Optimizing Office Building Energy Performance Through Integrated Design of Space Layout and Envelope Using eQuest

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Abstract- Buildings account for one-third of the global operational energy consumption and GHG gas emissions. The report by the IPCC (Intergovernmental Panel on Climate Change) shows that office buildings show an increasing trend in energy consumption. The share of demand for heating, cooling, and lighting the spaces in the building sector is significant in office buildings, as these are the most frequently used spaces. The proper design of office buildings can help reduce the operational energy consumption at the global level. This study seeks to find the optimum design solution for office buildings to achieve the objective. The space layout/plan form is a very important design parameter, along with the design of external walls. The Window Wall ratio is again an important design parameter in the design of the external wall/envelope. This study utilizes computer simulations to study the impact of space layout/plan form and WWR on energy consumption in office buildings in the semi-arid climate of Lahore. The tool used to generate the results is computer software eQuest. The office plan of the 6th Floor of the EE-2 building at the University of Lahore, Pakistan, is modelled as a case study. The findings indicate a significant 58.36% reduction in energy consumption when using an open-plan office layout compared to a cellular configuration at a 0.5 window-to-wall ratio (WWR) with windows exposed to the north direction. This study offers meaningful insights to support architects in making informed design decisions early in the planning process.

Keywords- Office buildings, Energy Consumption, Design, Space Layout, Window Wall Ratio

I. Introduction

Buildings are among the largest energy consumers worldwide, and this trend is particularly pronounced in Pakistan, where the building sector accounts for a significant share of the energy consumption, with HVAC systems consuming about 40 percent of total Energy in non-residential buildings [1]. According to the Intergovernmental Panel on Climate Change (IPCC), energy use in non-residential buildings, including office spaces, has been steadily increasing, primarily due to rising heating, cooling, and lighting demands. Office buildings, as some of the most frequently occupied spaces, play a critical role in this scenario due to inadequate climatic considerations [2-3]. Optimizing Energy performance of these buildings involves thoughtfully adjusting several design parameters such as, architectural space layouts, the building's geometric form, its orientation, the size and placement of windows, WWR, and the ratio between facade and floor area. Considering these parameters provide the opportunity to enhance energy efficiency and reduce environmental impact [4-5].

Space layouts of Office buildings have evolved considerably, transitioning from traditional cellular settings to green office designs. This has been shaped by historical, cultural, and technological developments, reflecting the changing needs of workplaces over time [6-7].

1.1. Evolution of the Design of Office Buildings

In the 19th century, cellular office layouts, characterized by enclosed spaces and individual rooms, were initially developed to prioritize privacy and minimize distractions [8]. In 1930, the rise of industrialization brought a surge in white-collar workers, leading to larger organizations and a need for more expansive office spaces. This era introduced the bullpen-style office, an open area with rows of desks grouped by department or function. While employees worked in these shared spaces, managerial staff retained private offices. This layout aimed to optimize space for growing workforces. The concept of the open-plan office emerged in Germany during the 1950s, inspired by the Burolandschaft or "office landscape." This design incorporated movable furniture and dividers, reflecting egalitarian values and promoting collaboration [9]. By the 1960s, open-plan offices became symbols of communication and teamwork, especially in Europe [10]. However, by the 1970s, they had evolved into simpler, more generic designs widely adopted by corporations, aiming to enhance communication and operational efficiency [11]. Over time, employees in open-plan offices began expressing concerns about noise and lack of privacy. In response, hybrid layouts combining cellular and open-plan designs became more common [12]. The 1990s marked a significant shift due to advancements in information technology, which allowed for more flexible and virtual working arrangements, reducing the need for traditional office spaces [13-14]. After the 2000s, the focus on sustainability led to the emergence of green office designs. These layouts prioritize natural ventilation, energy efficiency, and the use of sustainable materials. Studies have shown that employees in green offices report higher levels of happiness, health, and productivity. While these designs offer numerous benefits, such as better air quality and reduced sick days, they also come with higher construction costs, posing a challenge for widespread adoption [15].

The increasing demand for energy efficiency in buildings has placed significant emphasis on the role of architectural design and spatial layouts in achieving sustainable development goals [16]. Cellular and open office layouts can be improved for energy efficiency and adapted into green office designs to benefit occupant well-being [17]. Evaluating the energy performance of these layouts can guide the selection of the most suitable option, further supporting sustainable and environmentally friendly office design [18-19]. In hot and humid climates, such as that of Lahore, Pakistan, the energy performance of office buildings becomes a critical area of study due to high cooling and lighting demands. As office spaces constitute a substantial portion of urban building stock, optimizing their design to reduce energy consumption is both an environmental and economic imperative. This study aims to investigate the impact of office building layouts on energy performance. The study also highlights the role of envelope design on the energy performance of office buildings in the climate of Lahore, Pakistan. This study provides evidence-based recommendations for designing office buildings in a hot and dry climate (Semi-Arid) like Lahore that balance energy efficiency with occupant comfort and well-being. The findings will contribute to the broader discourse on sustainable building design, supporting architects, engineers, and policymakers in creating energy-efficient and user-friendly office spaces. The practical implications of the study will benefit the architects, designers at the initial design stage to make decisions regarding plan configuration and their impact on the overall energy performance of the office buildings.

1.2. Impact of Office Building Design on Energy Performance

Latha aims to determine the impact of space layout on Building Energy Performance, particularly in terms of lighting, ventilation, heating, and cooling loads, and identify the role of building perimeter variables on BEP. This research also investigates energy performance concerning layout changes across various building typologies in different geographic locations and climates. The systematic literature review methodology includes the initial retrieval of 4300 records published between 2006 and 2021 from journals with an impact factor greater than 2.0 on the Scopus database survey using keywords related to space layout and EPB. After applying exclusion criteria such as moving grey literature and non-English papers, this research narrows 55 relevant articles. The research indicates that 44% of articles utilized EnergyPlus for simulation, while the rest of the studies used other methodologies, including mixed methods, multi-objective optimization, case study, and statistical analysis. Synthesizing all articles, the authors highlight major key variables that significantly impact total energy demand along with thermal comfort and visual comfort, including the Orientation of the building and windows, layout configurations, shading details, window-to-wall ratio, glazing details, climate, and occupancy. Other influencing variables related to space layout on BEP include geographic location, climate, space occupancy data, and functional requirements. The review concludes that enhancing perimeter design variables and spatial configurations leads to significant energy savings. Well-thought-out layout design is the primary strategy to optimize energy consumption in all building typologies, especially in Hospital buildings that consume more energy than any other building due to diverse functional requirements. Proper size of buildings can lead to a reduction of 17-35% in energy consumption right glazing system can decrease energy load by 35%-40% [20].

Alghamdi presents a comprehensive study focusing on the impact of architectural building design parameters (ABDPs) on energy consumption and thermal comfort in Higher education buildings. By focusing on specific design choices, the authors aim to identify practical solutions to improve building performance while maintaining comfort levels for occupants. The study identifies fifteen ABDPs in an Australian Educational Building, lecture theatre, and their variabilities on Energy consumption and students' thermal comfort.

Based on the Literature Review, the following ABDPs are selected to perform the analysis.

1. Window to wall ratio.
2. Cooling Set-Point Temperature
3. Heating Set-Point Temperature
4. Building Rotation
5. External Wall construction
6. Roof Construction
7. Glazing Type
8. Local Study Type
9. Occupying Density
10. Mechanical Ventilation Rate per Area
11. Thermal Mass
12. Roof Window Openings
13. Building Locations
14. Infiltration
15. Crack Level

These parameters are selected based on their relevance to energy consumption and thermal comfort and are analysed using various simulation techniques to understand their collective impact on building performance. The study effectively demonstrates that strategic design decisions can substantially improve energy efficiency and thermal comfort in educational buildings. By prioritizing high-impact ABDPs, such as set-point temperatures and roof insulation, architects and engineers can create sustainable learning environments. Although the study's scope is geographically constrained, its findings offer valuable insights into optimizing building designs for energy and comfort goals. Future research could expand on this work by including diverse climatic zones and dynamic occupant behaviour models [21].

Srithongchai identifies thinner wall constructions and low-mass buildings in tropical climate areas that are exposed to environmental conditions with high temperatures and humidity. This study suggests the need for effective architectural solutions to mitigate these challenges, focusing on building layouts as a fundamental design solution. The study explores how 17 unique layout shapes, all designed with the same indoor volume, floor area, and set in Bangkok's climate, respond to sunlight. By observing how solar exposure influences indoor temperatures and the need for cooling energy, the research aims to uncover which geometric forms perform better in maintaining thermal comfort and reducing energy demand. The literature review highlights the critical role of thermal comfort for occupant well-being, emphasizing the need for energy-efficient designs in response to climate-specific challenges. After reviewing various articles, this study determines that key factors such as building form, window-to-wall ratio, surface area, and solar heat protection by self-shading significantly affect cooling and lighting energy demands. It justifies the need for this study by pointing out that most research on building performance has focused on non-tropical climates, leaving a gap in understanding how these factors apply to tropical regions. This research employs building energy modelling software SketchUp Modeler, Open Studio Thai version 1.7.0.7, and Energy Plus to conduct the simulation in two phases: with and without AC. The former phase examines the effect of exterior conditions on indoor DBT (Dry Bulb Temperature) while the latter explores how much sensible cooling energy is required to condition the indoor air. This study creates 17 distinct building shapes in SketchUp, from simple squares and circles to intricate forms like L-shapes, courtyards, and clusters and uses Open Studio and EnergyPlus to simulate how each design behaves thermally in Bangkok's climate. The analysis of wall area, sun exposure, shading, and energy use reveals how a building's layout directly influences its cooling demands [22].

Du investigates how the layout of interior spaces in office buildings influences their energy use for lighting, heating, and cooling across different climates. By examining eleven layout variations in a standardized office model, the research tests performance in three cities; Amsterdam, Harbin, and Singapore, representing temperate, cold, and tropical climates. To isolate the impact of layout design, other factors such as building materials, insulation, occupancy, and window-to-wall ratios are kept constant. Using advanced simulation tools Daysim for daylight analysis and Energy Plus for energy modelling, the study provides clear insights into how spatial planning can support energy efficiency, both with and without external shading. The results reveal that lighting demand is most affected by layout differences, with up to 46% variation seen in colder climates like Harbin. Strategic design choices, such as room orientation and space arrangement, proved especially important in managing energy needs. In temperate climates like Amsterdam, the placement of functions, particularly in sun-exposed areas significantly reduced heating requirements. Meanwhile, in tropical climates such as Singapore, thoughtful layouts helped minimize unwanted solar heat gain. Overall, the research underscores that small changes in space layouts can lead to meaningful improvements in energy performance, offering valuable guidance for climate-responsive office design [18].

Du Investigate how architectural space layout impacts Building Energy Performance (BEP). It aims to analyse the separate effect of space layout on heating, cooling, lighting, thermal comfort, and visual comfort. Research conducted a comprehensive literature review was conducted of 10 relevant articles to understand the existing methodologies and findings related to interior space layout and their effects on BEP. It proposes a method for studying the impact of space layout on BEP that includes identifying design variables (such as function allocation, space dimension, space form, interior partition, and interior planning) and energy indicators (energy end use, assessment period, and system boundary). The proposed method also suggests using BEP calculation methods (steady state method and dynamic simulation) that integrate daylighting and natural ventilation with energy simulation. The study uses this procedure to review all articles, as one article review is discussed in this paper as an example. Further, this study analyses the effect of space layout and changed WWRs, window orientations, shading systems, and floor areas on occupant comfort and visual comfort. Simulation tools used in different articles are Energy Plus, TRNSYS, IDA Indoor Climate, ESP-r, and Clim 2000. This study reveals that the energy used for heating, lighting, and ventilating in office buildings has been reduced by changes in space layouts as well as thermal and visual comfort. This research sets the foundation for future research in the critical area of architectural design.

The reviewed literature highlights significant progress in understanding the relationship between space layout and energy performance. Key findings consistently underline that space layout, coupled with optimized design parameters, can significantly enhance energy efficiency and occupant comfort across diverse building typologies and climatic zones. The existing literature about educational buildings specifically focuses on the active study areas, such as classrooms and computer labs, but the faculty offices areas of educational buildings remain unexplored. Furthermore, the effect of layout configurations with varying geometries or rearranging the functional zones of the layout has also been tested to check the building energy performance. Energy Analysis of faculty office spaces of educational buildings in a semi-arid climate can give a new insight. Additionally, a simulation-driven comparison of cellular and open-plan office layouts using eQuest can offer fresh insights into their distinct impacts on building performance, addressing a gap overlooked in existing research [23].

II. METHODOLOGY

This quantitative study uses the dynamic method of calculation using a computer simulation. The tool used to conduct simulations is eQUEST software version 3.65.7175. Many engineers and energy analysts have used this tool, which has been proven effective as an energy optimization tool. This study uses this tool to compare heating, cooling, and lighting energy loads across two different office space layouts: cellular plan and open office plan. Typical Meteorological Year (TMY) data for Lahore is employed to incorporate realistic climatic conditions, including temperature, humidity, and solar radiation, into the simulations.

2.1. Existing and Proposed Layout Model Description

The existing model for this research is the Faculty Office Wing in the EE building,6th Floor, at the University of Lahore, located in Lahore, Pakistan. (Figure 1.).

Figure 1. Satellite map of the University of Lahore, Lahore

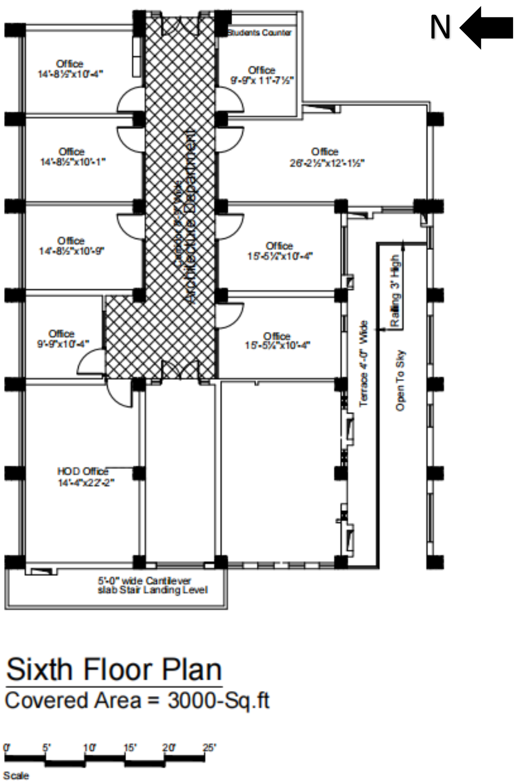


Figure 2. Layout of the Base Case Model
Source: Author

The building is situated in a hot semi-arid climate characterized by high temperatures during summer and mild winters. The total area of the office wing is 3000 square feet, designed to accommodate 20-25 occupants, including the Head of Department, senior faculty members, and administrative staff. The spatial configuration comprises key functional areas such as a Head office, a coordinator office, faculty offices, an admin space, a kitchen, male and female toilets, and a corridor with rows of offices along both sides. (Figure. 2)

The building's architectural features include an exposed wall on the north side with large windows, which allow significant daylight penetration. The north-facing wall has a Window Wall Ratio up to 0.5. This means that 50% of the wall is covered with the glazing material, i. e glass. The south-facing wall has small windows that open into a narrow service area. This limits the penetration of natural light in the office spaces facing the south side.

In the proposed layout model, all the partitioned walls of faculty offices have been removed. While the service area and the coordinator's office remain untouched. Rows of 22 faculty workstations have been arranged along the North-facing wall and the south-facing wall. (Figure. 3).

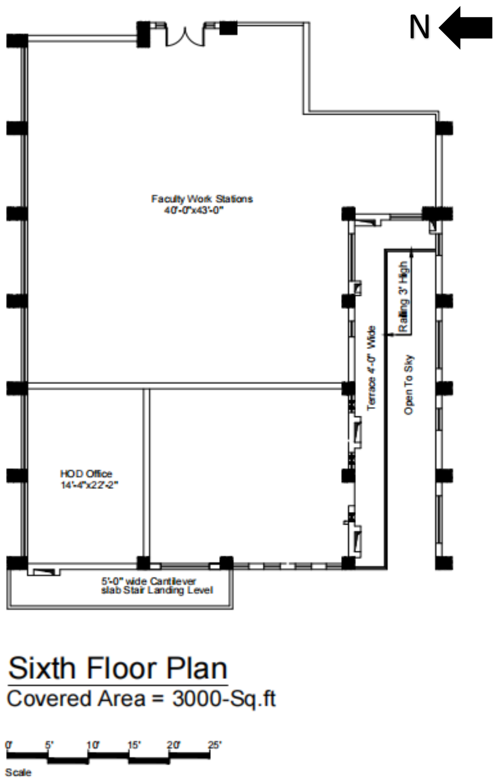


Figure 3. Layout of the Proposed Model
Source: Author

First, the simulation was carried out to find the separate effect of space layout on energy consumption. Two separate models for the base case and proposed layout were created in separate files based on the field investigation and final construction drawing. The information entered for both files was identical, with no variations in content or formatting between the two. The models of this educational building include six floors with a basement. The floor-to-floor height of this story is 13 ft, and to floor-to-ceiling height is 12 ft. The building structure is a cast-in-situ reinforced concrete frame structure. In the base case model internal partition walls were treated as adiabatic surfaces within the thermal zoning of the simulation software. A central air conditioning system, a DX fan coil, was modelled with identical efficiency and cooling set points (cooling setpoint = 24°C) in all scenarios. The following scenarios have been created.

Case 1: Base Case with WWR 0.5

Case 2: Proposed Model with WWR 0.5

As the literature showed, WWR is one of the significant design parameters in layout that can influence heating and cooling load as well as energy performance of the buildings. The following scenarios have been created.

Case 3: Plan with existing partition walls with a reduced WWR, i.e., 0.4

Case 4: Proposed Model without partition walls with reduced WWR, i.e, 0.4

Case 5: Plan with existing partition walls with a reduced WWR, i.e, 0.3

Case 6: Proposed Model without partition walls with reduced WWR, i.e, 0.3

Case 7: Plan with existing partition walls with a reduced WWR, i.e, 0.2

Case 8: Proposed Model without partition walls with reduced WWR, i.e, 0.2

Tables 1 and 2 are given, which show the details of the scenarios created in the software to generate results. The generated scenarios are compared via simulation eQuest, investigating the role of the presence and absence of partition walls and their impact on energy performance.

Table-1. Details of Case 1 & 2, which were compared via simulation eQuest

Sr.#	**Variables**	**Case-1**	**Case-2**
1.	Partition Walls	Yes (Base Case)	No (Proposed Model)
2.	WWR	0.5	0.5

Table-2. Details of Cases 3, 4, 5, 6, 7 & 8, which were compared via simulation eQuest

Sr.#	**Variables**	**Case-3**	**Case-4**	**Case-5**	**Case-6**	**Case-7**	**Case-8**
1.	Partition Walls	Yes (Base Case)	No (Proposed Model)	Yes (Base Case)	No (Proposed Model)	Yes (Base Case)	No (Proposed Model)
2.	WWR	0.4	0.4	0.3	0.3	0.2	0.2

Eight different scenarios were adopted to analyse the effects of varying WWR on energy consumption for heating, cooling, and lighting. These scenarios were applied to both types of models. For this simulation, building orientation and other parameters, including building envelope properties, construction details, and U-values of walls, floor, and roofs, HVAC system type and operational schedules, heating and cooling set point temperatures, lighting power density, equipment loads, and occupancy schedules, remain constant. Only the size of windows, i.e. WWR, remains a variable parameter. Then, by keeping WWR and other variables constant, the separate effect of building orientation on energy consumption was measured, using both types of layouts. The user interface of the software and the model of the building are presented in Figure 4.

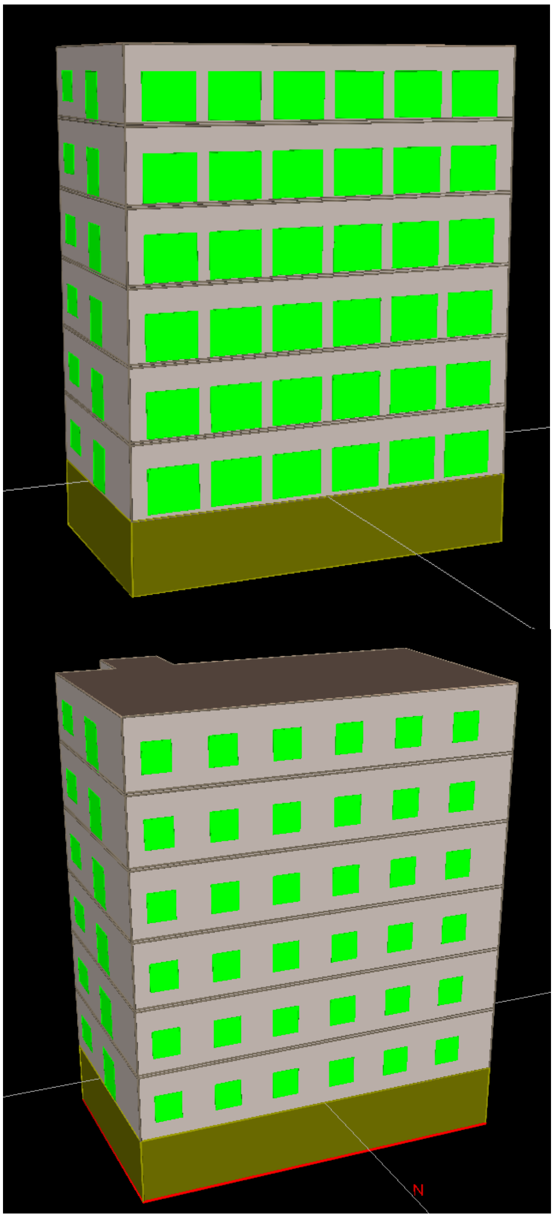


Figure 4. Energy Simulation Models with 50 % and 20 % windows on North wall generated from eQuest

III. Results and Discussion

The results of the simulations are discussed in this section. The impact of the layout of space has been studied by conducting simulations with the base case, i.e., the existing plan, against the proposed model, i.e. the model in which partition walls have been removed. Figure 5 (a) & (b) represent the graphs of electric and gas consumption generated from the software for Case-1 and the table showing total electric consumption of the year. Figure 6 (a) & (b) represent the graphs of electrical and gas consumption for Case-2 and the table of total electric consumption for the year generated from software. The results of the total electric consumption of both Case 1 & 2 are compared in Table 3.

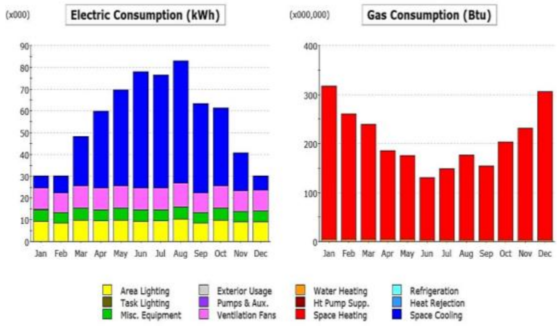
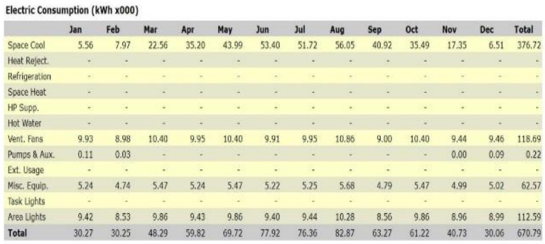


Figure 5. (a) Annual Electric Consumption (kWh x 1000) and Gas consumption (Btu x 1000,000) graphs for Case-1 generated from the software



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	5.56	7.97	22.56	35.20	43.99	53.40	51.72	56.05	40.92	35.49	17.35	6.51	376.72
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	9.93	8.98	10.40	9.95	10.40	9.91	9.95	10.86	9.00	10.40	9.44	9.46	118.69
Pumps & Aux.	0.11	0.03	-	-	-	-	-	-	-	-	0.00	0.09	0.22
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	5.24	4.74	5.47	5.24	5.47	5.22	5.25	5.68	4.79	5.47	4.99	5.02	62.57
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	9.42	8.53	9.86	9.43	9.86	9.40	9.44	10.28	8.56	9.86	8.96	8.99	112.59
Total	30.27	30.25	48.29	59.82	69.72	77.92	76.36	82.87	63.27	61.22	40.73	30.06	670.79

Figure 5. (b) Table generated by the software for Case 1 showing Total Electric Consumption (kWh x 1000) for the year

Figure 5 (b) shows the bar diagrams, generated through software, showing the breakdown of electricity consumption and gas consumption annually. Note that the values in Figure 5 (b) and all the results from eQuest, including Figure 6 (b), 7(b), and 8(b), 9 (b), 10 (b) , 11 (b) and 12 (b) should be multiplied by 1000.
It is evident from Figure 5 (a) and Figure 5 (b) that space cooling is higher in June, July & August, i.e, up to 85000 kWh. Similarly, gas consumption is higher in December and January, i.e, above 300,000,000 Btu.

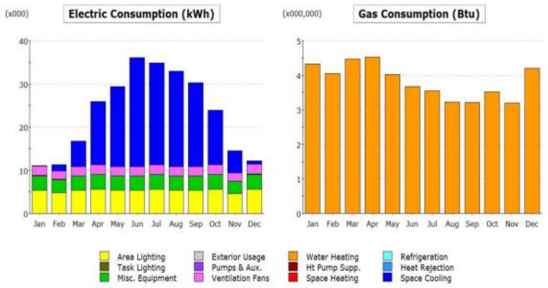


Figure 6. (a) Annual Electric Consumption (kWh x 1000) and Gas consumption (Btu x 1000,000) graphs for Case-2 generated from the software

It is evident from Figure 6 (a) and Figure 6 (b) that space cooling is higher in June, July & August, i.e, up to 35000 kWh. Similarly, gas consumption is higher throughout out the year i.e. above 3000,000

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.14	1.52	5.95	14.68	18.56	25.35	23.54	22.17	19.49	12.67	5.18	0.75	150.01
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	2.12	1.92	2.12	2.22	2.12	2.12	2.22	2.12	2.12	2.22	1.82	2.22	25.32
Pumps & Aux.	0.11	0.03	-	-	-	-	-	-	-	-	0.00	0.09	0.22
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	3.32	3.01	3.33	3.44	3.32	3.31	3.46	3.32	3.31	3.46	2.91	3.46	39.64
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	5.36	4.85	5.36	5.60	5.36	5.36	5.61	5.36	5.36	5.61	4.62	5.61	64.07
Total	11.06	11.32	16.76	25.94	29.37	36.14	34.82	32.98	30.27	23.95	14.53	12.12	279.26

Figure 6. (b) Table generated by the software for Case 2 showing Total Electric Consumption (kWh x 1000) for the year

Table 3. Electric Consumption(kWh x 1000) for Base Case Model and Proposed Layout Model

Sr.#	WWR	Case-1	Case-2
1.	0.5	670 x 1000	279 x 1000

The results in Table 3 show that the existing plan shows higher electric consumption, i.e., up to 670,000 kWh, and when partition walls have been removed in the same space in the proposed building model, the electric consumption is reduced to 279,000 kWh, showing a significant reduction. This reduction represents a significant decrease in simulated energy consumption. According to this, open plans perform better in hot climates as compared to cellular models with different enclosed spaces. The above cases have been analysed with the existing WWR, i.e., 0.5. The only varying parameter in the design was the removal of partition walls.

The next series of simulations has been conducted by varying Window Wall Ratios in both the existing cellular plan as well as open plan, removing partition walls. The simulations have been conducted to study the impact of window size in both types of plans. The details of the cases have been given in Table 2. Figure 7 (a) & (b), Figure 8 (a) & (b), Figure 9 (a) & (b) ,Figure 10 (a) & (b), Figure 11 (a) & (b) and Figure 12 (a) & (b) represent the graphs of electrical and gas consumption for Case-3, Case-4, Case-5, Case-6, Case-7 & Case-8 generated from software, respectively.

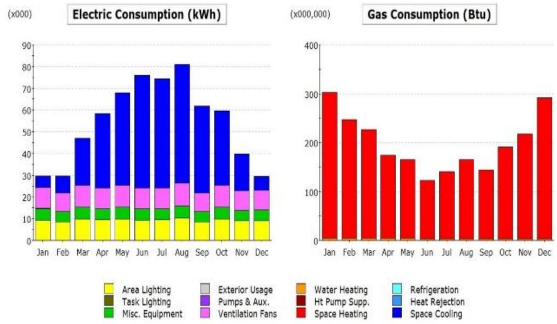


Figure 7 (a). Annual Electric Consumption (kWh x 1000) and Gas consumption (Btu x 1000,000) graphs for Case-3 generated from software

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	5.37	7.68	21.76	34.04	42.58	51.83	50.24	54.47	39.75	34.39	16.76	6.26	365.13
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	9.52	8.61	9.97	9.54	9.97	9.50	9.54	10.41	8.63	9.97	9.05	9.07	113.78
Pumps & Aux.	0.11	0.03	-	-	-	-	-	-	-	-	0.00	0.09	0.22
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	5.24	4.74	5.47	5.24	5.47	5.22	5.25	5.68	4.79	5.47	4.99	5.02	62.57
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	9.42	8.53	9.86	9.43	9.86	9.40	9.44	10.28	8.56	9.86	8.96	8.99	112.59
Total	29.67	29.59	47.06	58.24	67.88	75.94	74.47	80.84	61.73	59.69	39.75	29.41	654.29

Figure 7. (b) Table generated by the software for Case 3 showing Total Electric Consumption (kWh x 1000) for the year

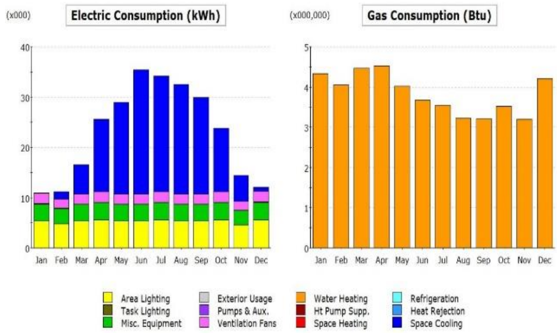


Figure 8 (a). Annual Electric Consumption (kWh x 1000) and Gas consumption (Btu x 1000,000) graphs for Case-4 generated from software

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.14	1.47	5.80	14.38	18.19	24.77	23.03	21.77	19.24	12.55	5.11	0.73	147.18
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	2.04	1.84	2.04	2.14	2.04	2.04	2.14	2.04	2.04	2.14	1.75	2.14	24.36
Pumps & Aux.	0.11	0.03	-	-	-	-	-	-	-	-	0.00	0.09	0.22
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	3.32	3.01	3.33	3.44	3.32	3.31	3.46	3.32	3.31	3.46	2.91	3.46	39.64
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	5.36	4.85	5.36	5.60	5.36	5.36	5.61	5.36	5.36	5.61	4.62	5.61	64.07
Total	10.97	11.20	16.53	25.55	28.91	35.47	34.23	32.49	29.94	23.75	14.39	12.02	275.47

Figure 8 (b) Table generated by the software for Case 4 showing Total Electric Consumption (kWh x 1000) for the year

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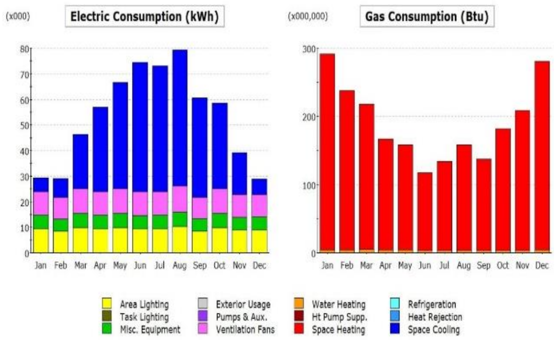

Figure 9 (a). Annual Electric Consumption (kWh x 1000) and Gas consumption (Btu x 1000,000) graphs for Case-5 generated from the software

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	5.24	7.47	21.17	33.17	41.54	50.66	49.14	53.30	38.88	33.60	16.33	6.07	356.57
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	9.22	8.34	9.66	9.24	9.66	9.20	9.24	10.08	8.36	9.66	8.76	8.78	110.16
Pumps & Aux.	0.11	0.03	-	-	-	-	-	-	-	-	0.00	0.09	0.22
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	5.24	4.74	5.47	5.24	5.47	5.22	5.25	5.68	4.79	5.47	4.99	5.02	62.57
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	9.42	8.53	9.86	9.43	9.86	9.40	9.44	10.28	8.56	9.86	8.96	8.99	112.59
Total	29.23	29.10	46.16	57.07	66.52	74.48	73.07	79.34	60.58	58.59	39.04	28.94	642.12

Figure 9 (b) Table generated by the software for Case 5 showing Total Electric Consumption (kWh x 1000) for the year

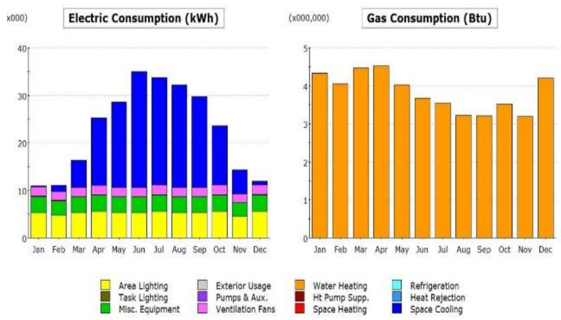

Figure 10 (a). Annual Electric Consumption (kWh x 1000) and Gas consumption (Btu x 1000,000) graphs for Case-6 generated from software

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.14	1.44	5.69	14.15	17.90	24.33	22.65	21.46	19.05	12.45	5.06	0.72	145.04
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	1.98	1.79	1.98	2.07	1.98	1.98	2.07	1.98	1.98	2.07	1.70	2.07	23.65
Pumps & Aux.	0.11	0.03	-	-	-	-	-	-	-	-	0.00	0.09	0.22
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	3.32	3.01	3.33	3.44	3.32	3.31	3.46	3.32	3.31	3.46	2.91	3.46	39.64
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	5.36	4.85	5.36	5.60	5.36	5.36	5.61	5.36	5.36	5.61	4.62	5.61	64.07
Total	10.91	11.11	16.36	25.26	28.57	34.97	33.79	32.13	29.69	23.58	14.29	11.94	272.62

Figure 10 (b) Table generated by the software for Case 6 showing Total Electric Consumption (kWh x 1000) for the year

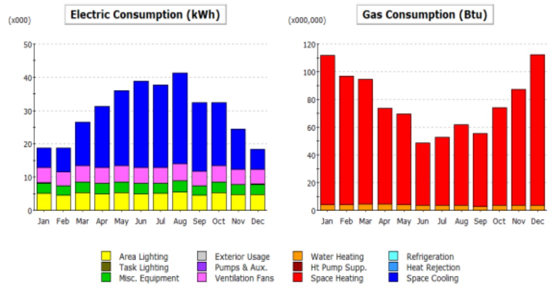

Figure 11 (a). Annual Electric Consumption (kWh x 1000) and Gas consumption (Btu x 1000,000) graphs for Case-7 generated from software

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	5.89	7.05	13.14	18.37	22.57	25.99	24.94	27.39	20.79	19.07	12.16	6.03	203.40
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	4.64	4.20	4.86	4.64	4.86	4.64	4.64	5.08	4.20	4.86	4.42	4.42	55.46
Pumps & Aux.	0.06	0.02	-	-	-	-	-	-	-	-	0.00	0.05	0.13
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	3.16	2.86	3.29	3.15	3.29	3.15	3.17	3.42	2.90	3.29	3.02	3.04	37.74
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	5.03	4.55	5.25	5.02	5.25	5.02	5.03	5.48	4.56	5.25	4.79	4.80	60.03
Total	18.78	18.67	26.54	31.18	35.98	38.80	37.77	41.37	32.45	32.48	24.39	18.34	356.74

Figure 11 (b) Table generated by the software for Case 7 showing Total Electric Consumption (kWh x 1000) for the year

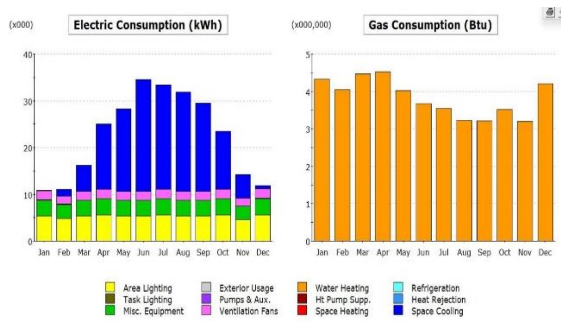

Figure 12 (a). Annual Electric Consumption (kWh x 1000) and Gas consumption (Btu x 1000,000) graphs for Case-8 generated from software

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.14	1.41	5.60	13.96	17.66	23.96	22.33	21.20	18.89	12.38	5.04	0.71	143.29
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	1.93	1.74	1.93	2.02	1.93	1.93	2.02	1.93	1.93	2.02	1.65	2.02	23.05
Pumps & Aux.	0.11	0.03	-	-	-	-	-	-	-	-	0.00	0.09	0.22
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	3.32	3.01	3.33	3.44	3.32	3.31	3.46	3.32	3.31	3.46	2.91	3.46	39.64
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	5.36	4.85	5.36	5.60	5.36	5.36	5.61	5.36	5.36	5.61	4.62	5.61	64.07
Total	10.86	11.04	16.22	25.02	28.28	34.55	33.41	31.82	29.48	23.46	14.23	11.88	270.26

Figure 12 (b) Table generated by the software for Case 8 showing Total Electric Consumption (kWh x 1000) for the year

The above Figures clearly show that space cooling is reduced when an open plan is simulated. The reduction from 80000 kWh to 35000 kWh on average. This shows the better performance of the open plan rather cellular plan. All the results of the electric consumption breakdown indicate that space cooling is a major contributor to the overall energy performance of buildings in local climatic conditions. The above results are compared in Table 4 in terms of the total electric consumption of the year.

Table 4. Electric Consumption kWh for Base Case Model and Proposed Layout Model with varying Window Wall ratios (Reducing WWRs)

WWR	0.4	**Case-3**	**Case-4**
	0.4	654 X 1000	275 x1000
WWR	0.3	**Case-5**	**Case-6**
	0.3	642 x 1000	272 x 1000
WWR	0.2	**Case-7**	**Case-8**
	0.2	356 x 1000	270 x 1000

Table 4 shows the electric consumption of the space with different window sizes, both in the existing cellular plan as well as open plan, which is proposed after removing partition walls. The results show different trends. Electric consumption is always lower in open plans with all window sizes as compared with the cellular plan, which is composed of many enclosed spaces. Only when the Window Wall Ratio is 0.2 (window covers 20% of the Wall area), the value of electric consumption is slightly different in cellular plan as compared to open plans. The difference in the value of electric consumption between WWR 0.4 and 0.3 is high in both types of plans. In the case with 0.4 WWR, the electric consumption of the existing cellular plan is 654,000 kWh, while it is 275,000 kWh in the open plan with the same WWR. In the case with 0.3 WWR, the electric consumption of the existing cellular plan is 642,000 kWh, while it is 272,000 kWh in the open plan with the same WWR. If the trends in both types of plans are observed regarding different WWRs, the cellular plan with small, enclosed spaces shows a significant reduction in electric consumption with a reduction in window sizes. The electric consumption reduces from 654,000 kWh to 356,000 kWh with a reduction in WWR from 0.4 to 0.2. On the other hand, the electric consumption does not show a significant change with a reduction in window sizes in the open plan. It reduces from 275,000 kWh to 270,000 kWh with WWR from 0.4 to 0.2.

IV. Conclusion

The space configuration or plan layout is a very significant factor that impacts the energy consumption in buildings. The research was conducted to investigate the effect of cellular plans and open plans on the energy consumption in semi-arid climates in office spaces. The study utilized dynamic simulations using eQuest to generate the results. The following conclusions can be derived from the results.

1. Open plans perform better compared to cellular plans in the climate of Lahore, which is semi-arid as far as energy consumption is concerned.
2. Cellular plan models can work well with lower Window wall Ratios, i.e, up to 0.2. This is for the external wall exposed to the North side.
3. Window size significantly impacts energy consumption in cellular plans but shows minimal effect in open plans within the tested WWR.range.

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