INTEGRATION OF SOLAR PHOTOVOLTAICS: TO SUFFICE INTERIOR LIGHTING ENERGY CONSUMPTION OF OFFICE BUILDINGS IN AHMEDABAD

An approach towards zero lighting energy consumption

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ABSTRACT

The study focuses on ways to reduce interior lighting energy consumption in daytime use office buildings and proposes use of solar photovoltaics to suffice the remaining lighting energy requirement. First, we minimize the lighting energy consumption through integration of daylight harnessing elements and use of controls to reduce artificial lighting needs. Then, we maximize on-site Solar Photovoltaics installation to offset artificial lighting demand.

We have demonstrated that up to three-four floors of a large daytime use office building can achieve net zero interior lighting energy consumption. The study shows that it is possible to achieve energy autonomy by changing the operation schedule of the building.

INTRODUCTION

India being the fifth largest consumer of commercial energy, represents 33% of total electricity consumption in building sector whereas interior lighting energy consumption in commercial buildings accounts for 20%-40% (ECBC 2007). The Indian power sector is highly dependent on coal, with 53% of the total installed capacity (Solar PV Industry 2010). Still the gap between the demand of customer connected to grid and the available electricity supply reported for 2009-10 was almost 84TWh (DIREC 2011). As the nation is facing an rising demand and supply gap in energy, it is important to tap renewable resources such as solar energy to meet energy demands. India has 300 sunny days/year, nearly receives an average hourly radiation of 200 MW/km² has tremendous solar energy potential (DIREC 2011).

Taking steps towards energy conscious architecture, buildings are technically of great potential for energy extraction by utilizing the surrounding existing environment. Therefore they provide an opportunity where both the means, that is improving the efficiency of energy utilization on the demand side and adopting the clean renewable energy technologies into the energy generation system that is on the supply side can be achieved simultaneously. Hereby this study realizes the rising attention in renewable energy resources with energy efficiency in building sector together. Exploring the potential of two arenas on a parallel ground as the main intention, this research work is formulated in order to connect these two fields in present scenario, intended to contribute as a substantial study framework for the new architectural development.

The framework of the study deals with a single building energy consuming sector that is interior artificial lighting, of a selected building typology that is day time use large office buildings and addresses to suffice it through exploring available Solar renewable energy resource that is through grid connected roof top SPV system, after minimizing the consumption, to providing a potential reduce in grid dependency.

CONCEPTUAL FRAMEWORK

The study found its conceptual grounds from a theory called ‘Trias Energetica’ which was introduced by Erik H. Lysen in 1996 (Lysen 1996). This ideology of three triads illustrates optimum energy use in a energy system, firstly minimizing the energy demand, secondly using renewable resource to generate the energy demand and at last if required supply fossil fuel efficiently for the remaining demand. It primarily emphasizes energy efficient design strategies to reduce loads of the building and then only integrated renewable energy resources for maximum energy extraction and to attain full economic feasibility. The study holds value as it intent to refresh the old theory and evaluates its implementation in the new era of development in India.

Figure 1 Illustrating concept of “Trias Energetica” theory
PREMISE

In last decade Office buildings have emerged as one of the fastest growing sector in India. These buildings mostly are characterized by large floor plate areas with deep plans, multi storied, open interior layout and maximum ratio of usable floor area to exterior envelope, where large numbers of people are placed to work for 8-10 hours a day, either in single or multiple working shifts. These buildings due to their building scale/architectural character/nature of operations or economic reasons are bound to create large central core areas that are detached from the exterior environment.

The natural light in these types of buildings is mainly through vertical side lighting openings on the perimeter, but the daylight zone rarely reach the first 4.5 m from the exterior opening plane. Core daylighting techniques bring daylight deeper into a building, however the application of traditional core daylighting methods, like atria and courtyards, are limited by building height and design, many building owners are unwilling to turn what could be rentable space into a daylighting atrium. Even latest technologies such as light guide systems like light pipe and anidolic ducts, which collect daylight from the perimeter zone and transport it to the core zones, sometimes find difficulty in merging with the building designs.

To provide visual comfort in core zones in such building typology is the most addressed issue for the designers. The efforts to create more comfortable visual interior environment using artificial interior lighting systems, is placing a high energy demand on the utility grid.

Focusing the above architectural issue, the study attempts to reduce the major energy load of artificial lighting of these buildings on the utility grid, through design strategies, then making them self-sustaining by serving the interior lighting energy consumption through the energy generated on-site by grid connected roof top SPV system.

METHODOLOGY

Approach to reduce ILEC –Demand side

For the above mentioned purpose, the study reasserts its premise by viewing large office floor plates and parting it into three zones, differing in daylighting penetration pattern under the use of light control sensors, to arrive at parameters which can help in achieving optimum ILEC. First zone is the “perimeter daylight zone” 4.5 m from the exterior window walls where daylight can penetrate sufficiently through windows and can serve the ambient lighting purpose of this zone completely, second zone is the “partially daylight zone”, next 4.5 m from the “perimeter daylight zone” where artificial and daylight both are needed to serve the ambient lighting purpose of this zone, the last is the “central core zone”, next 4.5 m from the “partially daylight zone” which is completely dependent on artificial lighting. (Fuller 1991).

This zoning helped in understanding that there is scope of working with building designing parameters which can help in reducing ILEC in first two zones that is “partially daylight zone” as well as “perimeter daylight zone”. Therefore the large floor plates were analyzed in varying scenarios such as change in aspect ratio, orientation, WWR and use of external daylighting devices such as louvers and lightshelves.

It was expected that the above attempts will enhance the daylight penetration pattern in “perimeter daylight zone” and “intermediate “partially daylight zone”. The impact of the performance of varying parameters will result in increase in the area of “perimeter daylight zone”, further reducing the “partially daylight zone” area. It is supposed that the ILEC will be reduced due to the variations in these two zones under the use of light control sensors.

However the core zone will still be unaltered by daylight penetration pattern and will require energy from onsite-SPV. It should be highlighted here that this zoning is done to arrive at the parameters which will help in reducing ILEC of the floor plate. However the analysis done in the study is not broken down zone wise, complete floor plates area as a whole is analyzed for ILEC.

Tools, parameters and scenarios for demand side simulation

Simulations were done in two parts, as the first part, deals with achieving optimum ILEC through passive and active methods. Design Builder on Energy Plus platform, was used to model various Energy Conservation Building Code (ECBC-2007-India) compliant hypothetical building models. Three large single floor plate of area 500 m², 750 m² and 1000 m² are analyzed in 18 varying scenarios that are, two building aspect ratio (1:1 and 1:2), two orientations (N-S and E-W) and two WWR (40 and 60%). Further they are analyzed under the impact of external daylighting devices in three conditions:

i. No device- Here no windows, on all sides, in all cases are treated with any devices.

ii. With external fixed louvers- In this case south orientation window were treated with horizontal louvers, east and west orientation window with vertical louvers with clerestory windows and north orientation window with no device.

iii. With external light shelf- In this case south orientation window were treated with exterior one level light shelf, east and west orientation window with vertical louvers with clerestory windows and north orientation window with no device.
From these scenarios the case with minimum ILEC for each floor plate was selected for SPV integration.

Building models

The models that are analyzed for this study are representatives of open office typology of buildings in Ahmedabad. They are based on a preliminary study based on inputs from real estate developers in the city. All other input parameters are based on the ECBC recommended standards and are kept constant. The models are simulated for single shift office space with working hours from 8:30 a.m. to 06:00 p.m.; weekends and public holidays are considered as unoccupied days. Density of people is 0.16 people/m², in other words, each person has 6.25m² of floor space.

The design illuminance has been set at 500 lux (for office use). The work plane height is 0.75m. In order to measure the electrical lighting savings due to daylighting, light control sensors have been used. The lighting control is linear type where the lights dim continuously and linearly from maximum electrical power, maximum light output to minimum electrical power, minimum light output as the daylight illuminance increases. With further increase in daylight, the lights are switched off. Task lighting is switched on and the luminaire type used is surface mounted fluorescent with the LPD of 10.8 W/m².

Windows are fixed at 1.0 m sill height and lintel height at 2.8 m from floor level, and 90% of the window area is glazing. Window area is varying in term of window wall ratio (WWR) 40% and 60%. The glazing type, specifically glazing material property such as visible light transmission (VLT) and solar heat gain coefficient (SHGC) is changed with the change in WWR as per ECBC table 4.5. For 40% WWR- 26% VLT, 25% SHGC and for 60% WWR-20% VLT, 20% SHGC glazings were assigned to models. Here the effective aperture for 40% WWR cases comes to 0.104 and for 60% WWR comes to 0.12 which is greater than 0.1, hence compiles with ECBC. However, when external devices such as louvers and light shelf are applied to models the VLT and SHGC is derived for each window assembly of all orientations by deriving projection factor and then multiplying ‘m’ factor to the base values. Therefore when light shelf and horizontal louvers are applied to south façade, for 40% WWR-37% VLT, 19.7% SHGC, for 60% WWR-32% VLT, 15.8% SHGC glazings are assigned to the models. Same as when vertical louvers are applied to East and West facade, for 40% WWR-32% VLT, 18% SHGC and for 60% WWR-30% VLT, 14.4% SHGC glazing are assigned to the models. In cases where light shelf is there on south orientation windows and vertical louvers are on east and west orientation windows, the clerestory windows above the 1.2 m window height is of clear glass with 75% VLT and 40% SHGC.

For the purpose of daylighting simulation the each of these models are divided into core and perimeter zone with virtual partitions wherein each zone has light control sensors.

The construction assembly and materials is same as the general trend for an ECBC compliant building.

Wall assembly– 18 mm thick external dense plaster, 230 mm thick burnt clay brick wall, 50 mm XPS extruded polystyrene- HFC blowing and 12 mm outside surfaces cement plaster with a total U-value of 0.440 W/m²K.

Roof and floor have been considered as adiabatic in order to simulate the model as an intermediate floor of a multi-storey building. Roof and floor assembly- 6 mm ceramic glazed tiles, 12 mm plaster, 150 mm
thick cast concrete, 70 mm XPS extruded polystyrene- co₂ blowing and 12 mm plaster with a total U-value of 0.409 W/m²K.

In order to enhance the effects of louvers and light shelf, the ceiling and walls internal plaster is provided with a smooth finish plaster, with material property, 0.7 visible reflectance and 0.3 visible absorptance.

It is important to note here that by ‘floor-plate’ one means that each model is like an intermediate floor of a multi-storey stand-alone building, which is having vertical openings on all sides. Hence, it is one in-between floor that is being studied and not the entire building, floor to ceiling clear height is 3 m. The flat-roof area to install SPV will be same as the floor plate area. It means that floor plate is a representative of the whole building, which has a uniform floor areas on all storeys and shape throughout the building height. As the floor plate area and roof area are assumed same, if in case of multi-storied building, where similar analyses is needed to be done for whole building and not for a single floor plate. Then the total ILEC of a building can be obtained by simply multiplying ILEC of the single floor plate to the no. of storeys, assuming uniform ILEC throughout all the floors of the building, whereas the roof area will be constant. This will illustrate the demand and supply side in a ratio, of no. of storeys and roof top. For instance, if a building is single storey the ratio of demand side and supply side will be 1:1 proportion or in case of five storeys building the ratio will be 5:1 proportions.

Approach for SPV simulations- Supply side

The study proceeds to its second part, to generate SPV power supply to suffice the optimized building ILEC. Energy plus software is used to simulate the performance of a grid connected roof top SPV system, based on a description of the SPV system and an hourly weather file. To simulate best case scenario for SPV simulation, highest Watt peak SPV module (Moser Baer solar 240 Wp module) was selected after market survey. The allowable maximum number of modules was calculated based on the available roof top area. Total no. of modules were defined in parallel and series connection to define roof top SPV array. This defined SPV array was modeled on roof top of building models using open studio plugin in google sketchup software, this helped in defining the tilt and orientation of the SPV array. Maximum rated power of the defined array was inputed in energy plus, with other technical input parameters. The total electric distribution system was defined with the connection of inverter to the SPV array. Simulating the defined SPV system using energy plus resulted in hourly AC power generation in watts and hourly energy generation in joules, for the selected most optimized building model cases.

<table>
<thead>
<tr>
<th>City</th>
<th>Ahmedabad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinates</td>
<td>23°02 N, 72°35 E</td>
</tr>
<tr>
<td>SPV installation Location</td>
<td>Roof top</td>
</tr>
<tr>
<td>Mounting</td>
<td>Fixed Type</td>
</tr>
<tr>
<td>Surface azimuth angle of SPV Module</td>
<td>180°</td>
</tr>
<tr>
<td>Tilt angle(slope) of SPV Module</td>
<td>23°</td>
</tr>
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</table>

**SPV Module details**

<table>
<thead>
<tr>
<th>SPV cell type</th>
<th>Crystalline silicon</th>
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</thead>
<tbody>
<tr>
<td>Max. Power Rating of a module</td>
<td>240 Wp</td>
</tr>
<tr>
<td>No. of cells in a module</td>
<td>60</td>
</tr>
<tr>
<td>Size of a module</td>
<td>1.64 m²</td>
</tr>
<tr>
<td>Active area per module</td>
<td>1.46 m²</td>
</tr>
<tr>
<td>Rated Current of module (Impe)</td>
<td>7.8 A</td>
</tr>
<tr>
<td>Rated Voltage of module (Vmp)</td>
<td>30.8 V</td>
</tr>
<tr>
<td>Short Circuit Current of module</td>
<td>8.34 A</td>
</tr>
<tr>
<td>Open Circuit Voltage of module</td>
<td>37.69 V</td>
</tr>
</tbody>
</table>

(i) **SPV system for 500 m² roof top**

| Roof top area available (60% of floor plate area) | 300 m² |
| System Output                                      | 24 kW |
| No. of modules                                     | 100 |
| No. of series modules in one array                 | 10 |
| No. of arrays in parallel combination               | 10 |

(ii) **SPV system for 750 m² roof top**

| Roof top area available (60% of floor plate area) | 450 m² |
| System Output                                      | 36 kW |
| No. of modules                                     | 150 |
| No. of series modules in one array                 | 10 |
| No. of arrays in parallel combination               | 15 |

(iii) **SPV system for 1000 m² roof top**

| Roof top area available (60% of floor plate area) | 600 m² |
| System Output                                      | 48 kW |
| No. of modules                                     | 200 |
| No. of modules in series                          | 10 |
| No. of arrays in parallel combination              | 20 |

**Inverter details**

| Inverter Efficiency | 98% |

**OBSERVATIONS**

To analyze the simulation results, observations from both simulation levels are mentioned below.
Level 1- For demand side optimization, it was observed that for all floor plates ILEC pattern was varying within a range between the worst case scenario and best case scenario, Graph-1 shows the worst case and best case of each floor plate. The percentage decrease in ILEC of all the cases of all three floor plate from the base- worst case scenario was between 3.5% to 8% and the percentage decrease in total energy consumption of all the cases of all three floor plate from the base-worst case scenario was between 3% to 6.5%. It was also observed that lightshelf were more effective for minimizing ILEC and louvers were more effective for reduction in overall energy consumption of the cases. Table 2, 3 and 4 illustrates varying ILEC of all building cases. For all floor plate best building case scenario came out to be the case with 1:2 aspect ratio, 60% WWR with light shelves in which the minimum ILEC was achieved. Whereas the worst case came up to be with 1:1 aspect ratio, 40% WWR with no device. Therefore for all floor plates scenario with 1:2 aspect ratio, 60% WWR with lightshelf was selected and was taken to second simulation level for SPV installation.

The ILEC per year for the selected cases were:-
500 m² floor plate— 25.385 kWh/ m²/year.
750 m² floor plate— 28.063 kWh/ m²/year.
1000 m² floor plate— 29.535 kWh/ m²/year.

Level 2- For supply side, it was observed that generation potential of 500 m² roof top SPV system was 4.1 times more than the ILEC of 500 m² single floor plate. The generation potential of 750 m² roof top SPV system was 3.7 times more than the ILEC of 750 m² single floor plate and the generation potential of 1000 m² roof top SPV system was 3.5 times more than the ILEC 1000 m² single floor plate on annual basis.

Therefore, it can be understood as, for 500 m² floor plate scenario ILEC of 4 storeys of a building can be served with same roof top SPV system, for 750 m² and 1000 m² floor plate scenario ILEC of 3 storeys of a building can be served with same roof top SPV system as shown in Graph-2.
Hundreds

Graph 4
Monthly energy generation & monthly consumption

Therefore, comparing the demand and supply ratio:-
For 500 m² floor plate: - 1.4.1
For 750 m² floor plate: - 1.3.7
For 1000 m² floor plate: - 1.3.5

Highest SPV system efficiency of 9.4% was marked in the month of July this is due to presence of less dust particles in the sky and high intensity of solar radiation in this month, whereas the lowest SPV system efficiency of 7.5% was marked in the month of December as shown in Graph- 3.

It was observe that highest energy generation for all three roof top SPV systems was marked in the month of March; this is due to moderate temperature condition in this month. The lowest energy generation for all three roof top SPV systems was marked in the month of August due to overcast sky conditions as shown in Graph-4.

Daily hourly interaction of ILEC and SPV energy generation was observe for 21st March, 21st June, 23rd September and 20th December. As shown in Graph- 5 to 8. This illustrated that for March, June and September energy generation hours range from 6:00 am to 7:00 pm and attain peak generation at 1:00 pm. whereas in December energy generation hours range from 7:00 am to 6:30 pm and attain its peak generation at 1:00 pm. It can be seen in March, June and September after 5:30 pm ILEC exceeds the SPV power generation therefore there is deficit of energy from SPV generation; here the energy from utility grid is required to serve ILEC. The same condition in December is attained at 5:00 pm.

The daily graphs show that peak ILEC occurs from 12:00 pm to 1:00 pm then from 2:00 pm to 5:00 pm. This period puts peak load on utility grid but here energy generated from SPV is in excess to suffice the load. Hence helps in reducing the peak load on utility grid.

Other important observation from the daily-plotted graphs that can help in total energy autonomy is the office working hours, which if can fall between the ranges of SPV energy generation hours, can further
help in achieving complete energy autonomy through SPV energy generation. As the graphs illustrates that the range of office working hours exceeds the range of energy generation hours from SPV. Here one can take initiative to shift the working schedule one hour before to completely fall under the range of SPV energy generation hours. This will add one more dimension of daylight saving and will add value to the investments in SPV system by further reducing the energy imports from the utility grid.

There was another observation noticed that at what time and date the SPV systems generates its peak energy and what is the energy generation at that point as shown in table 5. Then it was found out, at what time and date the peak ILEC occurs over the year and what is the energy generation at that point of time. It came out to be 4th December 05:00pm when ILEC is highest over the year but energy generated by the SPV system at this time is very low as shown in table 6. At this time the System need to import energy from the utility grid to serve the ILEC.

**Graph 5**
21st March hourly- generation v/s consumption

**Graph 6**
21st June hourly- generation v/s consumption

**Graph 7**
23rd September hourly- generation v/s consumption

**Table 5**
Date and time on which max. energy generation over the year occurred and ILEC at the same point of time

<table>
<thead>
<tr>
<th>Floor plates</th>
<th>Energy generation (kWh)</th>
<th>ILEC (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 m²</td>
<td>23.07</td>
<td>6.46</td>
</tr>
<tr>
<td>750 m²</td>
<td>34.6</td>
<td>10.74</td>
</tr>
<tr>
<td>1000 m²</td>
<td>46.14</td>
<td>15.1</td>
</tr>
</tbody>
</table>

**Graph 8**
20th December hourly- generation v/s consumption

**Table 6**
Date and time on which max. ILEC over the year occurred and energy generation at the same point of time

<table>
<thead>
<tr>
<th>Floor plates</th>
<th>Energy generation (kWh)</th>
<th>ILEC (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 m²</td>
<td>7.15</td>
<td>2.19</td>
</tr>
<tr>
<td>750 m²</td>
<td>11.3</td>
<td>3.29</td>
</tr>
<tr>
<td>1000 m²</td>
<td>15.7</td>
<td>4.39</td>
</tr>
</tbody>
</table>
CONCLUSION

We have demonstrated that integration of solar renewable energy resource at reduced interior lighting energy consumption level can offer self-reliance for lighting energy in large daytime use office buildings in Ahmedabad.

The study at energy efficiency level has demonstrated that with adoption of active energy efficiency measures such as ECBC standard complied models, low LPD, efficient artificial lighting and with use of daylighting controls sensors, the potential of the percentage savings in Interior lighting energy consumption from passive means that is harvesting daylighting is between 3.5% to 8% only and a percentage decrease in total energy consumption is up to 6.5% only, this also decreases with the increase of floor plate area.

The study has also explored the potential of solar renewable energy resource for energy generation through the present Photovoltaic technology. On a broader level, the study has demonstrated that the implementation of this research can help the building designers to reduce the dependency of their building energy loads on the utility grid. It can also support the present undulating energy scenario by reducing the peak interior lighting load on the utility grid during peak mid-daytime.

The study has presented a framework to help architects and designers to contribute towards energy conscious development. Here we have demonstrated a method to design up to 3 to 4 floors of a large daytime use office building to achieve net zero interior lighting energy consumption.

The theory of Trias energetic elaborated in the study is applicable to new architectural projects and may be extended to other systems like HVAC, equipment, etc. This framework it can use to detail out that, how much of the load of building energy systems can be sufficed by roof top SPV system and for how many floors.

There is a possibility explored in the study to obtain complete energy autonomy for interior lighting energy consumption by changing office operating hours to 7:30 am - 5:30 pm along with the integrated design efforts followed in the study. This will allow buildings to utilize the available solar energy in form of daylight in interior office spaces as well as for energy generation through SPV.

NOMENCLATURE

SPV- Solar Photovoltaics
ILEC- Interior Lighting Energy consumption
Max. – Maximum
Min. – Minimum
kWh- kilo Watt-hour
TWh- Tera Watt-hour
VLT- visible light transmission
SHGC- Solar heat gain coefficient
WWR- window wall ratio
ECBC- Energy conservation building code
LPD- Lighting power density

REFERENCES


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