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A Statistical Approach to Determine the Relationship between the Shape of Skyscrapers and Energy Consumption in Kuwait City

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Abstract: ***The skyscrapers in Kuwait draw the new skyline of Kuwait City. Wandering through streets of Kuwait City, one can observe new skyscrapers already formed the new urban image of modern Kuwait City, each skyscraper with a unique shape and form, width and height, glass and solid facade. One, therefore, questions the energy performance of new skyscrapers and electrical consumption load rests on the city. Sixteen skyscrapers are selected as case studies from four areas in Kuwait City: Jebla, Sharq, Mirqab and Bneid Al-Qar. On the other hand, eight shape variables are determined including: X_1 = Area of Average Floor Plan in (m^2), X_2 = Height (m), X_3 = Volume in (m^3), X_4 = Surface Area (m^2), X_5 = Compactness (m), X_6 = Shape Coefficient in (m^{-1}), X_7 = Relative Compactness and X_8 = South Exposure (m^{-1}). The purpose of the study is to study the relationship between the eight variables and the electrical consumption of each of the 16 case studies. A multiple linear regression operation (MLR) within the Microsoft Excel add-ins had been performed, then, a mathematical hypothesis had been employed after the statistical process to discover the overall model strength by (F-Significance) where its value was between 0 and 0.05 which is statistically significant and through the (P-Values). Four variables had been succeeded with values between 0 and 0.05, and they are X_1 (Area of Average plan), X_2 (Height), X_5 (Compactness), and X_7 (Relative compactness). Consideration, therefore, must be given to the four mentioned variables from the initial design stage in order to achieve efficient and sustainable skyscrapers at Kuwait City and other cites of Arabian Gulf.***

Keywords: Skyscrapers, Tall Buildings, electrical consumption, Energy Consumption, Statistical Regression

1.Introduction

Kuwait City has been a focal point for business and trading through more than 400 years ago. Kuwait is known as a commercial seaport in the Arabian Gulf, the trips and dive for the pearls, the source of economic and income for population before the black gold, the oil.

Kuwait City is flourishing-up with a construction of high-rise towers mainly consisted of the offices and retails and built mainly from reinforced concrete covered almost with glazing, thus leads to an economic booming in the business sector. While the need for the office buildings had increased, building more commercial and mixed-use towers was the solution to this demand. On the other hand, these fabulous tall buildings consume more energy and emit more CO_2 and greenhouse gases GHG to the environment.

Kuwait has desert composite arid climate with extremely hot and sandstorms in summer and cold in winter with a latitude that is ranged between °28.30` - °30.06` to the north of the equator and between the longitudes of °46.30` - °48.30` to the east of Greenwich (CSB, 2017-2018). The summer is the longest season in Kuwait from May to November where high increase in temperatures and some humidity, whereas the winter is a short season from December to February with a northwesterly wind.

Arid climate with high temperature degrees in Arabian Gulf area forms a dilemma that leads to continuous use for the Air-Conditioning (AC) during approximately nine months in the whole year, which means an excessive use for electricity. The large area of glazing, complicated systems and thermal comfort needs are factors increasing the need for more energy consumption.

The increasing in demands had raised up during the ten years 2007 to 2017 to 1.5 times. Kuwait has 10 power stations that generate electricity and the largest production through South Alzour and Sabiya where the generated energy is 17, 324 and 20, 327 million kWh respectively during the year 2017 (CSB, 2017-2018). The peak demand in megawatt (MW) had been increased through the 10 years; 2007 to 2017 from 9, 070 to 13, 800 and the installed capacity in megawatt (MW) is also raised within the same period from 10, 481 to 18, 743 (MEW, 2018). The population in Kuwait in year 2007 are 3, 399, 637 with kWh/Person equal to 12, 527, and this value is also grown-up after 10 years to reach 14, 413 per capita consumption in 2017 where the population reached 4, 500, 476 (MEW, 2018). These statistical numbers ensure the high demand of electricity consumption and enhance the importance of this.

This study considers several factors that are related to the shape and form of skyscrapers in Kuwait City In this paper the authors will examine the relationship between eight factors namely as: height, volume, compactness, shape coefficient, relative compactness, average floor area, surface area and south exposure.

2.Problem Definition

The increase demands to build more skyscrapers at Kuwait City have created extra load for energy consumption and extra demands for electrical production. The complexity of architectural forms of new skyscrapers is rising during the present and expected to increase in the future without limitations or controlling. Therefore, it is important to identify design parameters that will reduce the energy consumption of skyscrapers.

3.The Purpose

- To determine what are the building factors that have significant relationships to the energy consumption of skyscrapers in Kuwait City. The geometry factor of the skyscraper could play an important role in the effect on the energy consumption of the towers.
- To suggest design guidelines for better skyscrapers that will reduce energy consumption.

4.The Importance of the Study

The lack of studies on the Arabian Gulf region regarding to the shape, form, and energy consumption of skyscrapers is the main motive for this study. Results will develop new standards for shape factors of skyscrapers. Results will also help decision-makers in governmental parties developing building codes of practice that is related to the construction of skyscrapers, as well as to support architects in the evaluation processes for architectural design to achieve green buildings.

5.Criteria for Selecting Case Studies

The study is applied on commercial towers in Kuwait City with similar properties in their coastal location on the Arabian Gulf, where all of them had the percentage of occupancy above 90-95% approximately. The average age for the selected towers is 14 years, where they were ready to be used in the year of 2008, after the construction stage and with average number of floors equals to 36.

6.Literature Review

The importance of geometry in environmental performance is demonstrated in (Aya et al., 2021) study where properties and transformation are the parameters of geometrical shape to develop the architectural form. A relative compactness and thermal comfort are related to electricity consumption as concluded from (El-Agami et al., 2021) study. The height of the building is related to the relative compactness with a positive proportional relationship within the area of the heat load of the building (Khamma & Boubekri, 2017).

The shape envelope is a good factor that would be considered in energy consumption of the building as it was clearly noticed in (D'Amico & Pomponi, 2019) theoretical modeling study. The Glazing, building shape and orientation are variables that effect on compactness and relative compactness and both of the last two parameters are important factors of heat load and energy consumption (Pessenlehner & Mahdavi, n.d.). The shape coefficient is an important factor for the building load where increasing the total surface area will increase this factor and the overall energy load (Lin et al., n.d.).

The shape of surface area can be a significant factor that plays a role in cooling load thus affecting directly on the overall energy consumption of the building. The study of (Raof, 2017) indicated that, the rectangular façade is better than curved one in AC load without glazing area and the concave and convex facades had different interaction with environment at summer and winter seasons which is an indicator for the sensitivity of the façades design toward the climatic situation (Raof & Gadi, 2013). The study demonstrated that the shape of the building is regarded as highly valuable to electricity consumption and climate as well, where the horizontal curve of the façade can be a good factor that decreases the energy load of cooling in arid climate.

The Relative compactness, orientation, and window-to-wall ratio WWR are good parameters to determine the relationship for the building shape and energy at the initial stage of the project (Smith et al., 2021). The relative compactness (RC) had been taken into concern in (Mahdavi & Gurtekin, n.d.) empirical study, where there was a substantial correlation between the numeric values of the RC and the subjective assessment of the compactness of architectural shapes, then the building shape can be a good indicator for building shape and energy consumption in the early stage of design process as shown in (Roslan & Ismail, 2018) study.

7.Methodology

The shape of the building and orientation could be considered as valuable factors for energy consumption. In this paper, the shape and form of 16 commercial and mixed-use towers in Kuwait City will be considered to find the relationship between surface area, volume, avg. floor are, compactness, and shape coefficient and the electricity consumption by using the *analytical method*. The aiding tool used to achieve this methodology was the *(AutoCAD) program* as a measurement tool, for dimensions of parameters to multiply it by heights to get surface area or the south exposure within different area commands. The avg. of floor plans was calculated by dividing the total built-up areas by the number of floors. The volume had been calculated by multiplying the avg. floor plan by the actual height of the tower. While the surface areas and volumes are available; three items can be obtained such as the shape coefficient by dividing the surface area on the volume, and the compactness which is the inverse value of the shape coefficient, and finally the relative compactness which is a unitless value dividing the required tower compactness by the most compact tower (Hemsath & Yow, n.d.) and (Catalina et al., n.d.). Google Maps had been used to double-check the orientation of the 16 towers with respect to the maximum available architectural drawings during this time as they are shown in the below table, and the next table in the next page shows the real perspective views of the 16 towers in Kuwait City.

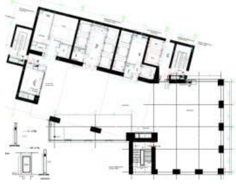
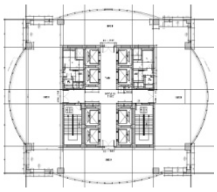
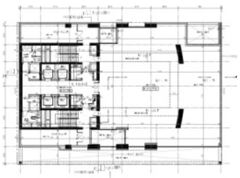
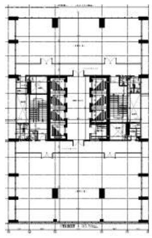
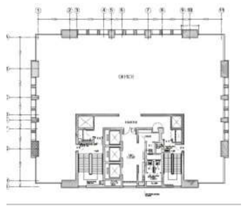
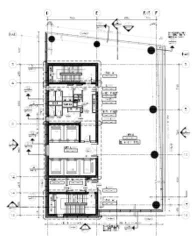
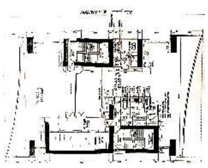
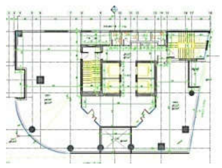
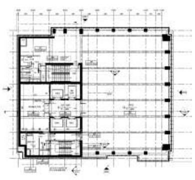
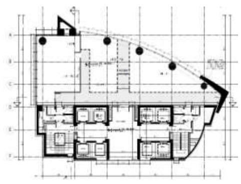
2D Plan				
Name of Tower	Al Hamra	Arraya	Baitak	Dhow
2D Plan				
Name of Tower	Jassim	KRE	Panasonic	Sahab
2D Plan				
Name of Tower	Al Nassar	Meshaal	Global	Mazaya
2D Plan				
Name of Tower	Injazzat	Awtad	Crystal	Arabia

Figure 1: Architectural plans - typical floor plans for the 16 selected towers

3D View				
Name of Tower	Al Hamra	Arraya	Baitak	Dhow
3D View				
Name of Tower	Jassim	KRE	Panasonic	Sahab
3D View				
Name of Tower	Al Nassar	Meshaal	Global	Mazaya
3D View				
Name of Tower	Injazzat	Awtad	Crystal	Al Arabia

Figure 2: Architectural 3D view for the 16 selected towers

Table (1) and (2) lists all of the 16 study cases and electricity consumption (kWh) for the year 2017 derived from the Kuwaiti electrical company the tables also list the eight shape variables for each case study which include: (Continue here).

Table 1: The calculation Geometry Description, kWh (2017), Avg. Floor Area, Height, and Vol. for the 16 selected towers

	Tower	Shape of Plan Description	Electricity Consumption (kWh)	Avg. Floor Area (m^2)	Height (m)	Volume (m^3)
1	Al Hamra	C-Shape	42, 556, 887	1, 845	413	761, 416
2	Arraya	Dribbled-Rectangles	22, 064, 850	770	300	231, 023
3	Baitak	Rectangular	12, 686, 780	748	140	104, 682
4	Al Dhow	Triangular	5, 974, 730	706	137	96, 706
5	Jassim	Cylinder-Square	20, 126, 130	1, 226	148	181, 419
6	KRE	Square-Curved	1, 884, 000	422	104	43, 926
7	Panasonic	Square	8, 892, 100	754	167	125, 966
8	Sahab	Square-beveled	2, 672, 790	690	83	57, 310
9	Al Nassar	Eye-Smoothed	5, 238, 170	606	150	90, 909
10	Meshaal	Rectangle-S. Concave	3, 604, 370	389	101	39, 246
11	Global	Squared-S. Curvy	4, 111, 530	1, 014	120	121, 670
12	Mazaya	Trapezoid	3, 506, 700	279	140	39, 049
13	Injazzat	Rectangle-D. Concave	4, 677, 600	577	132	76, 154
14	Awtad	Squared-S. Curvy	2, 450, 000	344	95	32, 645
15	Crystal	Square	10, 791, 290	906	240	217, 358
16	Al Arabiya	Hybrid	3, 712, 940	505	150	75, 737

Table 2: Surface Area, Compactness, Shape Coeff., R. C. and South Exposure for the 16 selected towers

	Tower	Surface Area (m^2)	Compactness (m)	Shape Coeff. (m^{-1})	Relative Compactness	South Exposure (m^{-1})
1	Al Hamra	107, 492	7.083	0.141	0.000283	0.074
2	Arraya	32, 035	7.212	0.139	0.000950	0.122
3	Baitak	26, 034	4.021	0.249	0.001169	0.036
4	Al Dhow	16, 342	5.918	0.169	0.001862	0.091
5	Jassim	20, 109	9.022	0.111	0.001514	0.064
6	KRE	9, 880	4.446	0.225	0.003081	0.149
7	Panasonic	19, 040	6.616	0.151	0.001599	0.126
8	Sahab	8, 820	6.498	0.154	0.003451	0.116
9	Al Nassar	13, 483	6.742	0.148	0.002257	0.109
10	Meshaal	7, 422	5.288	0.189	0.004101	0.041
11	Global	11, 400	10.673	0.094	0.002670	0.032
12	Mazaya	8, 372	4.664	0.214	0.003636	0.068
13	Injazzat	9, 579	7.950	0.126	0.003177	0.049
14	Awtad	7, 323	4.458	0.224	0.004156	0.099
15	Crystal	22, 223	9.781	0.102	0.001370	0.074
16	Al Arabiya	14, 850	5.100	0.196	0.002050	0.085

7.1 Study Tool:

The method of this study had been achieved by using multiple linear regressions (MLR) through Excel program add-ins. The data of electricity consumption had been fetched from the ministry of electricity and water for approximately one year starting from the period of the 1st of January 2017 to the 26th of December 2017. The aim of this study is to fill the gap of buildings' dimensions such as shape, height, and other factors like south exposure in which these factors will work as an added values to the previous study. Now, the target in this paper is to find the relationship between the following eight independent variables (X_i) that represent the (X-Axis), and the main response, the electricity consumption (EC); the correspond to the (Y-Axis) using (MLR) Based on (Bremer, 2012) study, where the (MLR) describes how a single response variable Y depends or interacted linearly with some predictor variables; (X_1, X_2, ..., X_i) all-together, where; (i=1, 2, 3, …, n), and (j=1, 2, 3, …, k), then the model described as:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots \beta_j X_{ji} + e_i$$

Dependent Variables (Y_i):

Y_i = Electricity Consumption (kWh) in 2017

Independent Variables (X_j):

X_1 = Area of Average Floor Plan in (m^2) X_2 = Height (m)
X_3 = Volume in (m^3)

X_4 = Surface Area (m^2) X_5 = Compactness (m)
X_6 = Shape Coefficient in (m^{-1})

X_7 = Relative Compactness X_8 = South Exposure (m^{-1})

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7. Results

The result shows the model is strong with high correlation where the multiple-R and R^2 are 98.96% and 97.94% respectively, and the significance-F is between 0 and 0.05 in which thus supports the strength of the results as it is shown in the below table.

Table 3: Statistical Regression Summary

Multiple R	0.989651
R Square	0.979410
Adjusted R Square	0.955878
Standard Error	2247047.054
Significance F	0.000031999

From Table (6), four of eight variables had been responded to the energy consumption where their values were between 0 and 0.05 and they are avg. floor area, height, compactness, and relative compactness.

Table 4: Variables output and P-Values

X_n		Coefficients	Standard Error	t Stat	P-value
	Intercept	-23817227	26, 164, 850	-0.910	0.3929
1	**Avg. Floor Area**	58356	12, 994	4.491	0.0028
2	**Height**	223229	53, 259	4.191	0.0041
3	**Volume**	-77	78	-0.984	0.3580
4	**Surface Area**	-325	461	-0.706	0.5027
5	**Compactness**	-4979741	1, 843, 547	-2.701	0.0306
6	**Shape Coeff**	-29017341	52, 929, 040	-0.548	0.6006
7	**R. Compactness**	4950558095	2, 069, 782, 201	2.392	0.0480
8	**South Exposure**	-25773001	22, 933, 410	-1.124	0.2981

After that, the fit plots had been extracted for the successful variables in Figures (1-4), and the fit equation shown in table (7) where the strength percentages of the R^2 is highest for the relative compactness, then compactness, height, and avg. floor area.

Table 5: Fit Plot Equation and R^2-strengths for the successful variables

No.	Variable	Strength Percentages-R^2	Fit Plot Equation
1	Relative Compactness	44.51	y = 4E+09x
2	Compactness	41.59	y = 1E+06x
3	Height	32.08	y = 43745x
4	Avg. Area Floor Plan	25.87	y = 8724.5x

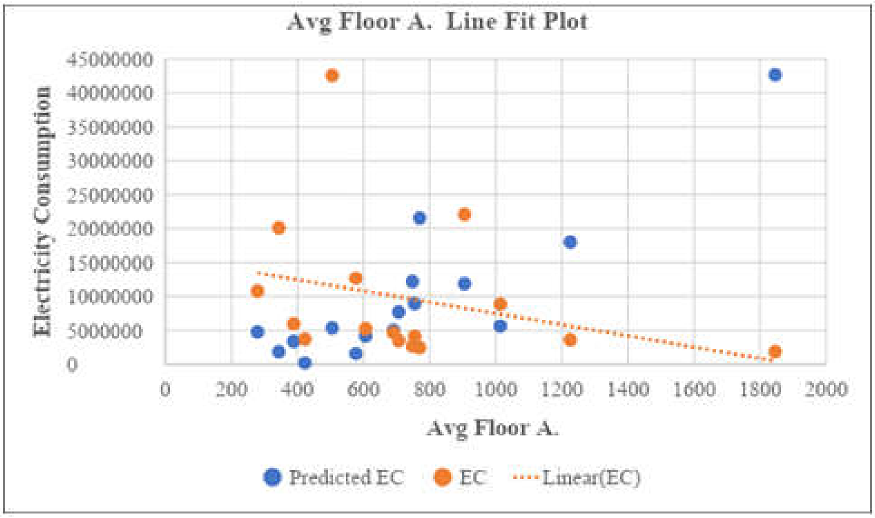

Figure 3: Plot between Electricity Consumption and Average Floor Plan

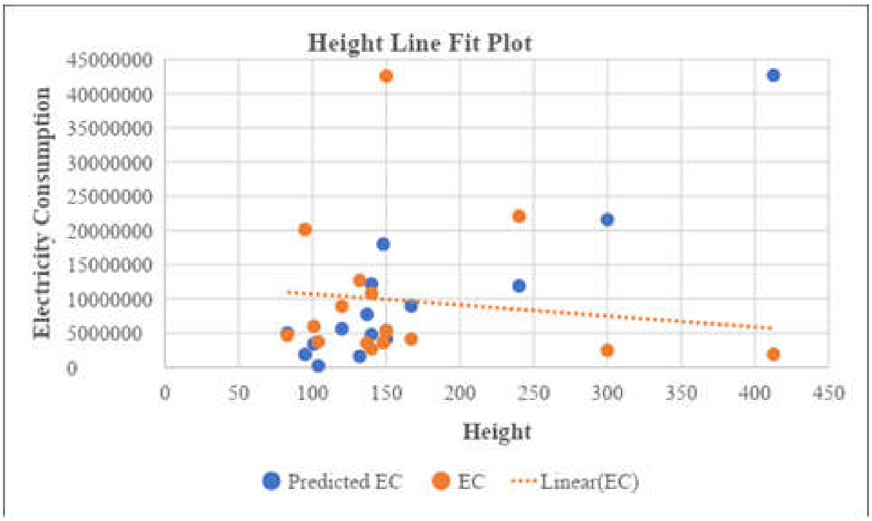

Figure 4: Plot between Electricity Consumption and Height

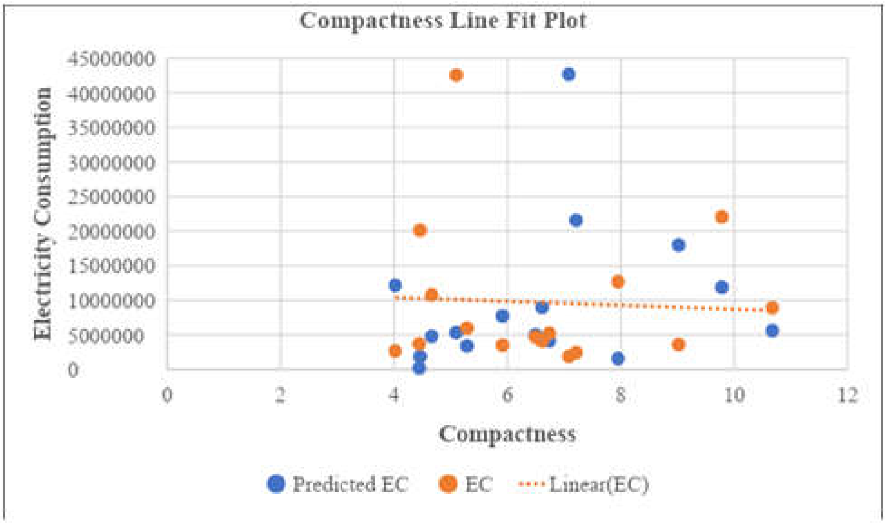

Figure 5: Plot between Electricity Consumption and Compactness

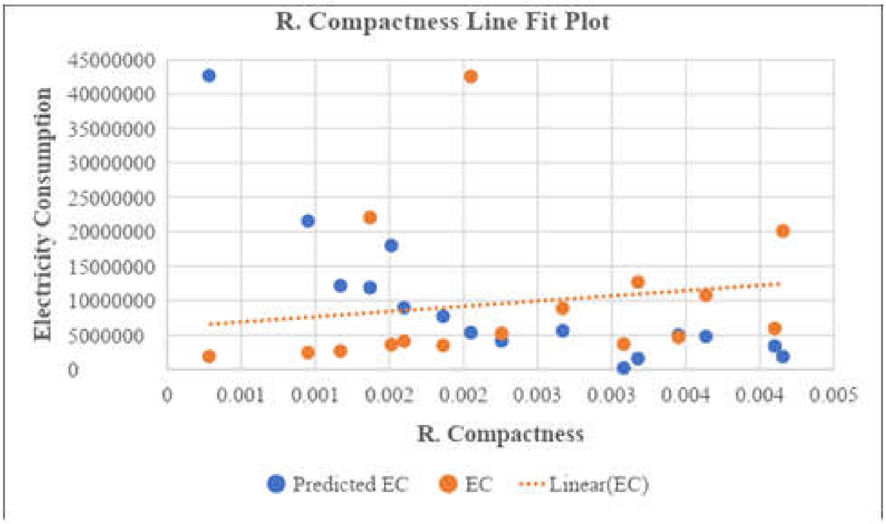

Figure 6: Plot between Electricity Consumption and Relative Compactness

8. Discussions

For the average floor area, the cooling strategy should be implemented to solve the factor of large floor area. The competition to create High rise or maximum possible heights for the towers should be controlled through sustainable renewable systems that would engage within the skyscrapers themselves such as wind turbines and building integrated photovoltaics (BIPV) as well as other technologies such as radioactive materials, and glass specifications like coatings and other thermal properties. The compactness should be kept lower in its ratio as much as possible to reach more efficient building, but this form a challenge because the surface area would be increased. Then we should treat the façade systems, the double or triple one through the mechanism of shading device; static or dynamic as well as the related technologies to it.

9. Conclusions and Recommendations

This study considered eight different parameters related to the skyscraper shape that had been engaged within the statistical regression process (MLR) to understand their responses to their energy consumptions. The results showed that four factors of eight had been responded to the electricity consumption variable and they are average floor area, height, compactness, and relative compactness in which these variables should be counted in the architectural design operation especially at the initial stage of the project to achieve sustainability within more efficient buildings by lowering the energy consumption thus related to carbon footprint and green-gas-emissions GHG.

10. Future Studies

While this study covers the extruded plans, there is still a gap between electricity consumption, shape, and form of the commercial towers that is worthy to be looked at in a future research. The convex façade where the surface is curved into exterior and the concave façade where the surface is curved into interior, as well as the inclined facades inwardly that create triangular forms or outwardly that create an inverse-triangles. Another point to be studied is to engage the shadows that are created by the surrounding towers on the targeted tower as a factor in the researcher calculation. The density of the surrounding streets i.e., cars, trucks or special machines and generators form another factor that is important to be considered where these items emit heat and will form kind of sources of greenhouse gases GHG.

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