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<th>Limits on Energy Efficiency in Office Buildings</th>
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1.0 OVERVIEW

Many sophisticated computer tools exist to calculate building energy demand but while they provide good levels of accuracy, they lack the flexibility to quickly compare a large number of scenarios. They also focus primarily on thermal performance for heating and cooling and do not easily allow other energy consuming systems to be compared and optimized.

To assist with the rapid prediction and optimization of building energy consumption at an early stage in the building design process, a spreadsheet-based building energy analysis tool was developed. The spreadsheet calculates energy consumed by HVAC systems, lighting, office equipment, domestic water systems and elevators. It also includes a simple daylighting calculation to allow building façades to be optimized for both thermal and lighting performance.

Many default values are included in order to minimize the amount of input data required. However, the spreadsheet format allows the user to customize the calculations used without the need for programming knowledge.

A further feature of the spreadsheet is that it allows the performance of Building Integrated Photovoltaic panels (BIPV’s) to be evaluated.

After briefly describing features of the spreadsheet, this paper presents results obtained in the following applications:

- To chart the history of energy consumption in office buildings over the last 50 years.
- To identify limits to energy conservation in office buildings given current and imminent advances in building technology.
- To explore the likely contribution from BIPV’s to offset energy consumption.
2.0 SPREADSHEET DETAILS

2.1 Weather Data

Readily available average climatic data are used. Several sources were found on the internet for the necessary input data including the US National Oceanic & Atmospheric Administration, the Australia Bureau of Meteorology, the World Meteorological Organization and the UK Met Office.

The average daily maximum and minimum temperatures for each month are used to derive daytime and nighttime temperatures for thermal calculations. Similarly, daytime and nighttime relative humidity values are used for latent heat calculations.

Records of bright sunshine hours are used to split each month into a number of equivalent sunny and overcast days. 24 hour average design solar radiation values, from sources such as the Chartered Institution of Building Services Engineers, Guide Book A, are used to derive average radiation intensities for each façade for both sunny and overcast conditions.

Eight thermal calculations are carried out for each building façade for each month as follows:

<table>
<thead>
<tr>
<th>Weather</th>
<th>Occupancy</th>
<th>Daytime</th>
<th>Nighttime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunny</td>
<td>Occupied</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unoccupied</td>
<td>Daytime</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nighttime</td>
</tr>
<tr>
<td>Overcast</td>
<td>Occupied</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unoccupied</td>
<td>Daytime</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nighttime</td>
</tr>
</tbody>
</table>

The results from each calculation are factored by the number of hours in each category to estimate energy consumption for the month. This is significantly more detailed than a manual estimate but not as sophisticated as the typical computational process that uses hourly weather data.

2.2 Building and Occupancy Data

The building is characterized by the length and width of a typical floor, the floor-to-floor height and the total number of floors. Core and perimeter zones can be defined as well as the orientation relative to true North. The thermal properties of glazed and opaque façade elements can be simply defined.

The occupant density, attendance factors, outside air quantities, heat output, hours of operation and days of operation per week may be specified. Lighting and equipment heat gains as well as infiltration levels may also be defined.
2.3 HVAC System Selection

Extensive built-in default values allow the rapid comparison of many system configurations as follows:

- All-air with air-water systems.
- Variable volume with constant volume systems.
- Mixed with displacement systems.
- Fan assisted with static terminal systems.
- Perimeter heating with terminal reheat.
- Control or not of winter humidity level.

Various optional energy saving strategies are also included:

- Exhaust air sensible and latent heat recovery.
- Air and water side ‘economizer’ for free cooling.
- CO₂ based outside air control.
- Daylight and occupancy sensing for control of artificial lighting.

System pressure losses and equipment efficiency values may be defined by the user.

2.4 Other Systems

The spreadsheet uses the building height and occupancy to estimate energy consumed by elevators. Simple calculations also estimate energy consumed by domestic water systems.

Energy produced by BIPV’s is estimated based on collection efficiency and percentage coverage data entered by the user.

2.5 Energy Sources

For each building system, the energy source and unit cost may be defined to estimate operating costs. A calculation is also made of primary energy consumption and equivalent amount of CO₂ released.

2.6 Benchmarking

The spreadsheet technique has not been rigorously benchmarked against other proven techniques or actual measurements although an earlier version, written specifically for a museum in Maine, provided, perhaps by luck, predictions within 10% of actual measured consumption in the first year of operation. Copies of the spreadsheet may be obtained free of cost from the author for further testing and comparative studies.
3.0 THE HISTORY OF ENERGY CONSUMPTION IN OFFICE BUILDINGS

In order to chart the progress of energy conservation measures in office buildings over the last 50 years, a hypothetical building model was analyzed. A 20 story building with a 40m by 40m floor plate and 80m overall height was assumed. All four façades were assumed to be 50% glazed. New York City weather records were used.

3.1 Pre-Energy Crisis Building

Prior to the worldwide energy crisis in the early 1970’s, energy conservation in buildings was rarely considered an issue. A typical office building of that era would include the following features:

- Combination of operable windows and air conditioning.
- Clear single glazing with internal shades.
- Use of generous amounts of energy to solve comfort problems.
- High artificial lighting levels.
- Negligible equipment loads.

Analysis shows that a building of this type would have had an annual energy consumption of approximately 328 kWh/m². The figure below shows the distribution of this energy:
3.2 Post-Energy Crisis Building

The energy crisis precipitated many innovations in building systems, materials and design, many of which were eventually mandated in building energy codes. The features of a typical building of this era are as follows:

- Reduced fresh air supply to occupants.
- Extensive use of dark and reflective glass.
- Increasing use of double glazing.
- Use of ‘economizer’ free cooling.
- Advent of variable air volume systems.
- Increase in equipment loads with the advent of personal computers.

Despite the increase in equipment loads, the various energy saving measures above had a dramatic impact on energy consumption. In this analysis, a 30% saving was achieved to give an annual value of approximately 230 kWh/m².

3.3 Contemporary High-Performance Building

Many of the energy saving systems and measures introduced after the energy crisis had the unforeseen side-effect of degrading the working environment. Reduced fresh air levels and variable volume systems in combination with the increased use of artificial materials in the workplace led to poor indoor air quality and problems such as sick building syndrome. The use of low transmission glazing reduced the sense of connection with the outdoor environment.
Modern building designs, particularly since the early 1990’s, have begun to address these issues while maintaining good energy efficiency. Common features include the following:

- Increased fresh air supply to occupants.
- Clearer glass with smart coatings and/or physical shading to control heat gain.
- More efficient artificial light sources with better color rendering.
- Better control systems with greater personal control of the immediate environment.
- Further increases in equipment loads.
- Displacement type air-conditioning systems.

The need to improve environmental conditions in the workplace, along with the increase in equipment loads, has slowed down improvements in energy conservation. Nevertheless, analysis shows that contemporary high-performance office buildings use 40% less energy than their pre-energy crisis counterparts. Annual energy consumption rates of under 200 kWh/m² can be achieved even in the New York climate where European style natural ventilation is not an option for much of the year.

### Annual Energy Consumption Profile

![Annual Energy Consumption Profile](image)

#### 4.0 LIMITS TO ENERGY CONSERVATION

While many innovative systems and design approaches continue to incrementally improve energy conservation, it is theoretically possible to make dramatic improvements with features such as the following:

- Eliminate ‘offgassing’ materials to allow a reduction in fresh air supply without adverse health effects.
• Improve façade performance with more extensive use of external shading and selective coatings. Possible use of electrochromic glazing products.
• Install daylight collection, distribution and control systems.
• Use more efficient artificial light sources.
• Optimize air-conditioning systems for energy consumption rather than initial cost or space requirements. Use more efficient equipment and drives. Employ heat recovery and more occupancy based controls.
• Use more efficient elevator drives and intelligent control systems.
• Reduce equipment loads by using computers with better power management and low energy flat screen monitors.

Despite the likely need to maintain minimum winter humidity levels in the future, analysis shows that the above measures could theoretically reduce energy consumption to about 90 kWh/m², less than half the current value. The chart below shows the relative energy consumption of different systems in this scenario.

The currently low cost of energy is the major obstacle towards achieving these low levels of consumption as it places severe restrictions on the economic viability of aggressive conservation measures.

5.0 THE IMPACT OF BUILDING INTEGRATED PHOTOVOLTAICS

As building energy consumption reduces to the level described in 4.0, the potential contribution of BIPV’s to the overall energy consumption becomes more significant.

Assuming a 15% PV generation efficiency and an 80% coverage of all opaque building surfaces with PV panels, the figure below demonstrates that 30% of the building’s annual energy requirements could be met by BIPV panels.
In the summer months, when electricity demand is at its highest, the PV contribution could be as high as 60%.

![PV Contribution to Energy Demand](chart.png)

This would suggest that for tall office buildings in the New York context, an annual energy consumption of about 66 kWh/m² represents the limit to energy efficiency given predictable advances in building materials, components and systems.

### 6.0 CONCLUSIONS

The simplified spreadsheet method for analyzing building energy consumption provides a rapid and flexible tool for the testing of options and the optimization of systems.

For a 20 story, 32,000m² hypothetical office building located in New York, analysis using the spreadsheet suggests that energy consumption below 90 kWh/m² is unlikely given current and probable advances in building technology.

BIPV’s can make a significant contribution generating around 30% of the building’s annual energy requirements.