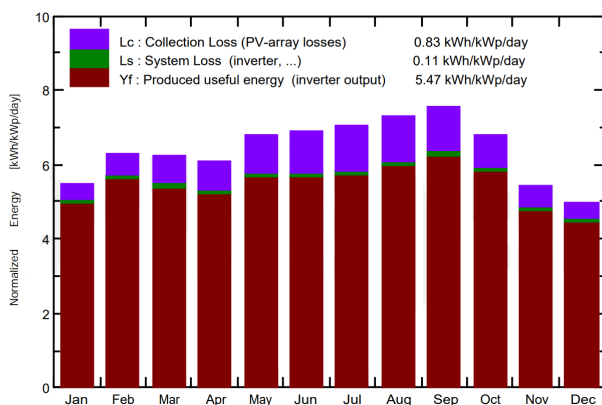


Fig. 6. Net production and losses of the proposed power plant in different months.

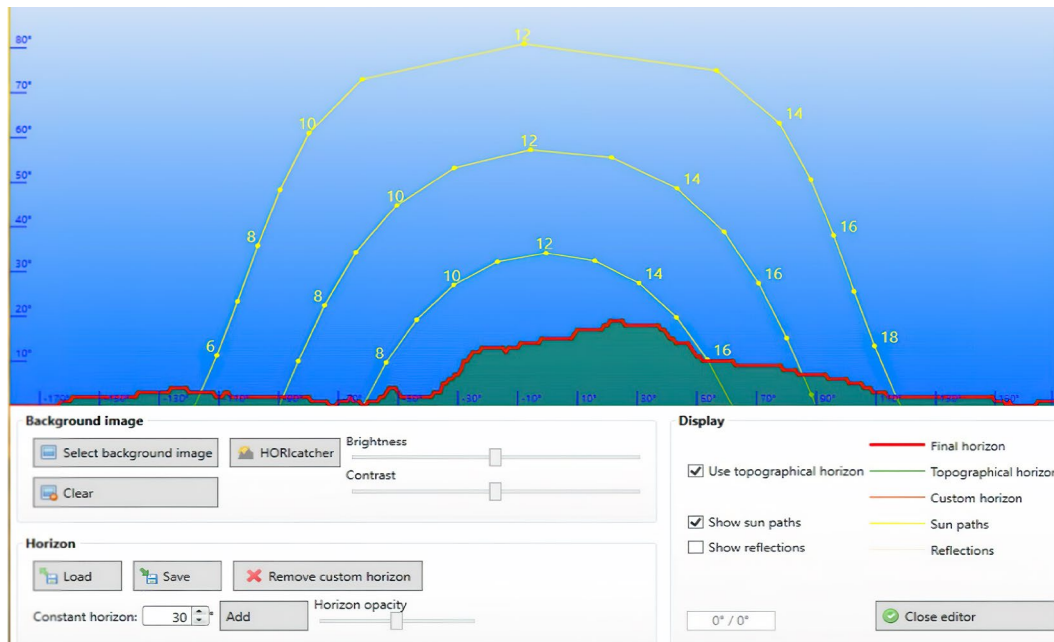


Fig. 7. Simulation of the far shadow (Sofeh Mountain) in MeteorNorm® software.

3.2. Smart building management system

Given the high expenses of the smart building management system, the proposal for its re-implementation was restricted to lighting management and intelligent control of the cooling and heating systems, both of which are also implemented using the KNX protocol. KNX, formerly known as European Installation Bus (EIB), is a building control communication system that employs information technology to connect numerous pieces of equipment such as sensors, actuators, controllers, executive interfaces, and displays.

This technology is used in electrical installations to perform building automation scenarios and processes. The low-voltage facility of the building was designed and studied using Siemens Simaris® software (Fig. 9). The map

of the building's smart boards is also shown in Fig. 10 and 11.

3.3. Lighting management system

DIALux software was used to evaluate the proposed lighting system. Figure 12 shows the ground floor zoning map, while Table 7 depicts the zone calculations. Figure 13 presents the color index of the incorrect ground floor components. Figures 13 and 14 demonstrate a 3D depiction of the ground floor. LED panels with high lumens per Watt are utilized in classrooms and offices, and with this choice, the goal of 11 W/m² for low energy buildings can be achieved. We can also utilize Downlight LEDs depending on the type of use and places, particularly in hallways with fake ceilings. Gobo projectors are recommended to light the building's northern wall. It is possible to reflect the green building logo, the university logo, and others on the building, which, in addition to its beauty, highlights the structure's low energy use. To use natural light, the appropriate arrangements with the architectural designer should be made to enable (if possible) alterations to the architectural plan of phase 1 in order to reduce the need for lighting in public spaces during the day.

In [31], the daylight simulation method is based on the SDA index. This index is expressed as a percentage of the floor area in which the minimum intensity of the desired lighting is provided in 50% of the specified hours and it is equal to 75–85% for low-energy buildings.

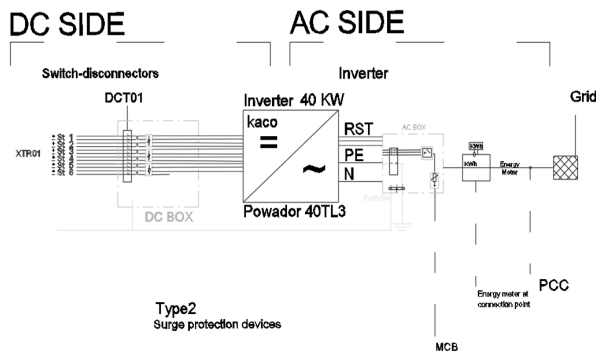


Fig. 8. Schematic diagram of the proposed solar power plant switchboard.

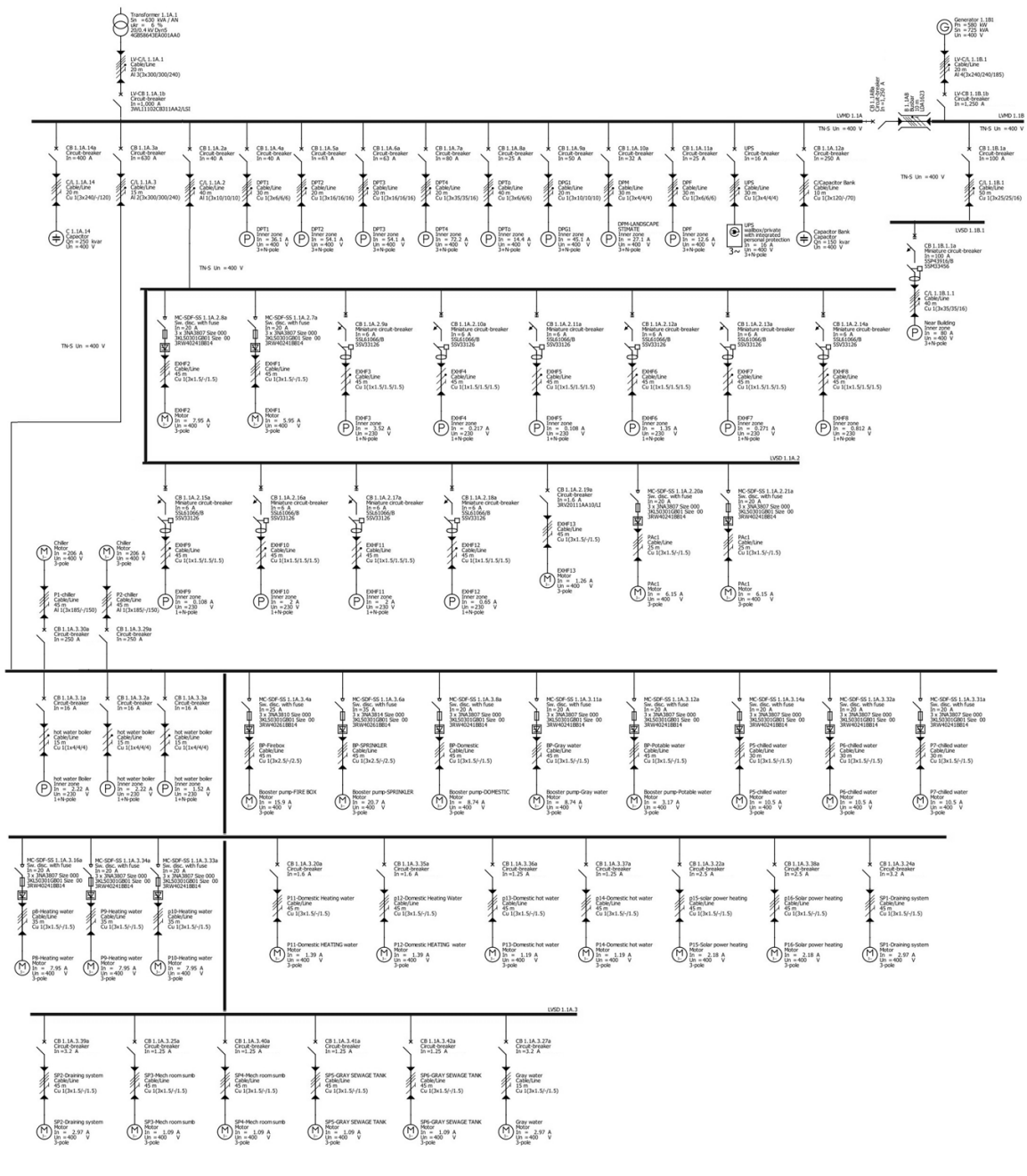


Fig. 9. Simulation of low-voltage system in Simaris software.

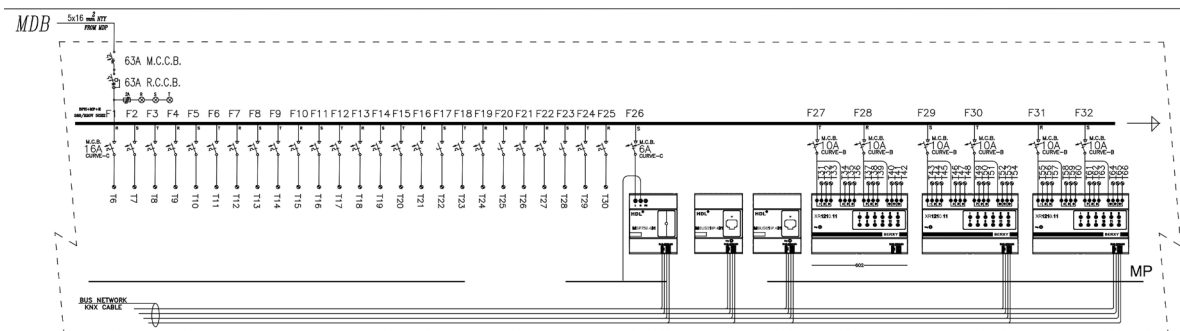


Fig.10. Single line diagram of the smart building boards.

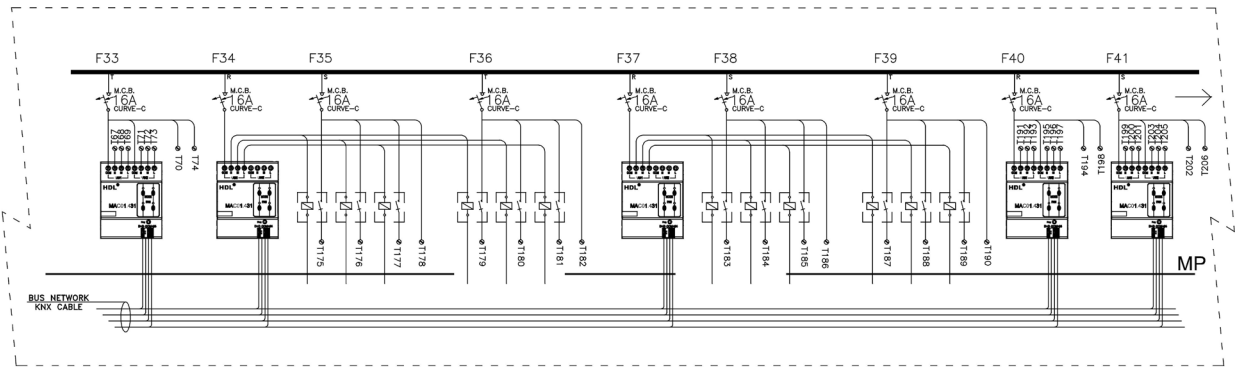


Fig. 11. Single line diagram of the smart building boards.

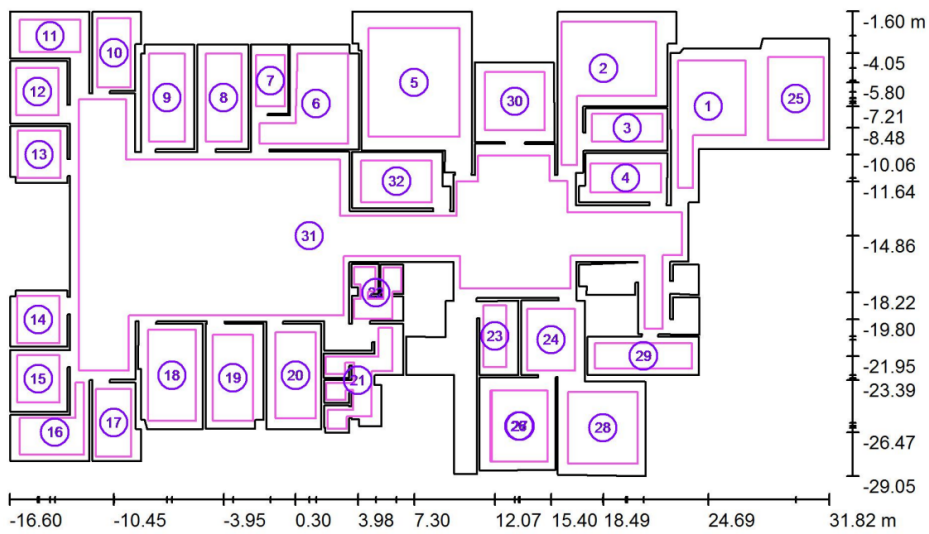


Fig.12. Ground floor zoning map.

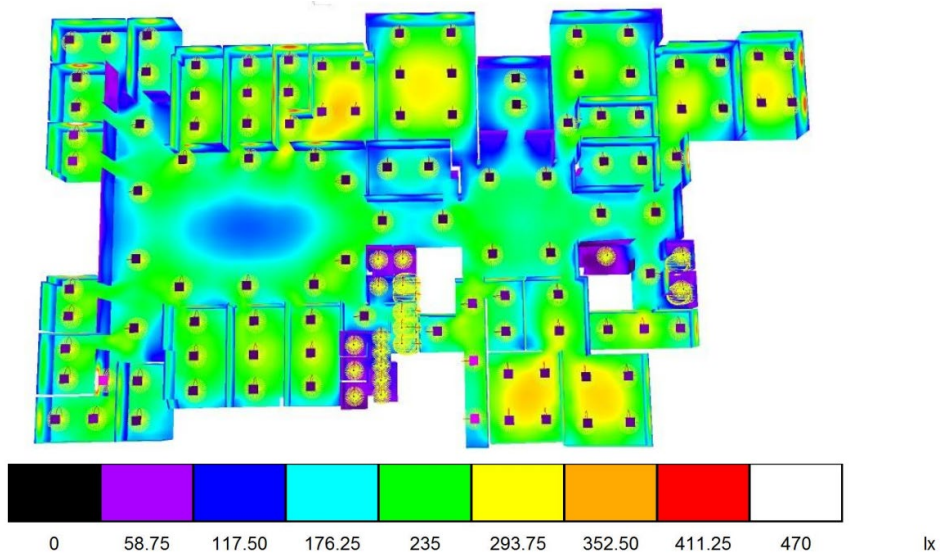


Fig. 13. Ground floor color index.

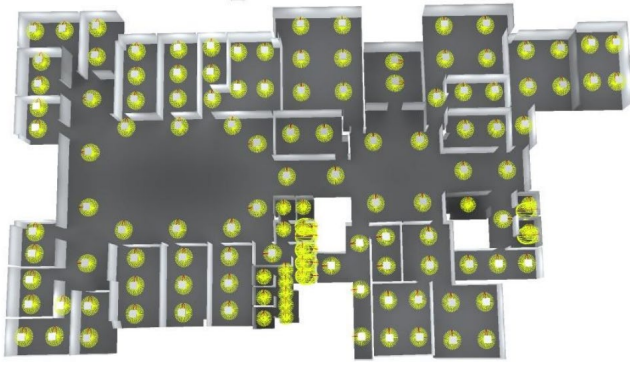


Fig. 14. 3D rendering of the ground floor lighting system arrangement.

3.4. Grounding and equipotential system

The ground system was designed according to [35] and [36], and the main structure was designed following [37]. The authors of [27] show how to calculate a shared ground system and connectivity. Because the project substation is located inside the building structure, it is not possible to separate the earth electrodes of low and medium voltage. As a result, a common ground electrode with a resistance of less than 1Ω was supposed to be appropriate for both voltage levels. Since the project is in a stony area, the best and cheapest technique to produce the ground electrode is to employ the ground electrode buried in the foundation. Figure 15 shows this combinational design.

Table 7. Lighting Calculations of Some Selected Parts of the Ground Floor (For Simplicity, only a Few Parts Are Shown)

No	Designation	Grid [m×m]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	$U_0=E_{min}E_{av}$	$U_1=E_{min}E_{max}$
1	Counselor's room	8×16	308	260	341	0.845	0.762
2	Counselor's room	16×16	280	211	324	0.754	0.652
3	Waiting room	8×4	288	238	332	0.827	0.717
4	Waiting room	8×4	261	219	289	0.840	0.758
5	Counselor's room	16×16	315	236	356	0.750	0.663
6	Counselor's room	16×16	362	272	412	0.752	0.660
7	Waiting room	8×8	317	265	365	0.837	0.728
8	Counselor's room	8×16	322	252	373	0.873	0.676
9	Counselor's room	8×16	268	224	298	0.835	0.751
10	Counselor's room	8×16	268	232	293	0.866	0.790
11	Manager office	8×8	374	318	406	0.850	0.783
12	Electrical room	16×4	325	264	374	0.814	0.707
13	Meeting room	16×16	341	285	375	0.835	0.758
14	Kitchen	4×8	288	254	315	0.882	0.808

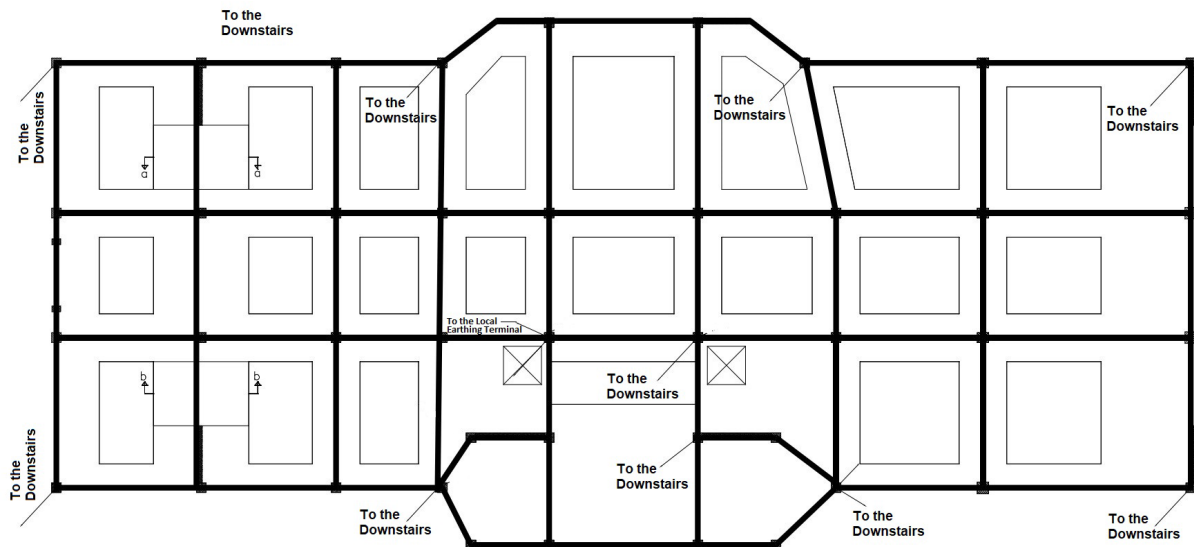


Fig. 15. Equipotential design of the last floor.

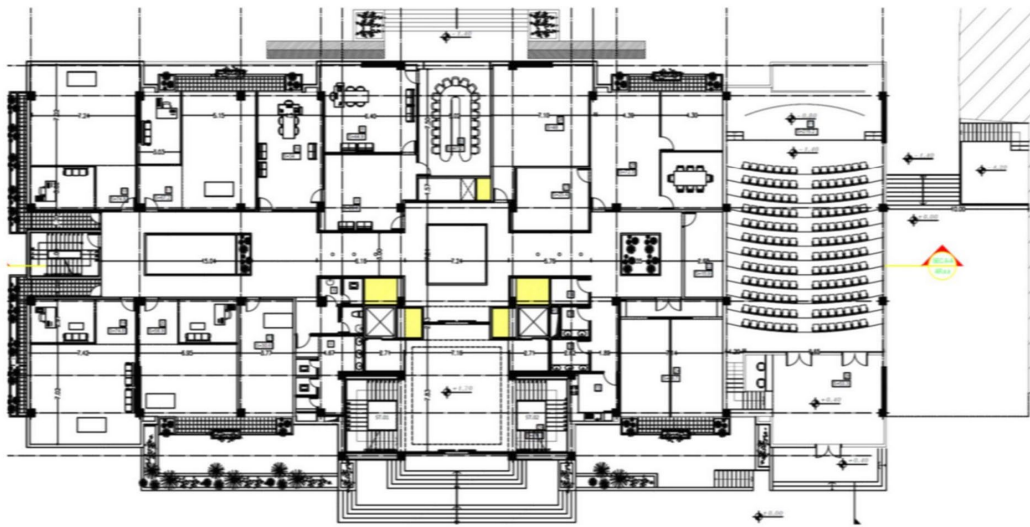


Fig. 16. Ducts considered on the ground floor.

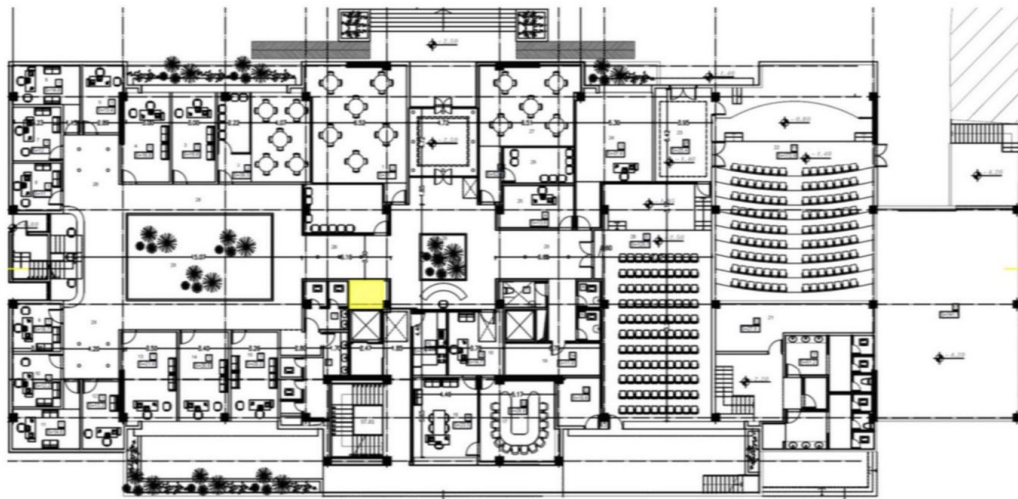


Fig. 17. The ducts considered in the floors.

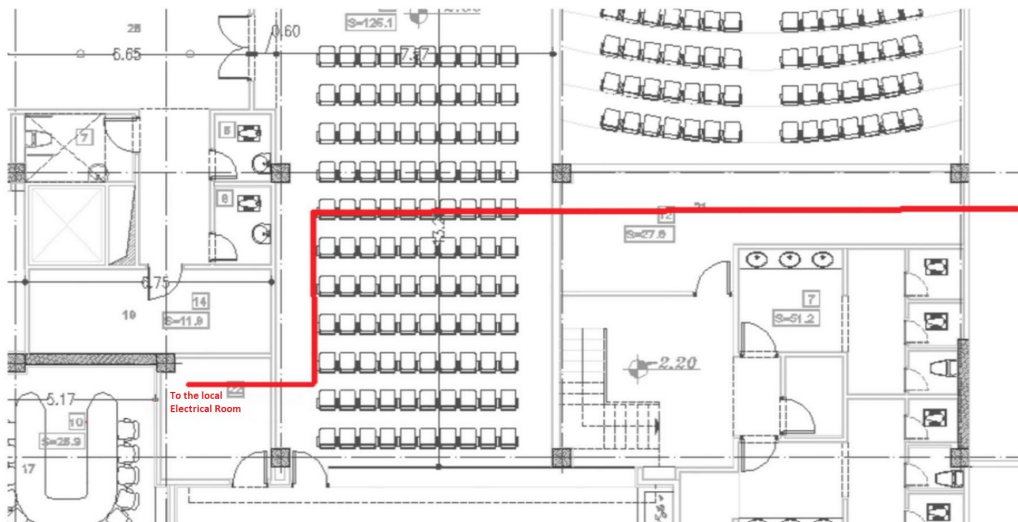


Fig. 18. The route of the main cables to the electrical room.

3.5. Risers and cable tray path

On the ground floor, only one duct was considered for the entry of electrical and mechanical facilities, and, according to the need, it was decided to divide the ducts into two categories, electrical and mechanical, with the main cables reaching the ducts through a cable tray. The number of ducts increases on higher floors. Figures 16 and 17 show the plan of the ducts considered for the ground floor and other floors.

The route of the main cables from the substation to the power distribution room and risers should also be determined with the necessary arrangements, which, according to the proposed design, involve the use of buried cables and cable trays in the specified space. Figure 18 demonstrates the path of the main cables from the substation to the electricity distribution room.

3.6. Transformer

The use of low-loss dry transformers is suggested for the main substation. According to [31], they should be selected considering the following:

- For each transformer, the maximum energy efficiency should be calculated using the load losses and no-load losses of the rated power.
- The total load loss for each type of transformer is calculated according to the value of total load power (demand power) or in other words the output load power of the transformer.

- The losses, including no-load losses and load losses, and the maximum efficiency coefficient of dry transformers under normal operating conditions and for rated power and nominal voltage of 20 kV, which are generally used in most parts of the country in the supply and feeding of building electricity with medium voltage branching, have to be calculated.

3.7. UPS and Capacitor Bank

Uninterruptible power supplies (UPS) are used to power special equipment and devices in spaces such as computer centers. During the operation of these devices, the load loss can be reduced by using devices with appropriate efficiency. The minimum efficiency for static type uninterruptible electrical devices is presented in Table 8.

The amount of reactive power flowing in the internal distribution network and the losses corresponding to it can be reduced by choosing a suitable capacitor bank. In addition, its use will bring other advantages, including an increase in the network's ability to provide active power, improvement in the efficiency of the distribution network and components of electrical panels, reduction in the cost of operation, and conservation of electricity. On the other hand, in office buildings where the level of harmonics is relatively high (usually more than 15%), it is better to use detuned inductors next to the capacitor.

The capacitor bank's capacity is estimated using the quantity of active power consumed, the average value of

Table 8. The Minimum Required Efficiency for UPS [31]

UPS rating [kVA]	Efficiency (%)
20 and lower	90
between 20 and 100	91
more than 100	93

Table 9. The Minimum Power Factor for Different Levels of the Building [31]

Energy rating of the building	The minimum value of the corrected power factor
Energy compliant building (EC)	0.92
Low-energy building (EC+)	0.94
Very low-energy building (EC++)	0.96

Table 10. How to Choose a Fire Alarm System [31, 34]

Type of building	Building of less than 5 floors from the ground floor, less than 11 units	Building of less than 5 floors from the ground floor, more than 11 units	Building of 5 to 10 floors from the ground floor, until 20 units	Building with 20 dwelling units or more	Buildings with more than 10 roofs or 5 000 m ² area
Conventional system	Optional	Up to 16 general type alarm units and 17 to 19 independent type alarm units	Up to 16 general type alarm units and 17 to 19 independent type alarm units	Not allowed	Not allowed
Addressable system	Optional	Optional	Optional	Mandatory	Mandatory
Description	It is optional to use the fire alarm system	It is mandatory to use a type of system	It is mandatory to use a type of system	It is mandatory to use the addressable system	It is mandatory to use the addressable system

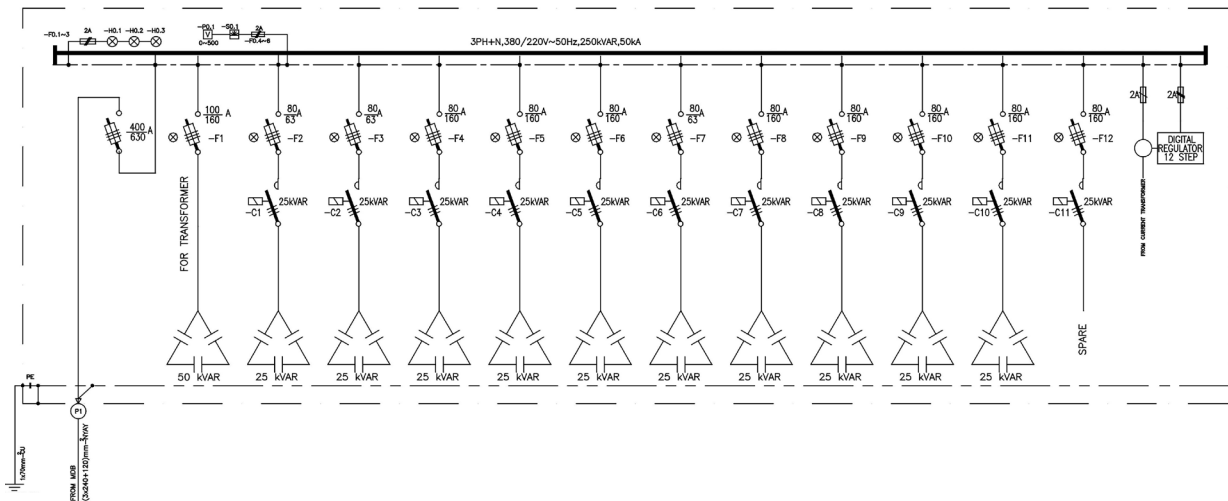


Fig. 19. Capacitor bank with 25 kVAR steps.

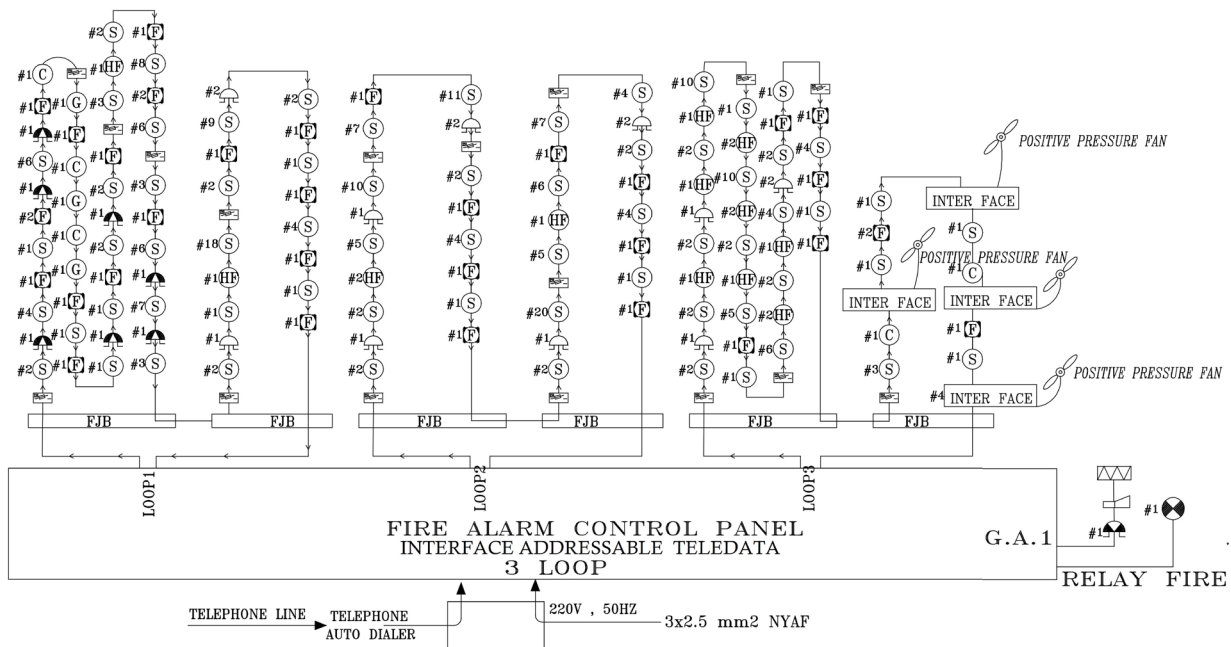


Fig. 20. Riser diagram of fire alarm-addressable system.

the power factor of electric consumers (initial coefficient), and the power grid's modified coefficient. From the point of view of reactive power regulation, according to the regulations of the electricity company, the minimum value of the power factor of the entire power supply network of the building is equal to 0.9 to measure the amount of apparent or reactive power consumption.

The amount of reactive power consumed for a power factor of 0.9 or higher is not included in the payment to the power company. The minimum value of the corrected power factor for different levels of the building is mentioned in [31] (Table 9). Considering that the faculty building is of a low-energy type, the capacitor bank should

be designed so that the minimum power correction factor is equal to 0.94. By performing the necessary calculations according to the method described in [28], the capacitor capacity needed to reach such a power factor is 300 kVAR. Figure 19 shows the proposed capacitor bank with 25 kVAR steps.

3.8. Fire Alarm System

A directive on fire alarm system design was prepared in the Central Council of the Iranian Engineering System. According to an instruction mandated by the Organization of Construction Engineering System of Iran, addressable fire alarm systems are mandatory for all residential

buildings with 5 floors and more, residential dwelling units with at least 11 units and more, and all buildings with more than 10 floors or 5000 m² area. This instruction is summarized in Table 10. According to this instruction and [31, 34], the architecture of this project's fire alarm system is addressable (Fig. 20).

IV. CONCLUSION

The technical feasibility studies of designing the electrical facilities of Isfahan University's virtual faculty in the form of a low-energy building were carried out in this paper. The project included various components such as a smart building management system, lighting system, a grounding and bonding system, a photovoltaic system (to supply the building's load), low-current electrical installations, transformers, uninterruptible power supplies, generators, and capacitor banks, with a required demand of 350 kW. The solar system installed provided around 30 kW through the rooftop PV system with 108 modules (6 parallel strings consisting of 18 series modules). The intelligent management system includes the lighting management system and the intelligent control of the cooling and heating systems, which use the KNX protocol for control. High-efficiency LED panels were employed in the lighting department, with the goal of consuming less than 11 W/m². Downlight LEDs were also utilized depending on the type of use and area, particularly in corridors with artificial ceilings. An addressable building fire alarm system was used in video monitoring and fire extinguishing facilities. In the rocky ground of the location, the grounding system and the main connection of the structure were merged and designed in the simplest and cheapest method possible. A low-loss dry transformer was utilized to feed from the public electrical distribution network. The motors were controlled by a soft starter and a multi-speed control and start-up system. Given that the faculty building is a low-energy one, the capacitor bank should be constructed so that the minimum power correction factor is 0.94. If the architectural, mechanical, and electrical design standards outlined in this paper are implemented, the building can be deemed to fall within the EC+ or low-energy building category.

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