PalArch's Journal of Archaeology of Egypt / Egyptology

ROLE OF SMART TECHNOLOGY IN ARCHITECTURE-PAVING THE WAY FOR SMART FACTORY BUILDING IN KARACHI

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Humaira Nazir, Ubaid Ullah, Bushra Khan, Hassaan Bilal Rashid. Role of Smart Technology in Architecture-Paving the Way for Smart Factory Building in Karachi--Journal of Archaeology of Egypt/Egyptology 20(2), 2133-2162. ISSN 1567-214x

Keywords: Thermal Comfort, Building Envelop, Factory Building, Smart Building, Indoor Environmental Quality, Karachi, Smart Building.

ABSTRACT

The concept of "smart buildings" is used to improve efficiency in the interior and exterior of a building, and it helps in providing services to the user according to the space requirement. The goal of this study is to propose a strategy for energy-efficient smart industrial buildings in Karachi that takes into account the building envelope, low energy for cooling, and appropriate electrical appliances. The study was conducted in Karachi, Sindh, Pakistan, because of its status as a "hub of industrial activities." Mixed research methods, both quantitative and qualitative, have been used to gather and analyze data, evaluate outcomes, and draw conclusions. A physical questionnaire survey was used to obtain the data. A detailed survey of the two existing factories and an analysis of the architectural planning of one factory building were carried out. In addition, Autodesk Revit was used for simulating the data and analyze the use of energy efficiently with operative temperature for thermal comfort. Findings from surveys and interviews indicated that the lack of efficient indoor environmental quality, lack of natural ventilation, inappropriate use of materials, and insufficient space planning resulted not only in suffocation and chronic illness in enclosed spaces like packaging and production areas but also increased energy consumption. Concluding, factory space is not a space designed for machines, but human needs and comfort should be considered in designing a factory. Smart building is a new norm that is being adopted for many building types around the globe, and results of simulation indicated that smart building guarantees minimum use of energy for cooling and maintaining a comfortable indoor environment for the user.

INTRODUCTION

The effects of climate change are already being felt all over the world. It affects not only the natural world but also human societies and economies. Extreme weather events occurring more frequently and more intensely, sea levels rising, and biodiversity loss are just a few of the effects we are now experiencing. Additionally, pollution from fossil fuels can lead to respiratory problems and other health issues for both humans and animals. Therefore, it is crucial to reduce our reliance on these harmful sources of energy and transition towards more sustainable alternatives that slow down the pace of climate change. Conversely, the construction sector is responsible for a significant amount of greenhouse gas emissions due to the energy-intensive processes involved in maintaining structures and providing comfort to the occupants, as 39% of the global emissions are contributed by buildings (UN, I., 2020), and after industrialization, CO2 emissions into the atmosphere increased (Zheng, Saina, et al., 2021). Therefore, it is a challenge and a responsibility for architects and urban designers to consider climatic factors as a major design element because one of the most important factors contributing to environmental change is a lack of climatic considerations in the construction industry, which causes harmful gases to be released into the environment.

In addition, as the world's population continues to grow and urbanize, the demand for new domestic and non-domestic architecture and infrastructure will increase, making it crucial for the construction industry to adopt sustainable practices and technologies to decrease the harmful effect of the construction industry on the surroundings and environment. Therefore, architects and planners are using a variety of techniques like sustainable design, green building design, eco-friendly design, smart or intelligent design, and energy-efficient design to achieve lower or zero carbon footprints, lower greenhouse gas emissions, and provide comfort to both the environment and the user while competing with the modern world that is now moving towards smart technologies, and these smart technologies in buildings are changing the norms of planning and construction. It helps in maintaining building management easily, reduces costs and usage of energy, improves cooling, heating, and ventilation systems, increases not only the property value but also the users' comfort, and builds an eco-friendly environment. Hence, smart technologies, when integrated into any building design, are one of the solutions to adopt for environmentally friendly buildings that can also lead towards zero-carbon buildings to sustain the environment and occupant comfort and increase building efficiency by boosting the building's capacity to sense and respond, turning the building into a smart building. A smart building is an integrated system of building systems. It joins individual computer networks into a bigger supernetwork, similar to the Internet (Sinopoli, J.M., 2009). Harris (2012) defines a smart building as a medium that receives input, decides overall responses, and gives output according to adaptability and adjusting temperature.

The use of smart technologies in domestic architecture is evident worldwide; however, this concept is now not limited to domestic architecture, and it has been noticed that the design and desired efficiency of non-domestic architecture have also evolved over time, and non-domestic structures such as factories are also being converted to smart structures.

If considering Pakistan, the manufacturing sector contributes around 64% of GDP to the overall economy (Ahmed, 2014). The main sectors in Pakistan are the cotton industry and manufacture, accounting for about 65% of product exports and approximately 40% of the workforce (Kashif et al., 2019). Pakistan's economy mostly derives from the industrial sector and is currently dependent on the labour force. Major active industries in different cities of Pakistan include cement, ceramics, cotton, glass, iron, steel, jute, leather, matches, paper and board, ship building, silk and rayon, sugar, vegetable ghee, and woolen industries (Ahmed, 2014).

Considering the largest city in Pakistan, Karachi, is Pakistan's economic hub with active industrial zones such as SITE, Korangi Industrial Area, Korangi Creek, Bin Qasim Industrial Park, Landhi Industrial Area, and others that manufacture and produce paper and board, jute, iron, steel, cotton, class, cement, matches, vegetable ghee, leather, silk, wool, ceramics, ship building, and so on (Hassan and Mohib, 2003). Therefore, Karachi was selected for the specific field of research and design as it has a major chunk of industries in Pakistan. However, if considering industrial architecture, there is a lack of environmentally and user-friendly buildings generally in Pakistan and specifically in Karachi.

The envelope of a factory building and its planning in Karachi do not have a positive effect on the environment, workers' health, or their work efficiency (Ajmair and Hussain, 2017). The main cause is the inefficient space planning and design of the industrial sector, where walls are placed for the comfort of machines only. There is a need to rethink the design of a factory building, as a factory building is more than just a function that serves machines; it is also a place where labourers spend the majority of their time, and the building itself is a block that responds to the climate. Many factory workers experience chronic illness due to poor indoor environmental quality, a lack of natural ventilation, the maintenance of physical structures, sanitary issues, and many more factors. It also impacts Pakistan's GDP because Pakistan's GDP depends on laborers' work efficiency (Ahmed, 2014).

Therefore, the purpose of this research was to see if smart technologies could be used in the design of a factory building to make it not only environmentally and user-friendly but also energy efficient.
Below is the study's specific goal:

Determine how smart technologies can be used in the study area's factory building planning and design with the goal of lowering energy usage and improving indoor environmental quality for a positive impact on workers' health.

The task set to achieve the goal was to propose a smart factory building design in Karachi, focusing on the efficient use of technology as a blend with architecture to improve indoor environmental quality, maintain a healthy environment for labourers with the minimum use of energy for cooling, and make the building environmentally responsive.

LITERATURE STUDY

Overview of Smart Building

Intelligent buildings have been improved to smart buildings, which combine building optimization with the Internet of Things (IoT) to improve building efficiency and provide long-term solutions for environmental and life safety (Hoy, 2016). For nearly two decades, the "smart" building has incorporated intelligent control systems and smart and networked equipment in addition to the standard building functions and structure. The intelligent systems control the temperature, humidity, and ventilation rates, etc. By using building mass, smart buildings may be viewed as a thermal storage medium (Verma et al., 2019). In addition, smart building technology includes building management systems, security systems, and facility management systems connected to an Integrated Building System. It helps to operate a single system connected to all facilities rather than a traditional building system in which each system is operated separately (Sinopoli, 2009).

Talking about the evolution of smart buildings, building automation reflects back to the 1900's but actively started with the birth of DDC (Direct Digital Control) in the mid of the 1970's. Leading building automation professionals were early contributors to making it a reality. In the late 70's, the revolutionary development of DDC systems exploded and traditional pneumatic control systems shifted to the building automation market as DDC was much lower in cost and highly functional as compared to pneumatics. In 1974-1975, the first computer for building monitoring was developed on DDC and named RCMS, or Remote Control and Monitoring System. This is the time of the evolution of an intelligent building that integrates with IT installations and is flexible enough to solutions, responsive and adaptive. In the 1990's and 2000's, IT development evolved from the concept of proprietary to client-server architecture, and mainframe computers were replaced by web server farms. Hence, IT development gives us another era of revolution, and that is connectivity through the internet of things. The phrase "Internet of Things" was invented by Kevin Ashton in 1999, a new term with known and advanced functions. Before 1999, pervasive computing, ubicomp, and ambient intelligence were all terms used to describe it. In the same year, LONTALK was developed and added to ANSI, SEMI, IFSF, and EN. It is optimised for control and is widely used in industrial control, building systems, and home automation. It is now being adopted as an International Control Networking

Standard in the ISO/IEC 14908 standards family (Buckman, Mayfield, and B.M. Beck, 2014). Hence, building automation systems started to integrate into buildings in the 1990's, termed "intelligent buildings."

The term "intelligent building" is being updated from time to time. Originally named "automated building" in 1985, "responsive building" till 1991, "effective building" and now the upgraded form of intelligent buildings is "smart buildings" (Parlak, 2020). The specific features and criteria for assessing smart buildings in different time periods are given in Table-1.

Table 1. The Specific features of each elements and criteria for assessing smart buildings (source: Pitroda, 2015)

Automation (1981-1985)	**Response (1986-1991)**	**Efficiency (1992-now)**
Automatic control of the building and the possibility of remote control	Building control by the users as well as the automatic control	Achieve optimum performance and reduce costs.
providing a setting that is comfortable and functional for users to meet their needs.	providing a setting that is comfortable and functional for users to meet their needs	Applying the best building security and safety system.
Flexibility to confront future changes	Adapt the internal building environment to the surrounding environmental.	Space management so that the future changes can be controlled.
The ability to achieve compatibility between the various functional elements in the building.		Building management through the environmental control in the building systems.
Providing comfort to users without any human intervention.		Management business

If talking about the modern trends in smart building design in present times, smart building trends increase the efficiency, responsiveness, and adaptability of the building according to the needs of the environment and user, making it more effective, energy efficient, and comfortable for the user. These advancements have changed the concept of architecture from static to dynamic spaces according to the environmental needs of light, wind, heat, cooling, or user requirements. According to Ahmed et al. (2015), some sustainable applications of smart technologies on the building's skins and facades are energy-generating building skins, dynamic and kinetic smart building skins, solar shaded skins, double skins, smart green building skins, and more.

In addition, according to Wei and Li (2011), the technologies that make a building smart are:

1. Intelligent Building Control System (BCS): A building control system is used to manage mechanical, electrical, and electromechanical services.

2. Input Information: Each system in a smart building has a means of receiving information.

3. Information Processing and Analysis: Information processing is controlled by the building control system.

4. Time Consideration: In smart building design, the time consideration factor is one of the key elements. The system should respond on time to avoid maximum damage.

5. Building Management System (BMS): A building management system is an open programming language that shares subsystems to control electrical, mechanical, and electromechanical systems.

Industrial revolution and smart factories

Back at the end of the 18th century, a new revolution named the "industrial revolution began as new materials and construction techniques emerged and industry started working as a societal economy. Mechanization became the central part of the increase in economy, labour, and production until the beginning of the 19th century. Hence, the industrial revolution changed the way people lived. Two major advancements in technological up gradation are building automation and machine connections through **IIoT** (Elheddad et al.).

In addition, smart building envelopes and smart factory concepts emerged after the industrial revolution, and developed countries are adopting automation in buildings and machines to make them energy efficient and more reliable for indoor and outdoor environments and to increase productivity. First-generation countries have used smart technologies in factory building envelopes and interiors to increase efficiency (Umair et al., 2021). A factory is said to be smart through the interconnectivity of tools known as Cyber Physical systems (CPS). It connects and analysis the data, which can be further used to create better products and more efficient techniques. Used by producing companies, a smart factory works by using technology like computing (AI), robotics, analytics, huge amounts of information, and therefore the internet of things (IoT), and might run for the most part autonomously with the flexibility to self-correct. However, the operations manifest themselves within the four walls of the factory (Umair et al., 2021). The foundation of smart factories is smart manufacturing, which links the factory to other components in the digital supply network and facilitates better supply chain management. Additionally, they are built on digital manufacturing, in which a product is digitally connected throughout its entire life cycle with the aid of a digital twin (Lee and Kim, 2018). Hence, smart factories are supported by the Industrial Internet system, consisting of hundreds and thousands of sensors and systems operated by a single central operator. It acts as the link that binds everything (Figure 1).

Moreover, smart factories also have the potential to improve the overall comfort and well-being of building occupants. For example, advanced HVAC systems can monitor and adjust temperature and humidity levels to create a more comfortable and healthy indoor environment. Additionally, smart lighting systems can adjust lighting levels and colour temperatures to promote productivity and reduce eye strain. As technology continues to advance, the possibilities for improving building performance and occupant comfort are endless. The smart building envelope can respond to changing external and internal conditions and adjust its performance accordingly. This can lead to significant energy savings, a reduced carbon footprint, and improved occupant comfort and productivity (Lee and Kim, 2018).

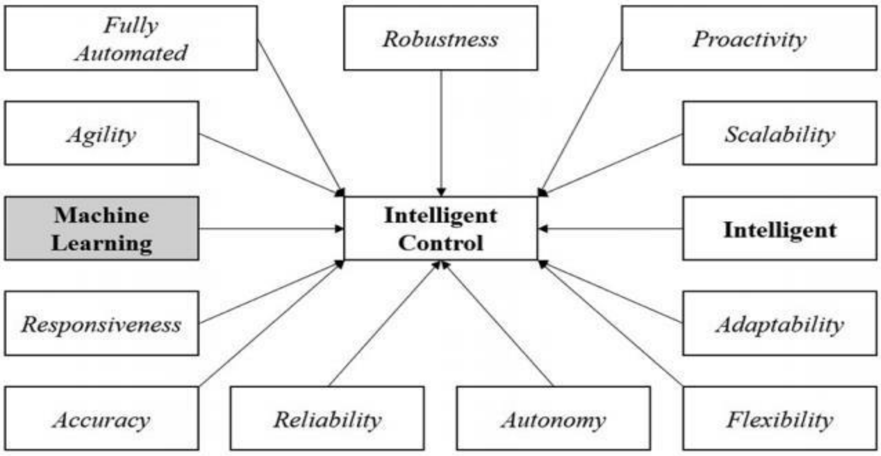

Figure 1: Connection of sensors and machines with one central part that controls the activity (Mittal et al., 2017)

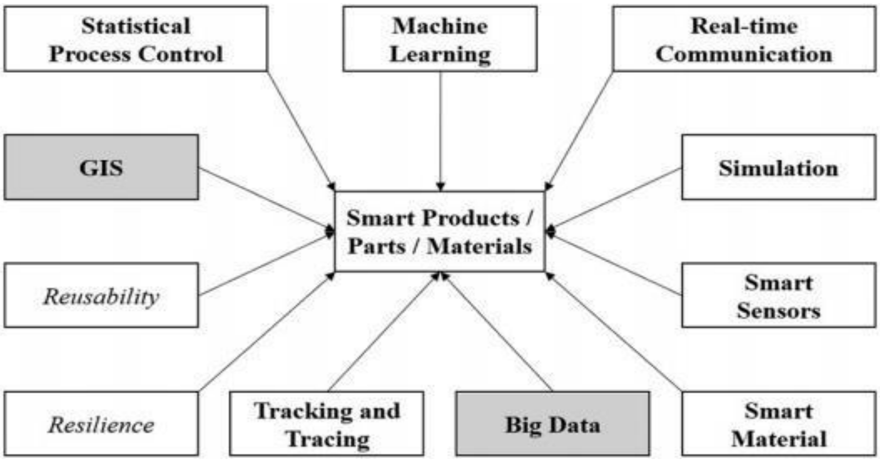

Figure 2: Connection of machines with one another that links with bigger platform as shown in Fig 3.8 (Mittal et al., 2017)

Conceptual Framework

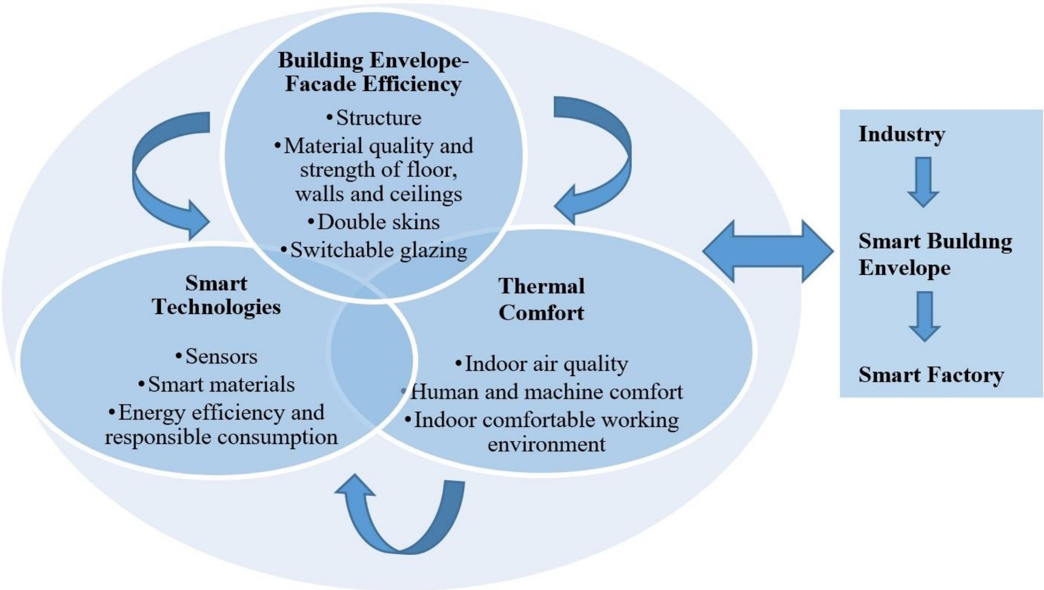

Figure. 3: Conceptual framework (Author)

METHODOLOGY

The article's primary goal is to propose an approach for energy-efficient smart buildings in Karachi that takes into account the building envelope, low energy for cooling, and appropriate electrical appliances. For this purpose, the primary technique of data collection was a qualitative approach because interviews are one of the most significant sources of case study material.

Other additional methods were also employed, such as case studies, questionnaires, informal conversations, observation, photography, layout design analysis, and in-depth document analysis, mostly of news items and reports.

A factory building in the site area of Karachi was selected and surveyed to understand the problems of the users, ventilation, day lighting, and space planning issues. The factory building's floor plans were drawn up, which is supposedly the most effective technique for documenting, understanding, and communicating spatial qualities.

In addition, structured interviews were conducted with the users of this building. Structured interviews, sometimes known as "questionnaire surveys," use structured questions. The research sample consisted of factory owners, employees engaged in production lines, and architects and developers. A sample of 100 individuals was selected using a random sampling process in which two factory owners, 20 architects, and 68 workers were involved.

In order to evaluate the thermal comfort of the interior spaces, the building was modelled, and energy efficiency was also studied with simulation. Building Information Modelling (BIM) is a complex 3D model-based method that gives AEC professionals all the data they require to plan, design, build, and maintain buildings and infrastructure. BIM enables people engaged in design and construction to keep track of the data they produce while doing their work while helping them work more effectively (Bouhmoud & Dalila, 2021). For this study, Autodesk Revit was chosen for the design of a G+4 industrial building proposed in Karachi. The building was designed so that thermal comfort is provided to the inhabitants of the building and to optimise efficiency in terms of self-energy production.

To achieve this objective, all the building materials were created using the "family creation tool' in Autodesk Revit, which allows the user to assign physical and thermal properties to the building elements used to model the building. Once the modelling was completed, thermal loads were simulated by assigning thermal parameters to the building materials and other relevant data such as power loads, lighting loads, etc.

Area of Study- Karachi

Karachi is Pakistan's largest city and the provincial capital of Sindh, covering a total area of 3,527 km2. It is situated on the Arabian Sea coast (latitude: 24.56′-00" N and longitude: 67.01′-00" E) and is both the nation's largest seaport and main commercial and industrial center.

Dadu District is on its northeastern boundary, Thatta District is on its south-eastern border, the Arabian Sea is on its southern border, and the Lasbela District of Baluchistan Province is on its western border **(Figure 4).** Karachi experiences high relative humidity throughout the year, with the wettest month of August being 85 percent and the driest month of December being 58 percent.

The winds in Karachi blow south-west to west for around half of the year, including during monsoons. The wind usually shifts to the east and north-east during the winter, keeping the average temperature around 21 degrees Celsius. May and June are the warmest months, with average maximum temperatures reaching 35 °C. The month of January is the coldest of the year (Hasan, and Mohib, 2003) **(Figure 5)**.

Pakistan's single port is Karachi, and it is home to a large number of the country's industries and enterprises. In the formal sector, Karachi has 4,500 industrial units. Many of these sectors are focused on exports. For the informal sector, no statistics are available. However, the informal sector, which mostly works in the garment, leather, textile, carpet, and light engineering sectors in low-income settlements, employs 75% of the working population (MPD- KDA, 1989) (Karachi Development Plan 2000, KDA).

The area that has been selected for the study is Sindh Industrial Trading Estate (SITE) (Figure 11), because it is one of the oldest industrial areas in Karachi, Pakistan. SITE Town is located in the southern region of Karachi and was named after the Sindh Industrial and Trading Estate. One factory was selected for a detailed case study, named Printech Packages (Pvt) Ltd., located at Fakhruddin Valika Rd., Metroville Sindh Industrial Trading Estate, Karachi, Karachi City, Sindh. Two other factories were also surveyed in order to achieve the research's goal.

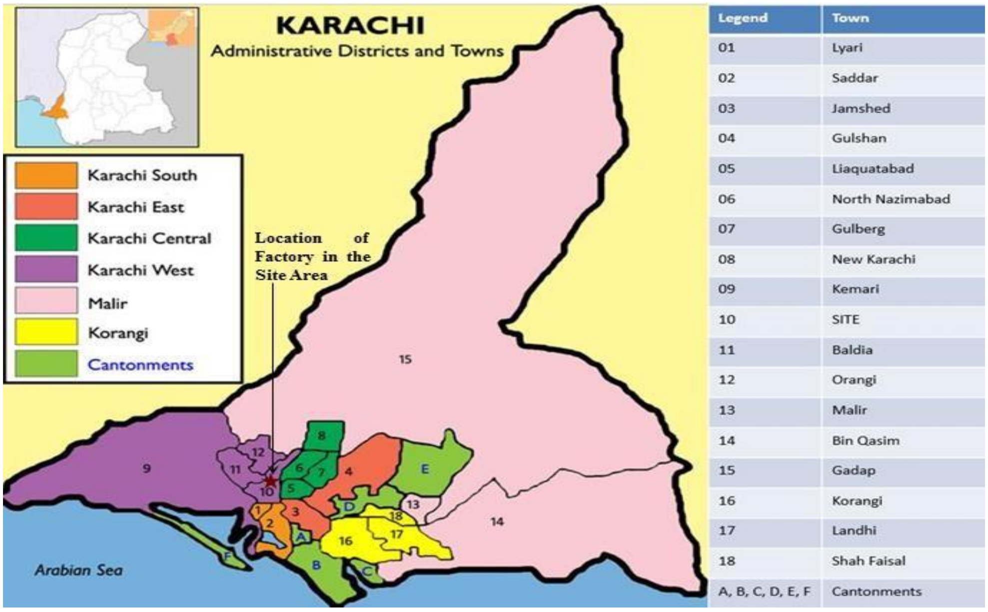

Figure. 4: Map of Karachi with district and town boundaries and study area (http://www.kmc.gos.pk/)

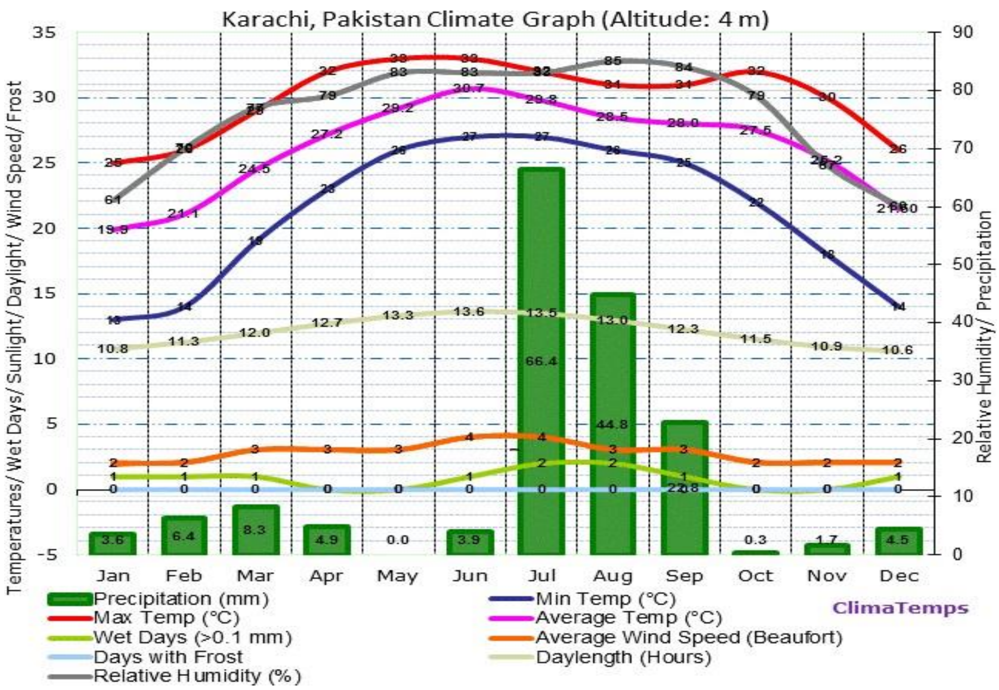

Figure. 5: Climate of Karachi (Source: Climate and average monthly weather in Karachi, Pakistan, n.d.)

FINDINGS AND ANALYSIS

Survey and Interviews Results

This research relies on surveys of existing factories, their analysis, and interviews with stakeholders are given in the following figures.

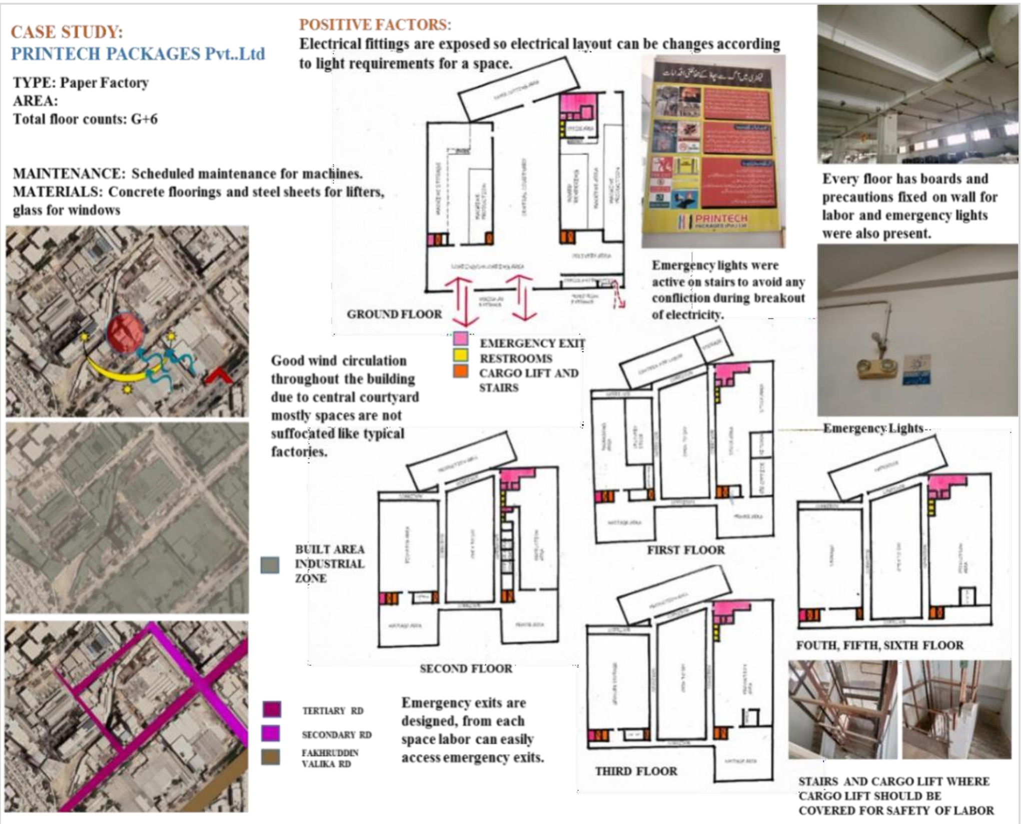

Figure. 6: Analysis of spatial layout of factory building (Source: Author)

Figure. 7: Analysis of form and massing, and ventilation of factory building (Source: Author)

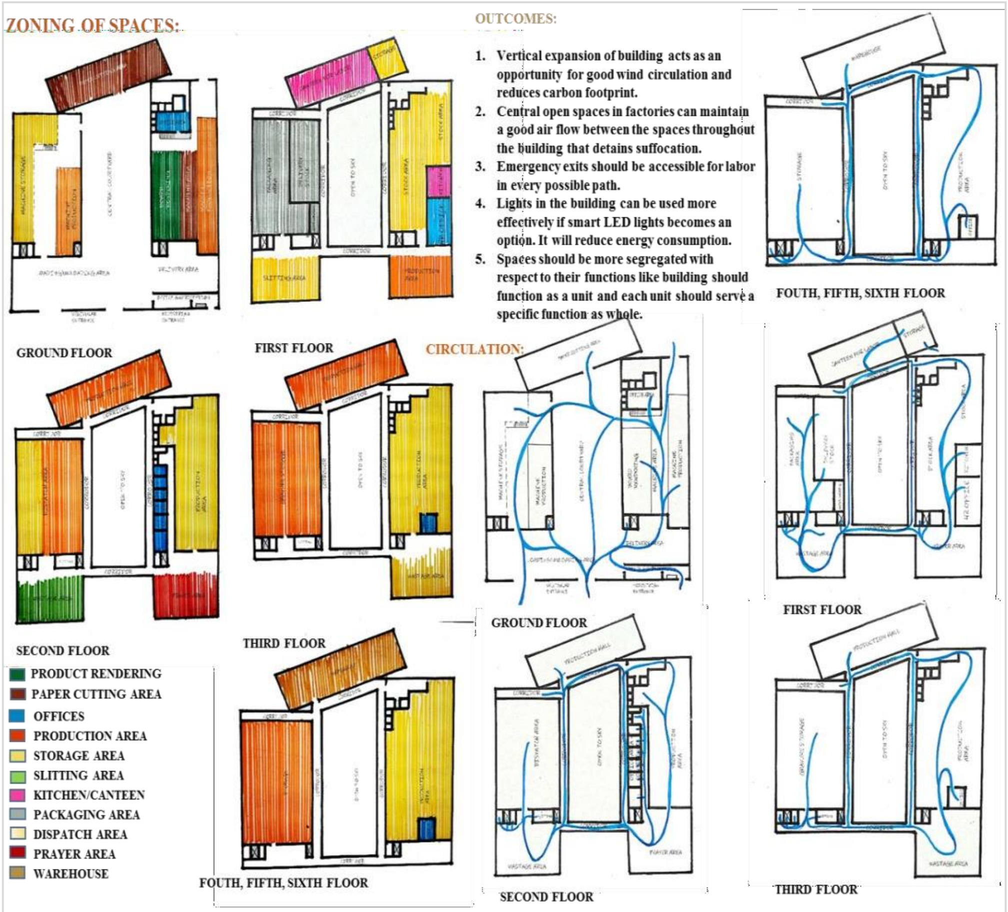

Figure. 8: Analysis of zoning and circulation of factory building (Source: Author)

An analysis of floor plans in terms of spatial layout and circulation, natural ventilation, form, and massing of a factory shows that the factory is not well ventilated and has day lighting issues. Interior spaces are very hot because air conditioning is not provided in the production areas, which already lack natural light and ventilation, and workers are forced to work in this environment, which causes them to suffer from chronic illness**(see Figure 6, 7 and 8).** This situation also slows down the work progress and reduces the quantity of the products. In addition, a power breakdown also interrupts the working process. Therefore, it is required to redesign the factory to resolve the issues that provide a healthy environment for the workers and use minimum non-renewable energy sources, which in turn reduce the harmful impact on the environment.

The results of the surveys and questionnaire for respondents' perspectives on the smart building idea, smart building envelope, thermal comfort, and applying smart technology in non-domestic buildings such as the factory in Karachi were collected from factory workers, factory owners, and architects and are mentioned below.

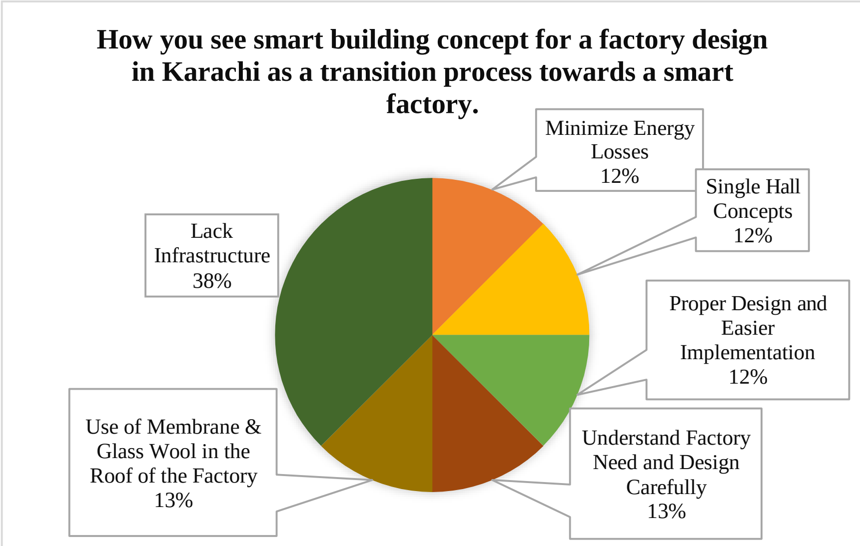

Figure. 9:(A) Concept of smart building and application of this concept to a factory building (N = 100). Source: Authors, 2023.

Considering the transition process from traditional buildings to smart buildings influences the design of a factory. According to the survey's findings, 12 percent of respondents say that smart facade design can be a gateway to minimizing energy losses. The same percentage is considering this concept as a way to make flexible spaces where many functions can be done in a single space rather than designing multi-story buildings. Almost half of the respondents (38 percent) say that the concept of smart buildings can be applied to a smart factory. However, the lack of technology and infrastructure in Karachi is a big challenge to applying the concept of smart buildings. For 12 percent of the respondents, the concept of a smart building will be a modern boom not only in terms of design but also in terms of the functionality of the building and its envelop that will act smartly in the contextual fabric.

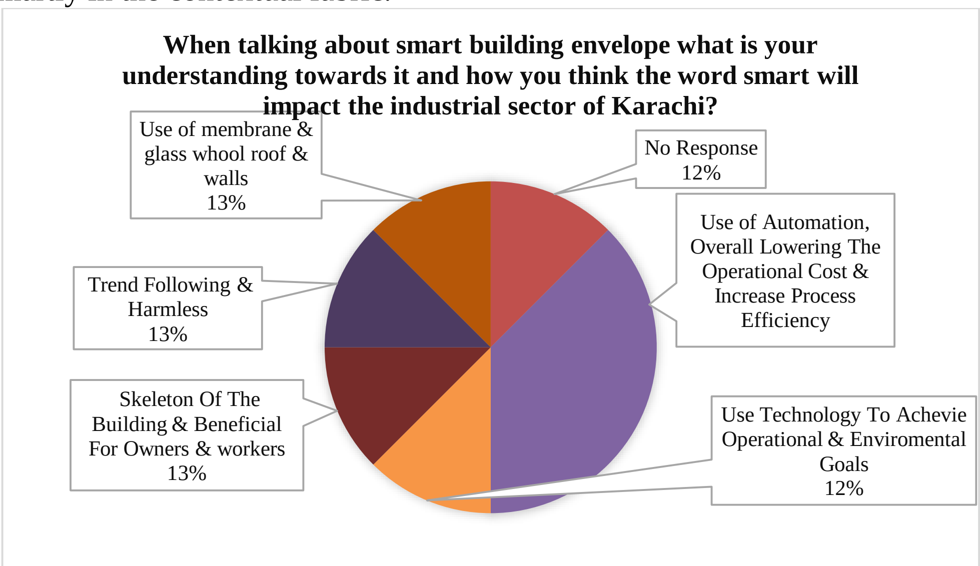

Figure. 9 :(B) Concept of smart building envelope and its impact in industrial sector (N = 7100). Source: Authors, 202

It will also create great opportunities for the users. 13 percent of the respondents claimed that the use of membrane and glass wool now-a-days in the roof of the factory is paving the way to apply the smart building concept for a factory design in Karachi **(see Figure 9A).** To understand the concept of smart buildings and their use in buildings, survey results show that 37 percent of respondents said that smart building design results in an overall enhancement of efficiency and a lower operational cost, which in turn reduces energy consumption. Energy consumption is a major factor in factories since production areas need a huge amount of electricity, and when there is a shortage of electricity in Pakistan, that is being fulfilled by load shedding, and this negatively affects the industries of the countries as industries suffer a billion rupees per year loss due to failures in the power grid. In addition, respondents say that in smart factories, the process and working will be proper as per international standards and will take less time to produce larger amounts of products. For 13 percent of the respondents, the smart building envelope is the skeleton of the building, and it could be beneficial for owners as well as workers. For 12 percent of respondents, a smart building refers to the use of technology to achieve certain goals like reducing operational costs, improving the environment, or providing other benefits. In addition, 12 percent of respondents have no idea about smart buildings or smart envelopes **(see Figure 9B)**.

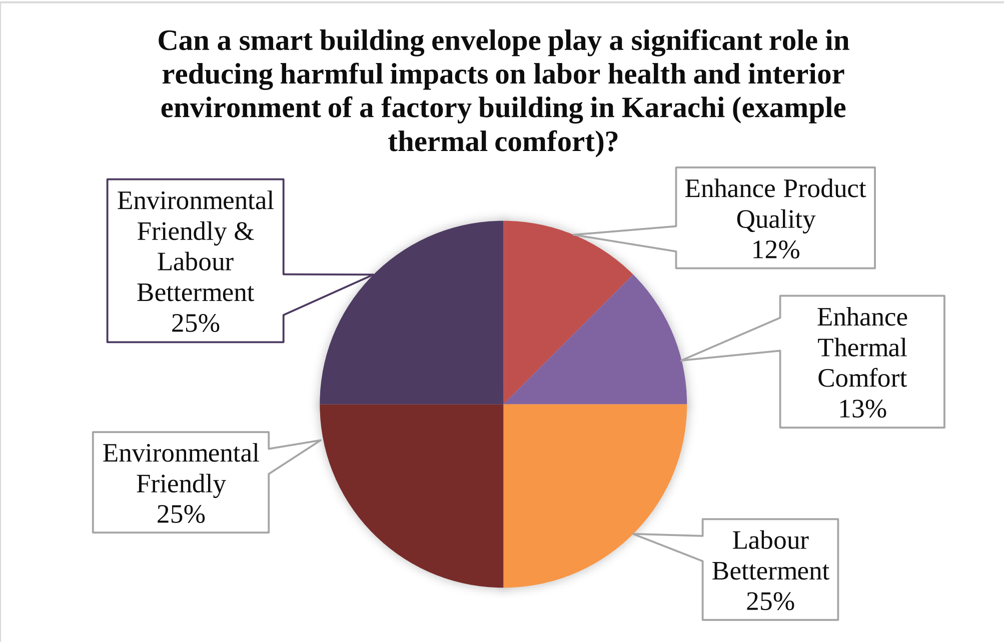

Figure. 9:(C) Impact of smart building envelope on environment and user's health in a factory building (N = 7100). Source: Authors, 2023.

The survey results about the impacts of the smart building envelope on the users health and interior environment indicated that half of the respondents (25 percent) say that the smart building envelope will help reduce harmful impacts on labour and interior spaces as well as respond positively to the environment, i.e., it will be environmentally friendly. 13 percent of the respondents feel that the thermal comfort of the occupant will also be impacted by the smart envelop, as it will work according to the climatic conditions and give a positive response to the user in terms of thermal comfort. Thermal comfort is a key concern in factories due to the special requirements of some specific spaces, such as storage and packing facilities. Many individuals feel dizzy as a consequence of the lack of ventilation in these interior spaces. Factories in general do not have any insulation measures installed or any thermal comfort measures adopted, which causes suffocation in the interior. Heat also plays a part in the summer, when temperatures in Karachi approach 40 degrees Celsius. According to the study, the thermal comfort level for Karachi residents fluctuates between 24 ^{o}C and 27 ^{o}C with relative humidity ranging from 50% to 60% (Panjwani et al., 2014)**.** Hence, thermal comfort and ventilation in a factory building can be maintained and accurately monitored through the use of smart technologies, which can aid in the prevention of factory fires and the provision of a comfortable environment for humans. In addition, 25 percent of the respondents considered that this technology will be in favour of labour, and 12 percent claimed that it will enhance the quality of products because machines and workers will work in a controlled and comfortable environment **(see Figure 9C).**

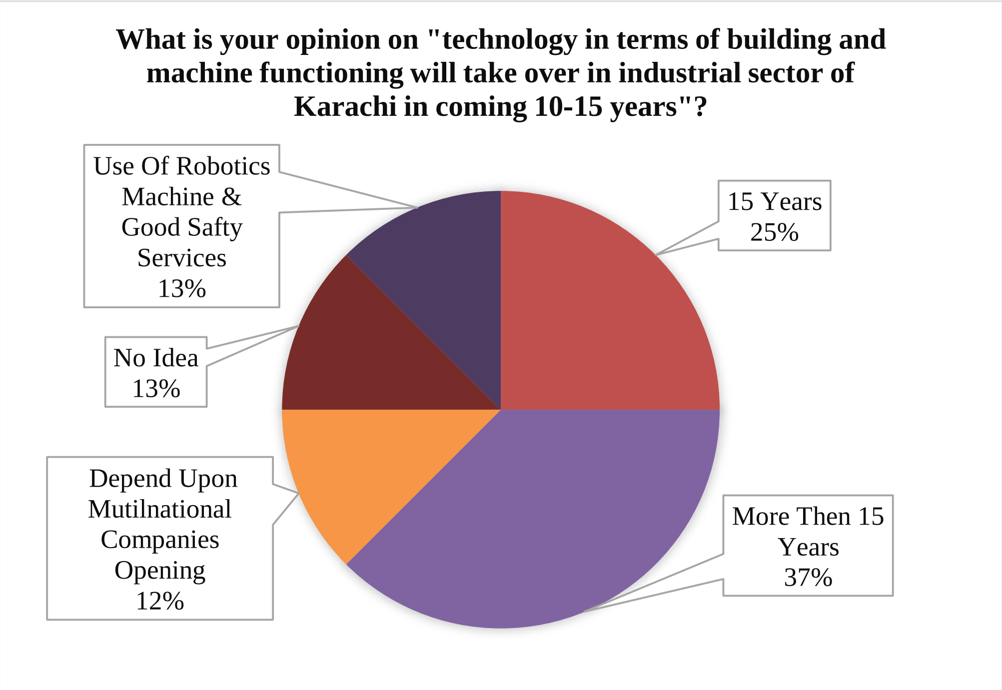

Figure. 9 :(D) Users opinion about the advancement of industrial sector in terms of smart technology application (N = 7100). Source: Authors, 2023.

More than half of respondents (52 percent) believe that Pakistan will adopt this technology during the next 15 years, according to the survey findings on the development of buildings with the use of smart technologies. The other respondents are doubtful if the smart building idea would be used in Pakistan, as they believe that doing so is dependent on both the availability of modern technology and the country's economic status **(see Figure 9D)**.

After surveying and analysing the factories in Karachi, along with discussions with the stakeholders, the following problems have been identified in the industrial sectors of Karachi:

1. Thermal comfort
2. Energy consumption

Therefore, these issues were addressed in the final design proposal for a factory building.

Building Information Model of the Proposed Building

After analysing the factory's' space layout, circulation, and questionnaire findings, a final design proposal for the factory is made **(Figure. 11, 13 and 14)**, and the thermal comfort and energy consumption of the new building are calculated through simulation (. The simulation models-BIM and computational-**(Figure. 10, 12),** and collected data are given in detail below.

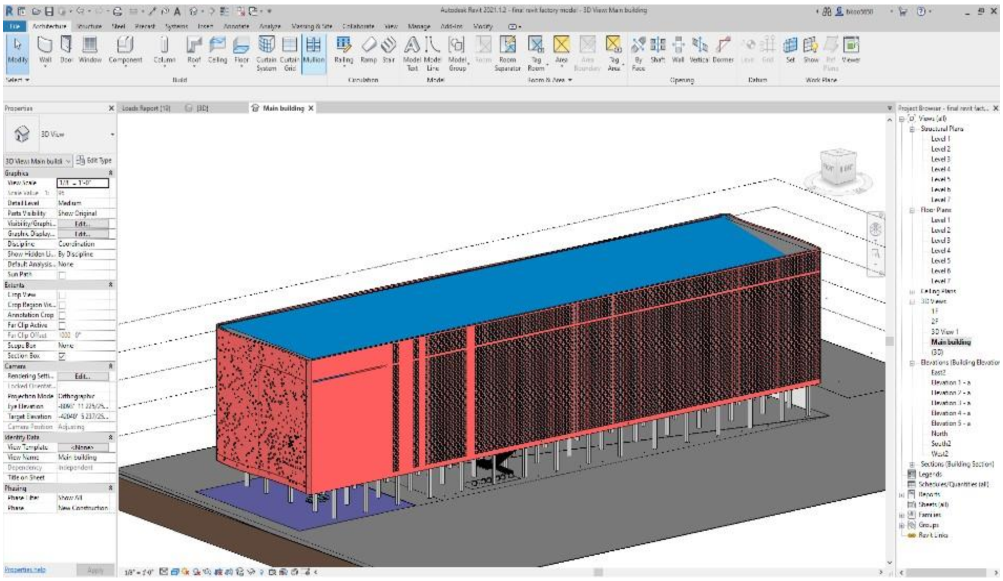

Figure. 10: BIM model of the proposed factory Building (source: Author)

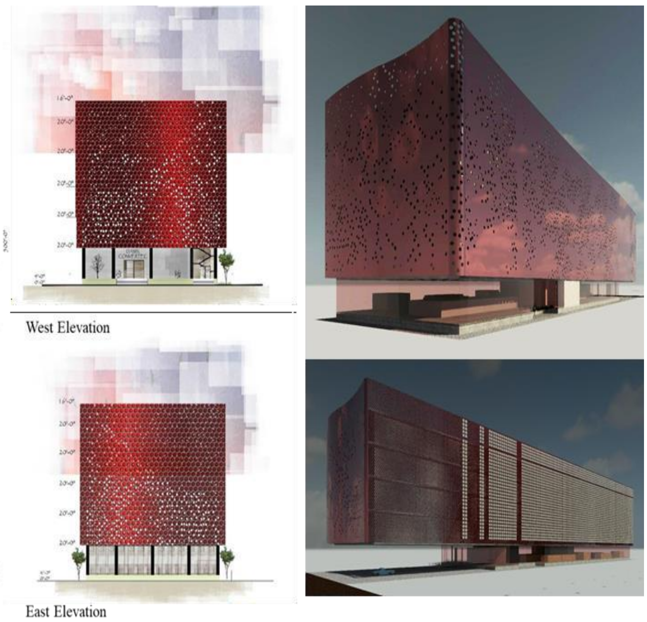

Figure.11: Proposed floor plans of factory **Figure.12:** Model for simulation (Author)

Figure.13: Section atBB'

Figure.14: Section atAA'

Computational Thermal Simulation on Autodesk Revit

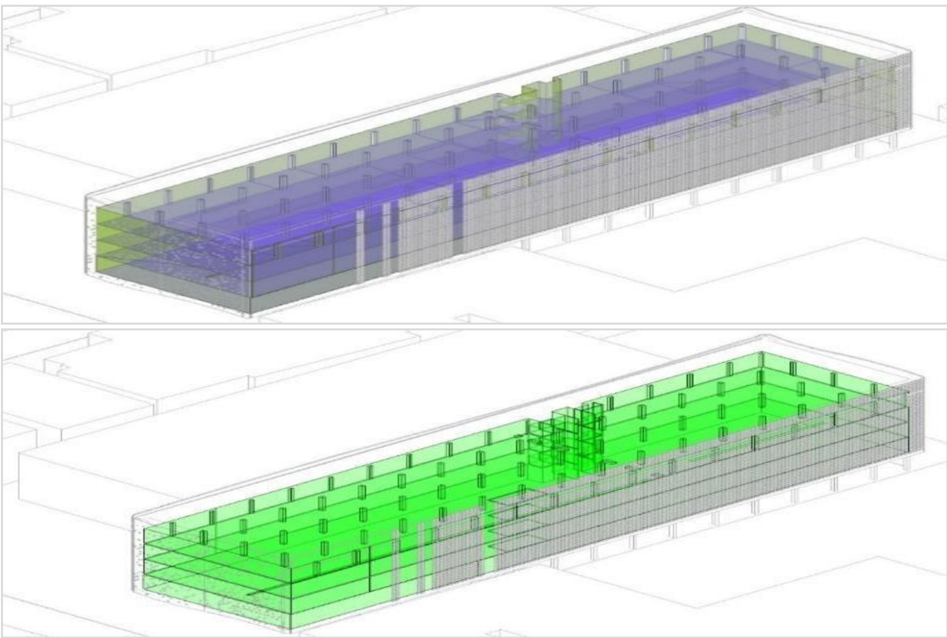

Figure.15: Computational simulation on Autodesk Revit (source: Author)

The energy simulation was used to investigate the impact of the suggested air conditioning unit installation on factory building cooling energy consumption. The simulation was also used to investigate the factor of heat insulation by proposing a solar-shaded smart skin around the building and providing rooftop solar panels. The energy consumption in the planned industrial building was modelled using Autodesk Revit **(Figure 15),** which included contributing factors such as HVAC systems, lights, machinery, and inhabitants. On an hourly basis, the interior loads of inhabitants and equipment were calculated. The blinds' activation, ventilation, and other building control systems were also calculated hourly. Below are the results of the energy simulation **(see Figure 16)**.

Analysis Prosperities

By default, analysis properties are generated from information in conceptual types. Prosperities of schematics Types are used when override is selected.

Category	**Override**	**Analytic Construction**
Roofs	☑	Sloping roof with solar panels (U=0.1589 W/m^2.K)
Exterior Walls	☑	Metal curtain wall with 1ft insulation (U=0.5149 W/m^2.K)
Interior Walls	☑	Frame partition with ¾ in gypsum board (U=1.4733 W/m^2.K)
Ceilings	☑	8 In lightweight concrete ceiling (U=1.3610 W/m^2.K)
Floors	☑	8 in lightweight concrete floor desk (U=1.3610 w/m.k0
Slabs		Slab edge R-10 insulation (U=0.1160 W/m^2.K)
Door	☑	Metal (U=3.7021 W/m^2.K)
Exterior Windows	☑	Large double-glazed windows (reflective coating) - industry
Interior windows	☑	Large single-glazed windows (U=3.6869W/m^2.K) SHGC=0.86
Skylights	☑	Large double-glazed windows (reflective coating) -industry

All | None | Shading factor for exterior window | 0

OK | Cancel

Figure.16: Building Material Parameters for Thermal load Analysis (source: Author)

Table 2: Simulation results of required indoor operative temperature of the factory building with the required energy (source: Author)

Building Summary	
Inputs	
Building Type	Manufacturing
Area (S.F)	203,129
Volume (CF)	3,848,475.39
Calculated Results	
Peak Cooling Total Load (kW)	**600.3**
Peak Cooling Month and Hour	July 3:00 pm
Peak Cooling Sensible Load	534.2
Peak Cooling Latent Load (kW)	203.3
Maximum Cooling Capacity (kW)	619.3
Peak Cooling Airflow (CFM)	68.107
Peak Heating Load (kW)	110.5
Peak Heating Airflow (CFM)	16,090
Checksums	
Cooling Load Density (Btu/[h.ft^2])	12.39
Cooling Flow Density [CFM/SF]	0.34
Cooling Flow / Load (CFM/ton)	324.79
Cooling Area / Load (SF/ton)	968.68
Heating Load Density (Btu/[h.ft^2])	1.86
Heating Flow Density (CFM/SF)	0.08

The simulation was then run for a full year. The load parameters from the measurement duration of two weeks (two shifts, no work on weekends or national holidays) were assumed to be typical for the whole year **(see Table 2)**. Despite the fact that load profiles fluctuate based on client demand and equipment usage, this assumption may be considered a baseline case.

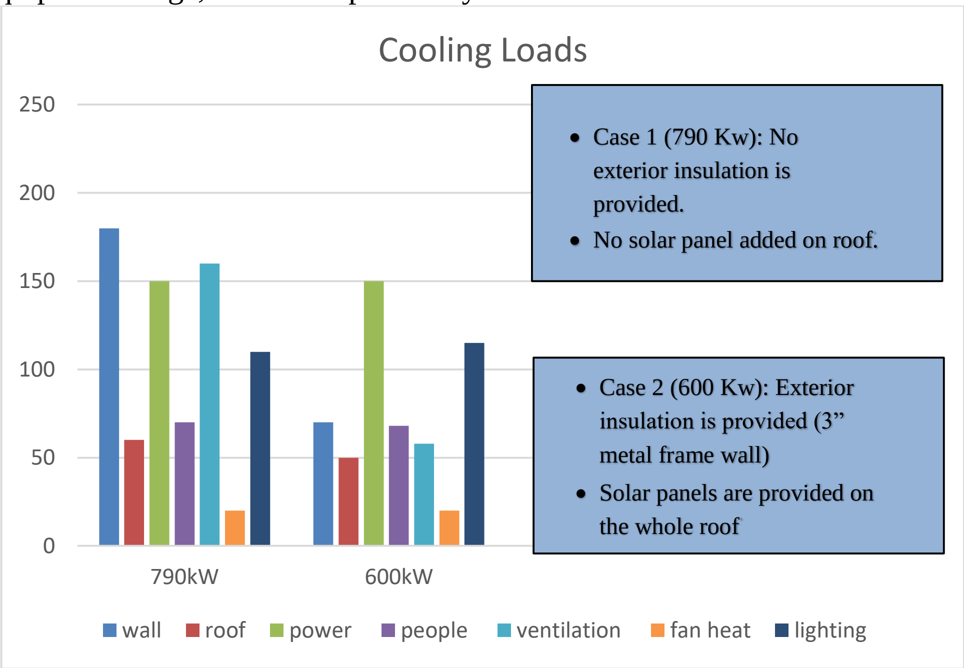

Figure.17: Comparison of cooling load with and without insulation (Source: Author)

The peak cooling load is 600 kW in the proposed factory building, so we need this quantity of energy to counteract the impact of heat and maintain a temperature of 27–28 ^{O}C in the summer. When comparing the energy generated by the solar panels installed in the factory, which is 850 kW, with the demand for energy that is 600 kW to maintain the normal interior temperature, it is clear that the solar panels are sufficient to meet the peak cooling load requirement while also giving 250 kW extra that may be utilized for other purposes. However, it suggests that more solar panels should be installed in the building to meet the energy requirements of the machines and other similar appliances.

Table 3: Thermal load parameters for hourly based Energy Analysis for proposed building (source: Author)

Parameter	**Value**
Energy Analysis	
Area per Person	260.00SF
Sensible Heat Gain per person	250.00Btu/h
Latent Heat Gain per person	200.00Btu/h
Lighting Load Density	1.20 W/ft^2
Power Load Density	1.00 W/ft^2
Infiltration Airflow per area	0.04CFM/SF
Plenum Lighting Contribution	20.0000%
Occupancy Schedule	Warehouse Occupancy – 7 AM to 4 PM
Lighting Schedule	Office lighting - 6 AM to 11 PM
Power Schedule	Office lighting - 6 AM TO 11 PM
Outdoor Air per Person	5.00 CFM
Outdoor Air per Area	0.06 CFM/SF
Air changes per hour	0.000000
Outdoor air method	By people and by area
Heating set point	21.11 ^{o}C
Cooling set point	28.00 ^{o}C
Humidification set point	0.0000 %
Dehumidification set point	70.0000%

The indoor environmental conditions of the connected production zone are controlled by a central HVAC system with an evaporation humidifier (the floor plan area is 203,129 square feet). The temperature and humidity are set to 22°C and 46%, respectively. The air exchange rate ranges between three and six times every hour **(see Table 3).** A solar panel system is installed on the whole roof, and a simulation is run for thermal load analysis. Building material parameters for this purpose are shown in **Figure 16**. For exterior insulated walls, the air gap in the cavity wall is kept at 1’-0" with the 3" metal skin to get the heat gain value of the walls. Moreover, peak cooling load is calculated for the interior environment before and after applying the insulation to the walls and roof and comparing it with the building without insulation. The result of the simulation clearly indicates that the building without insulation is using more energy (790 kW) than the building with insulation (600 kW), as shown in **Figure 17**. This implies that proper insulation can cut down on the energy usage of any building.

Table 4 Summary of zones with the effect of proposed installation of an air conditioning units on the building cooling energy demand (Source: Author)

Zone Summary	
Inputs	
Area (SF)	203,129
Volume (CF)	3,848,475.39
Cooling Setpoint	23°C
Heating Setpoint	21°C
Supply Air Temperature	12°C
Number of People	781
Infiltration (CFM)	0
Air Volume Calculation Type	VAV – Dual Duct
Relative Humidity	46.00% (Calculated)
Psychometrics	
Psychometric Message	None
Cooling Coil Entering Dry-Bulb Temperature	27°C
Cooling Coil Entering Wet-Bulb Temperature	18°C
Cooling Coil Leaving Dry-Bulb Temperature	10°C
Cooling Coil Leaving Wet-Bulb Temperature	10°C
Mixed Air Dry-Bulb Temperature	27°C
Calculated Results	
Peak Cooling Load (Kw)	**600.3**
Peak Cooling Month and Hour	June 3:00 pm
Peak Cooling Sensible Load (kW)	564.7
Peak Cooling Latent Load (kW)	54.6
Peak Cooling Airflow (CFM)	68.107
Peak Heating Load (kW)	110.5
Peak Heating Airflow (CFM)	16,090
Peak Ventilation Airflow (CFM)	16,090
Checksums	
Cooling Load Density (Btu/[h.ft^2])	10.40
Cooling Flow Density (CFM/SF)	0.34
Cooling Flow / Load (CFM / ton)	386.79
Cooling Area / Load (SF/ton)	1,153.61
Heating Load Density (Btu/[h.ft^2])	1.86
Heating Flow Density (CFM/SF)	0.08
Ventilation Density (CFM/SF)	0.08
Ventilation/Person (CFM)	21

Table 5 Result summary of thermal analysis (Source: Author)

Components	**Cooling**		**Heating**	
	Loads(kW)	**Percentage of Total**	**Loads(kW)**	**Percentage of Total**
Wall	83.8	12.46%	18.8	16.98%
Windows	0.0	0.00%	0.0	0,00%
Door	0.0	0.00%	0.0	0.00%
Roof	50.0	9.00%	0.0	0.00%
Skylight	0.0	0.00%	0.0	0.00%
Partition	0.0	0.00%	0.0	0.00%
Infiltration	0.0	0.00%	0.0	0.00%
Ventilation	62.6	10.25%	91.7	83.02%
Lighting	120.7	29.18%		
Power	151.0	24.55%		
People	78.9	12.74%		
Plenum	0.0	0.00%		
Fan Heat	12.3	1.98%		
Reheat	0.0	0.00%		
Total	600.3	100%	110.5	100%

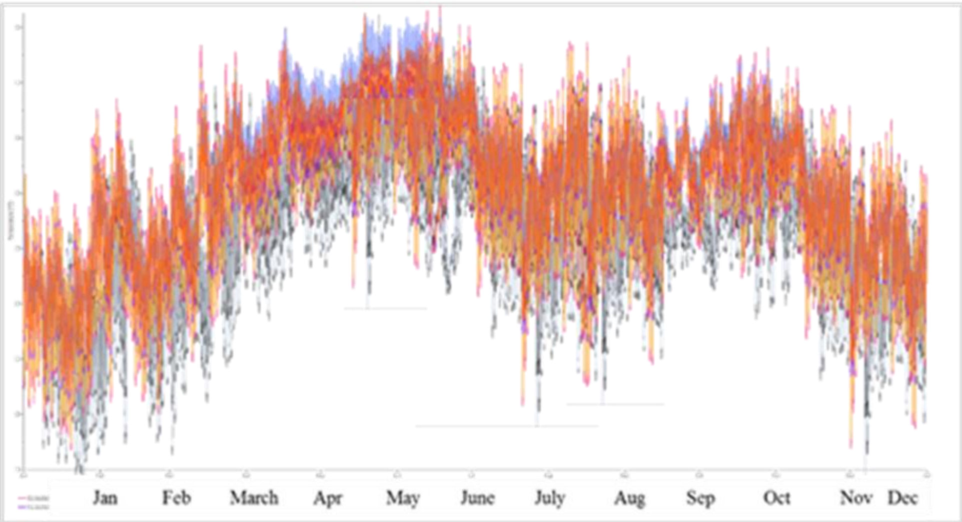

Figure.18: Temperature range within adaptive thermal comfort: 23.7 -29.1 degrees Celsius (source: Author)

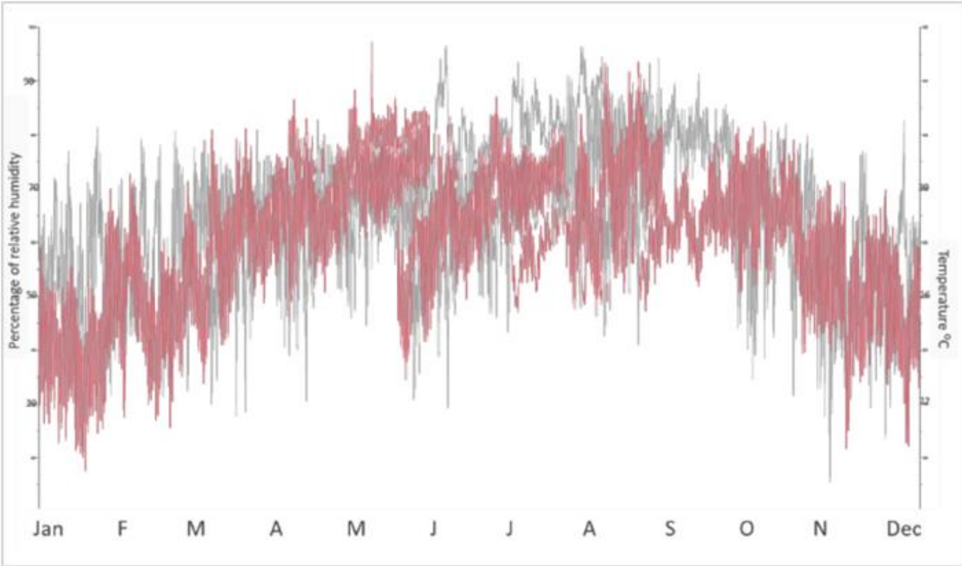

Figure.19: Comparison of relative humidity and temperature (source: Author)

The operative temperature of the factory is compared with the walls' construction techniques and solar-shaded smart skin or façade, adaptive to changing climatic conditions with and without ventilation. When simulated, a factory without cavity walls and no shading devices shows higher operative temperatures in all months and the least number of hours in the range of indoor thermal comfort. Block masonry walls with a cavity, climate-adaptive solar-shaded smart skin or façade, and a roof with the covering of solar panels give more hours within the range of adaptive thermal comfort when ventilated. According to the findings, switching from a standard 0'-6" concrete wall to a wall with cavities and a façade with a metal curtain wall can save up to 28 percent of energy **(see Table 5).**

When considering a factory's peak day performance in the summer, the interior operative temperature increases to 29.1 degrees Celsius without ventilation and reduces to 26.9 degrees Celsius with ventilation to 28.4–23.7 degrees Celsius **(see Table 4).** Figure 26 shows a graph comparing the performance of a factory building with an operative temperature in the adaptive thermal comfort range for the entire year when ventilated with the solar-shaded smart skin and metal curtain exterior walls.

Table 5 shows a graph that illustrates the outcomes of interior values from factory simulations with relative humidity and operative temperature; with ventilation, there appears to be a proportionate increase in relative humidity. Temperature drops when relative humidity rises, but people utilise fans to be comfortable. This suggests that increasing energy demand has a climate cause.

DISCUSSION

A shift towards implementing smart technology into the interior of buildings can solve the energy crises, ventilation and indoor comfort problems and provide better solutions in areas like warehouses and production areas where there is little natural ventilation or where conventional techniques, like air conditioners, cannot be a solution. All this work is based on the smart building concept and as a result, it is said that smart building guarantees minimum use of energy for cooling and maintaining a comfortable indoor environment for the users. Hence, based on the findings of the study, this research presented some suggestions that need to be incorporate in the design of any factory in Pakistan to make it users and environmental friendly.

Solar Shaded Smart Skin

Between the internal and external environments, the building skin serves as an environmental filter, addressing and resolving a variety of issues including technical performance, aesthetic appeal, and ventilation, among others. Adaptive facades are building skins that can change in response to changing weather on a daily, seasonal, or annual basis. In order to effectively and efficiently meet occupant comfort and well-being needs, an element must be able to adapt to or benefit from the conditions of the exterior environment. Unlike permanent facades, which remain in place regardless of the weather, adaptive facades are multi-parameter envelopes with excellent performance that can be mechanically or manually adjusted to meet the demands of occupants and internal loads. In addition, solar shading, often referred as "solar control" or "solar protection," encompasses a range of strategies used to reduce the quantity of heat and light entering a structure from the sun. It serves to improve the indoor environment as well as the comfort of building occupants (Premier, 2019). Research has supported the use of adaptive solar blinds. Therefore, a solar shaded smart skin that can adjust to changing climatic conditions and control the amount of both heat and light entering into the building is recommended.

Building Control System (BCS)

The HVAC systems are managed by the same building automation and management systems that control other aspects of the building, such as air quality, precipitation, and air velocity. The Building Control System allows HVAC management to be limited to times and locations where internal comfort is most needed in order to reduce energy consumption (Tahir et al., 2015). Therefore, it is recommended for use in factory buildings.

Thermal Comfort/ Temperature Control/ Dehumidifying and Dust Control

One of the major issues in the industrial sector is thermal comfort. This research suggested a solution to this issue by using chillers that can accurately work by using a smart control system to accurately manage the temperature of the interior environment, dehumidify paper storage areas, control dust in production areas, or maintain the specific temperature for product quality. The BA Smart is a modern-day air-handling unit with a specialized AHU controller, an inbuilt control panel, sensors, and a control valve. The controller and HMI display are designed by System Air. BA smart air handling, which is truly plug and play, not only saves space but can also reduce energy consumption by up to 40% (Wang et al., 2010).

Energy Consumption/ Solarization

Building energy consumption costs can be minimized by reducing their dependency on the main grid by using solarized energy. Excluding machine energy consumption, the rest of the energy requirements are fulfilled by making the proposed building a smart building that generates its own energy using 400W solar panels.
Panel dimensions are 2024.0 mm long by 1024.0 mm wide by 40.0 mm deep.

Smart LED Lights

DALI (Digital Addressable Lighting Interface) networked based lighting that controls lighting in building automation founded by Phillips's lighting in 1884 (Mahmoud, 2021) is suggested for use in the factory building.

Smart Sensors

Sensors in the proposed factory building are suggested for use to sense temperature, water, and humidity. The sensors are waterproof and are designed as industrial technology. It is easy to install, has a 15-year life span, and a long battery life (Frank, 2013).

CONCLUSIONS

Technology is developing and advancing at an extraordinary pace, and it is having an unprecedented influence on facilities and the building construction sector. More automated, customer-focused, and energy-efficient buildings are becoming the norm. A balance of smart building elements and architectural quality that is both aesthetically pleasing and functional must be created in light of the present array of technological breakthroughs, as this may help to satisfy user needs.

Architecture and technology have a long-standing interdependent connection in which developments in one discipline permit or require changes in the other. Contemporary architecture's new generation is significantly different from earlier generations. They are moving with the changing paradigms, and in today's world, smart technologies in building have changed the whole scenario of construction. Smart buildings, both domestic and non-domestic, have a technological identity, and technology is heavily involved in the design of their shape, volume, façade, and materials (Vaisi, 2012). Earlier, technology was limited only to residential architecture, but now industrial architecture is adopting it.

One of the necessities for sustainable industrial growth is the provision of an appropriate thermal environment for employees in order to improve their health and productivity. Installing a lot of expensive equipment and spending a lot of money on running it to keep the building at an acceptable temperature is a common way to attain comfort. However, a well-designed building with smart technologies allows residents to adapt it to their requirements and desires, such as adaptive solar blinds, moving partitions seasonally, etc.

On the other hand, a climate change study found a link between rising global temperatures and the rate at which heating, ventilation, and air conditioning (HVAC) systems are installed. Furthermore, since a major source of energy from fossil fuels has been widely used to generate electricity, the final energy demand is also concerned with energy conservation. Therefore, different strategies must be considered to conserve energy. The building envelope, particularly the selection of materials and design, as well as the surroundings, such as plants and vegetation to promote natural ventilation, are major elements determining building energy usage. Other significant factors include effective lighting, heating, ventilation, and air conditioning (HVAC) systems. Building envelopes, cooling systems, and appliances should all be carefully considered when designing structures, especially in tropical regions like Karachi. The climate has a significant impact on the selection of appropriate building technology, such as a cooling system and energy-efficient appliances. Finally, if natural ventilation is used, thermal comfort should be maintained with minimal building energy usage.

The simulation findings also demonstrated that automating lighting, adaptive solar shading devices, cavity walls, and door operation may significantly cut energy use. It was also shown that, depending on the building and HVAC performance features, a 50–60% reduction in energy consumption is achievable.

Data availability statement

The authors will make the raw data used to support this article's conclusion available without any delay.

Author contributions

Conceptualization, Humaira Nazir,and Bushra Khan; project administration, Humaira Nazir, Ubaid Ullah, and Bushra Khan**;** methodology, Humaira Nazir,and Bushra Khan; data collection, Humaira Nazir, and Bushra Khan; formal analysis, Humaira Nazir, Bushra Khan, Ubaid Ullah, and Hassaan Bilal Rashid; writing—original draft preparation Humaira Nazir; writing, review and editing, Humaira Nazir, Bushra Khan, and Ubaid Ullah; All authors have read and agreed to the published version of the manuscript.

ACKNOWLEDGEMENTS

The authors are very thankful to the Chairperson of the Department of Architecture and Environmental Design at SSUET, Mohammad Fazal Noor, and Pervez Sadiq, an Industrial Consultant, for their assistance throughout this study.

Conflict of interest

The study's authors declare that there were no financial or commercial links that may be viewed as having a possible conflict of interest.

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