A Study on Variations in Electrical Energy Consumption Due to Changes in Building Orientation. Case Considered: A Computer Simulation Model of a 4 Storey Commercial Building at Ahmadabad, Gujarat, India

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Abstract— A very important facet upon which a nation's economy is considered growing, stagnant, or declining is its net energy production. Since the advent of electrical energy production on a global scale, the biggest question that arises is whether the energy being produced is used judiciously. Electrical energy generation is a trillion-dollar industry expected to make noticeable advancements towards energy production in sustainable and environmentally friendly ways. India as a developing nation has been able to quench its thirst for electrical energy to a large extent since the development of a large number of hydro-electricity generation projects. As of 2019, India was 0.6% short of its energy demand but is expected to become an energy surplus nation by the end of the decade still, power shortages are still prevalent and commonplace in the country. This study aims at optimizing the electrical energy consumption of a hypothetical building set in the Indian metropolis of Ahmadabad using Energy Model Simulation Software by implementing changes in orientation of the structure which is considered a critical aspect of passive solar architecture.

Keywords: Electrical energy, Energy production, Energy optimization
ASJC Codes: 2102, 2215, 2216, 2611

I. Introduction to Passive Solar Architecture and Passive Solar Building Design Practices

Since ancient ages, Indians are known to have understood and incorporated the knowledge of celestial bodies in their architecture. The use of naturally available light and heat from the sun was widespread while incorporating designs to allow maximum utilization. Such energy-efficient practices were at first being considered obsolete and their significance is being realized as time passes.

Solar passive architecture is a branch of architecture aiming to utilize as much solar energy (in the form of heat and light) as possible. The building envelope (exterior walls and contacts) acts as a heat exchanger due to temperature difference within and outside the building and the material used in construction. Hence, controlling features of the building envelope is handy while optimizing energy consumption. Minimization of the energy usage is done using assembling the most effective combination of instruments such as window/door placement and size, type of glazing, the orientation of the structure, thermal insulation, thermal mass (property of the mass of any building which enables it to store heat providing thermal inertia in response to temperature fluctuations) and shading. These practices are easy to adopt while constructing a new building whereas existing buildings can be adapted to desired specifications. The above-mentioned instruments collect, store, distribute, and reflect solar heat in winters and reject it in summers. These methods are labeled as Passive Solar Building Design Practices as they don't incorporate the use of mechanical and electrical aids used in Active Solar Building Design Practices such as solar heaters.

II. Importance of Passive Solar Architecture and the Role of Orientation in Building Design

Buildings are highly complex products of engineering, design, and technology providing service lives lasting many decades. A building is supposed to be an environmental system within itself and the interaction between this internal and external environment and its impact has magnified the roles buildings play in our day to day lives. Therefore it is of vital importance to make these engineering marvels as technically and ecologically adept. A major facet requiring refining to a large extent is optimizing the energy consumption and reducing it as much as possible. Based on the ideology making the most of what is easily available, passive solar architecture and its design practices are a viable option for optimizing and reducing energy consumption by harnessing the most abundant form of energy available to man, solar radiation.

In order to construct any building and simulate and estimate its energy consumption, a key role is played by the orientation of the building. This is because the earth revolves in a clockwise manner around the sun while rotating in an anti-clockwise manner on its axis, so everywhere on Earth, the sun rises in the east and sets in the west. As the sun is the main energy source for all energy system on earth either directly or indirectly, the direction from which solar radiations arrive and its relative orientation to the structure plays an important role in the energy efficiency of the building. For example, A building with its main facade oriented towards north is expected to receive comparatively less heat (by solar radiation) as compared to the same structure if oriented eastwards or westwards since the latter would have a direct incidence with respect to incoming solar radiations.

Also, as assumed by a layman the sun never follows a true semi-circle path while traversing from east to west. Depending on the latitude and longitude, the path deviates either north or south, so a sun path diagram is derived for the location of the construction site and instruments of passive solar architecture are used accordingly.

Hence, the instruments of passive solar architecture are of unmatched importance to a building and its electrical energy efficiency models.

III. VERIFICATION OF THEORY USING ENERGY MODEL SIMULATION SOFTWARE

In order to prove the above-mentioned theory, a hypothetical building is modeled in the Ahmadabad metropolitan region in the Indian state of Gujarat.

The model is constructed using eQUEST (Quick Energy Simulation Tool) version 3.65.

The selected building has ground+3 storeys with each storey having a floor area of 18,600 Sq.ft. The upper storeys can be accessed by 2 stairwells and 2 elevators from the ground floor.

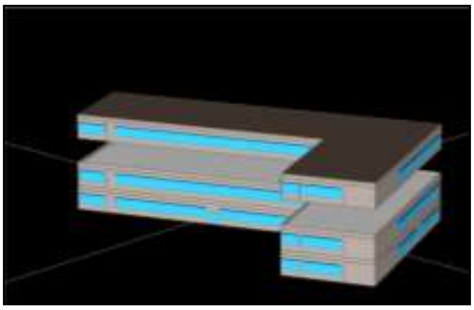


Fig. 1:3-D Block model of the selected building

The selected building is simulated for annual total electrical energy consumption in 5 cases. The cases are as follows:

Case 1: The orientation of the building is North North West
Case 2: The orientation of the building is North
Case 3: The orientation of the building is North North East
Case 4: The orientation of the building is East North East
Case 5: The orientation of the building is East

Legend:

Red – Case 1

Yellow – Case 2

Blue – Case 3

Green – Case 4

Violet – Case 5

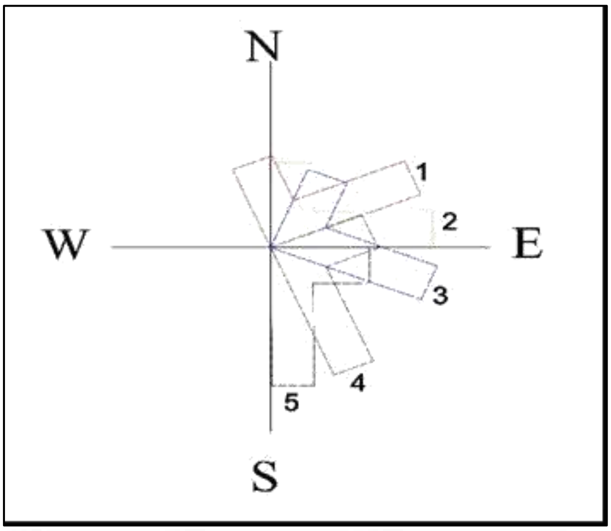
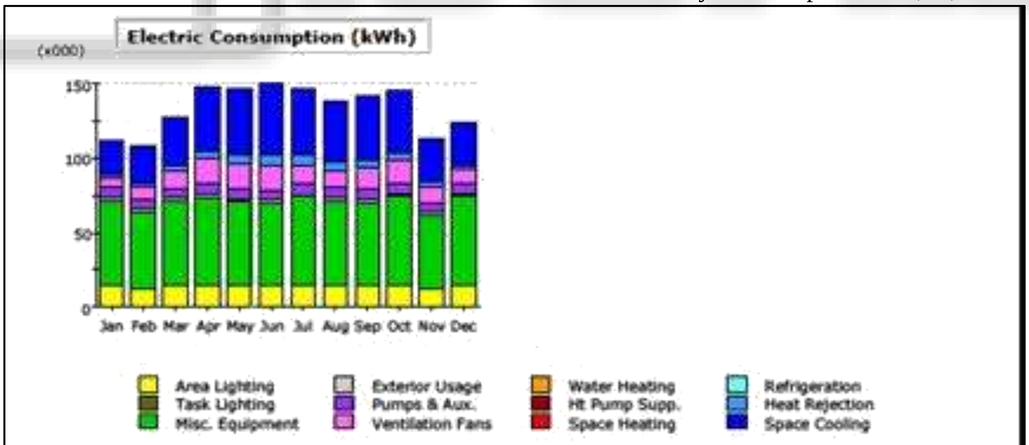


Fig. 2: A schematic representation of the cases in consideration

On simulation of the above mentioned cases, the following results were obtained:

A. Case 1

Total Electricity Consumption = 16,00,360 kWh

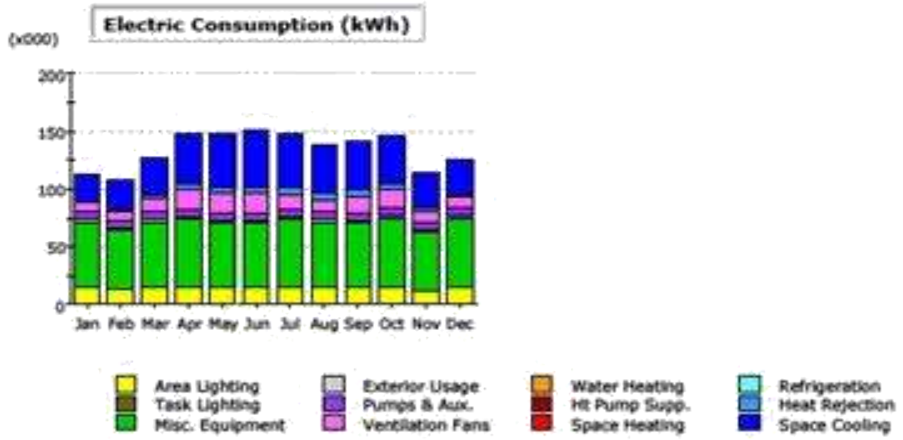


Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	23.0	35.5	32.9	43.1	44.8	48.0	44.6	40.8	42.2	41.8	29.4	29.0	445.2
Heat Reject.	1.7	2.4	3.3	5.0	5.4	6.2	6.2	5.8	5.6	5.0	3.2	2.8	52.5
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	6.9	8.1	11.8	16.8	17.0	16.8	12.8	10.9	13.7	15.6	10.3	8.8	149.6
Pumps & Aux.	6.9	6.2	6.9	7.2	6.9	6.9	7.2	6.9	6.9	7.2	5.9	7.2	81.9
Ext. Usage	2.4	1.8	2.0	2.0	1.4	1.4	1.4	2.3	2.2	2.3	2.3	2.4	23.7
Misc. Equip.	56.5	51.1	56.5	58.4	56.5	56.2	58.7	56.5	56.2	58.7	49.6	58.7	673.6
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	14.5	13.2	14.5	15.2	14.5	14.5	15.2	14.5	14.5	15.2	12.5	15.2	173.7
Total	112.0	108.2	128.0	147.6	146.5	149.9	146.1	137.6	141.3	145.7	113.2	124.0	1,600.4

B. Case 2

Total Electricity Consumption = 16,05,089 kWh

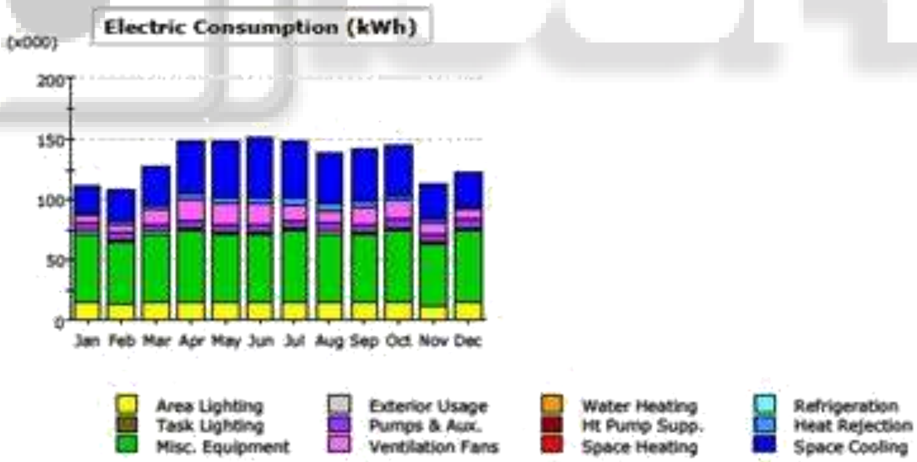


Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	23.4	25.7	33.1	43.4	45.2	48.6	45.0	41.2	42.4	42.1	29.8	29.4	449.3
Heat Reject.	1.8	2.4	3.3	5.1	5.6	6.4	6.4	5.9	5.7	5.1	3.2	2.8	53.7
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	6.7	7.8	11.3	16.4	16.9	16.7	12.5	10.6	13.1	15.1	10.2	8.7	146.1
Pumps & Aux.	7.1	6.4	7.1	7.4	7.1	7.1	7.4	7.1	7.1	7.4	6.1	7.4	85.0
Ext. Usage	2.4	1.8	2.0	2.0	1.4	1.4	1.4	2.3	2.2	2.3	2.3	2.4	23.7
Misc. Equip.	56.5	51.1	56.5	58.4	56.5	56.2	58.7	56.5	56.2	58.7	49.6	58.7	673.6
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	14.5	13.2	14.5	15.2	14.5	14.5	15.2	14.5	14.5	15.2	12.5	15.2	173.7
Total	112.4	108.4	127.9	147.8	147.2	150.8	146.7	138.2	141.3	145.9	113.8	124.4	1,605.1

C. Case 3

Total Electricity Consumption = 15,98,490 kWh

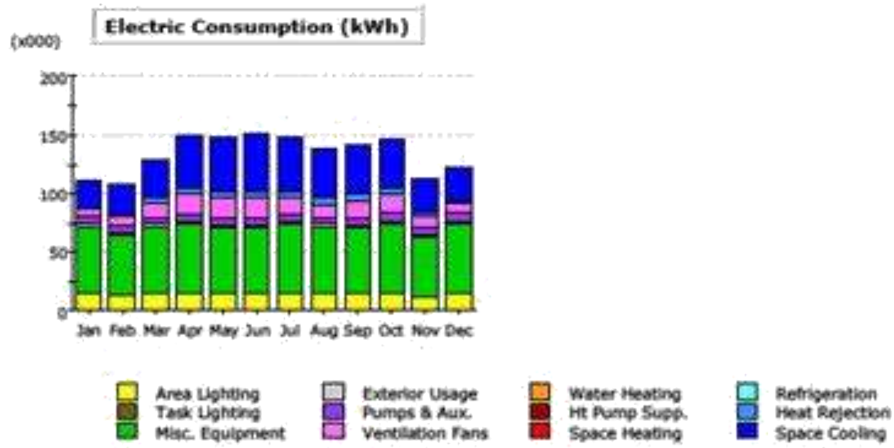


Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	22.7	25.3	32.9	43.5	45.2	48.5	44.9	41.0	42.3	41.4	29.1	29.5	445.4
Heat Reject.	1.7	2.3	3.3	5.0	5.5	6.2	6.3	5.8	5.6	5.0	3.2	2.7	52.7
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	6.2	7.6	11.5	16.9	17.3	17.0	12.8	10.8	13.5	15.1	9.8	8.1	146.7
Pumps & Aux.	6.9	6.3	6.9	7.2	6.5	6.9	7.2	6.9	6.9	7.2	5.9	7.2	82.7
Ext. Usage	2.4	1.8	2.0	2.0	1.4	1.4	1.4	2.3	2.2	2.3	2.3	2.4	23.7
Misc. Equip.	56.5	51.1	56.5	58.4	56.5	56.2	58.7	56.5	56.2	58.7	49.6	58.7	673.6
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	14.5	13.2	14.5	15.2	14.5	14.5	15.2	14.5	14.5	15.2	12.5	15.2	173.7
Total	111.0	107.6	127.7	148.2	147.3	150.7	146.5	137.9	141.2	145.2	112.4	122.8	1,598.5

D. Case 4

Total Electricity Consumption = 16,02,868 kWh

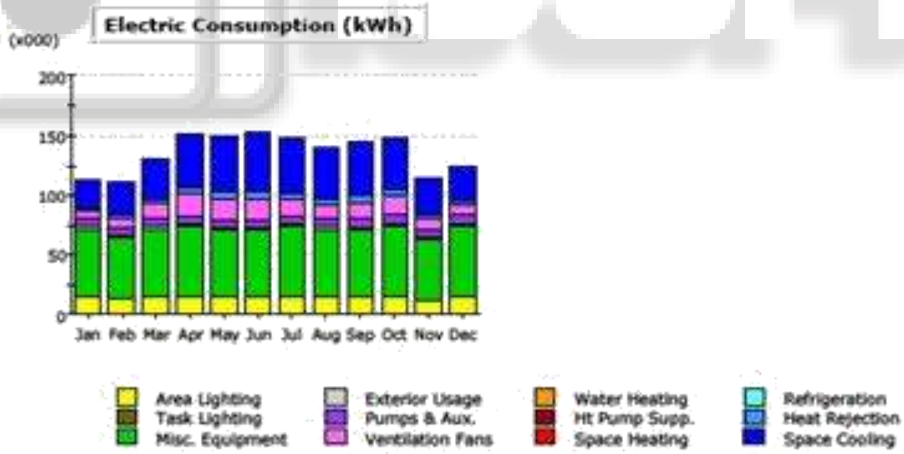


Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	22.3	25.4	33.3	44.1	45.4	48.6	44.8	40.9	42.6	41.8	29.0	28.1	446.6
Heat Reject.	1.7	2.4	3.3	5.0	5.4	6.1	6.1	5.7	5.5	5.0	3.1	2.7	52.0
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	6.3	8.2	12.3	17.9	18.0	17.7	13.2	11.1	14.3	15.9	9.9	8.0	152.8
Pumps & Aux.	6.7	6.1	6.7	7.1	6.7	6.7	7.1	6.7	6.7	7.1	5.8	7.1	80.5
Ext. Usage	2.4	1.8	2.0	2.0	1.4	1.4	1.4	2.3	2.2	2.3	2.3	2.4	23.7
Misc. Equip.	56.5	51.1	56.5	58.4	56.5	56.2	58.7	56.5	56.2	58.7	49.6	58.7	673.6
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	14.5	13.2	14.5	15.2	14.5	14.5	15.2	14.5	14.5	15.2	12.5	15.2	173.7
Total	110.4	108.2	128.7	149.6	148.1	151.1	146.5	137.8	142.2	145.9	112.3	122.1	1,602.9

E. Case 5

Total Electricity Consumption = 16,23,130 kWh



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	23.5	26.5	34.3	45.3	46.8	49.9	45.8	42.0	43.7	43.0	30.0	29.4	460.1
Heat Reject.	1.7	2.4	3.4	5.3	5.7	6.5	6.5	6.1	5.9	5.2	3.3	2.8	54.9
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	6.3	8.2	12.1	17.8	17.7	17.3	12.7	10.7	13.9	15.5	9.9	8.1	150.0
Pumps & Aux.	7.3	6.6	7.3	7.6	7.3	7.3	7.6	7.3	7.3	7.6	6.2	7.6	87.0
Ext. Usage	2.4	1.8	2.0	2.0	1.4	1.4	1.4	2.3	2.2	2.3	2.3	2.4	23.7
Misc. Equip.	56.5	51.1	56.5	58.4	56.5	56.2	58.7	56.5	56.2	58.7	49.6	58.7	673.6
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	14.5	13.2	14.5	15.2	14.5	14.5	15.2	14.5	14.5	15.2	12.5	15.2	173.7
Total	112.3	109.8	130.2	151.2	150.0	153.1	148.0	139.4	143.6	147.6	113.5	124.1	1,623.1

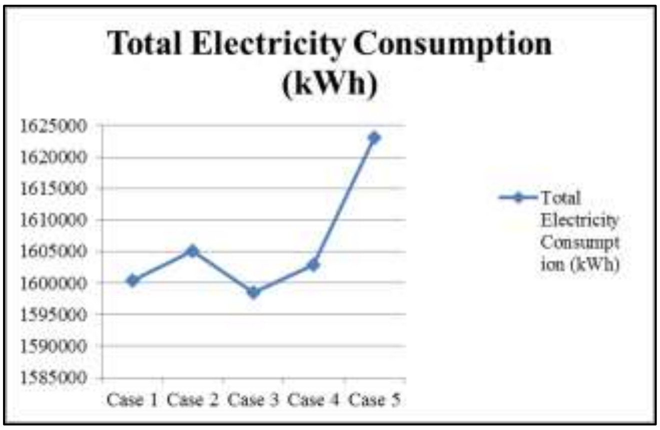


Fig. 3: Graph depicting variations in total electricity consumption of the cases in consideration

IV. Conclusion

From the simulation results, one can recognize the underlying gist of the study, that changing orientation alone can affect the energy consumption (in the selected case, a difference of 24,640 kWh is measured). On the basis of the above results, it can be established that instruments of passive solar architecture (in this case, building orientation) play an important role in contributing to total electrical energy consumption and thus are a strategic factor in deciding the energy efficiency of a structure.

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