Comparison between conventional and PV integrated curtain wall systems

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Abstract

In today’s world, we are becoming aware of the importance of reducing fossil fuel-driven consumption by buildings. The building industry is pursuing other energy alternatives to promote sustainable and environmentally conscious architecture. PV systems are one of the most promising technologies for the building industry and can be considered as a very viable alternative. Renewable energy conversion systems, such as PV curtain wall, improve the environmental aspects of the building, while reducing fossil fuel energy consumption.

It has not yet been determined, how equivalent PV Curtain wall systems are in terms of building performance qualities when compared with conventional curtain wall systems. Issues such as heat gain characteristics, cost of the wall system and building operating costs reduction, must be addressed before curtain wall systems can be considered as replacement materials by the construction industry. These uncertainties create a gap between PV technology and construction industry slow down the process of full integration of PV into the curtain wall system and make PV technology less eminent limiting its applicability.

Discussion under the following categories to show its equivalency to other conventional curtain wall systems:

The advantages and disadvantages of PV curtain wall systems in reference to the above mentioned categories will be discussed in this paper.

1 Introduction

Curtain wall systems are prefabricated elements that usually integrated with the exterior of the buildings providing the protective skin. This skin could have openings for vision and ventilation. As a facade of a building, the curtain wall
serves as a filter from outside to inside and vice versa to outside. In a way, it acts as a gateway from the building to the site and environment. Exterior wall gives the building its architectural and esthetic character, and it can also contribute to the stiffness of the building frame.

For PV application, facades have great potential. PV can be considered as a cladding material of curtain wall and it can also be an important component of the skin. It can be opaque or transparent. It can be applied on the whole façade as well as on some part of it. As such PV could have significant role in the integral energy strategy of a building as well as environmental aspects. Major enhancements in curtain wall system can be made by full integration with the photovoltaic systems. It can add better quality to existing design concepts; push the technical boundaries of the traditional curtain wall systems to higher levels and reduce the impacts of the common defects. Integrating photovoltaic technology with the cladding design process will greatly improve energy and comfort benefits. PV curtain-wall systems can be applied in many ways. A façade could be created of a combination of glazed areas and opaque PV panels or it could have the combination of PV modules with opaque and transparent ones.

It has major impact on global energy consumption. PV systems provide direct environmental advantages. The most important environmental benefit is the reduction CO₂ emissions. It is not possible to compare CO₂ with the money in the present but for the future air pollution will be serious problem. “Each square meter of PV panel will avoid approximately 1800 kg of CO₂ in 25 year period”. [3] PV systems also represent a statement of environmental interest. Photovoltaics convert solar radiation to electricity without a need for fuel supply or damaging environmental impact. Once the system is installed, electricity is produced with no extra maintenance, pollution, or consumption of non-renewable resources.

2 Physical characteristic of the system

2.1 Thermal properties

Thermal properties have direct effect on efficiency of the building components by influencing heat flow. These properties are:

- Thermal transmittance (quantified by U-factor) is the coefficient of heat transfer. [4]
- Solar Heat Gain Coefficient (quantified by SHGC) is control the solar heat gain. Mainly is the ratio, on the solar heat gain through a window or door to that incident on the window or door.
- Shading Coefficient (quantified by SC) is the ratio on the solar heat gain through fenestration with or without integral shading devices. [4]
It is important to estimate thermal control requirements carefully. In different region, different climatic zone, different side of the building thermal effects are also different. There are two issues that should be balanced economically in an optimal way. These are potential insulation of the wall system and interior thermal control. Balancing these two issues depend on the ratio of opaque to transparent areas, glazing method or type, spandrel or wall panel area, sun control or sun shading and air conditioning factors. These issues should be identify clearly during the system design for the economically, esthetically and functionally better solution. [1] Insulation of the system, in most cases, PV itself can act as an insulation material. Some studies show that thermal radiation can be reduced by 35% and 31% if PV added on the design. [5]

Existing, traditional wall systems often consist of thick, heavy materials and acts as a barrier in transmitting thermal effects during the thermal transition. Usually for the curtain-wall systems light and thin materials are being used, which transmit thermal effects in a better way.

Curtain wall systems can be designed as a total glass, total opaque or in a glass to opaque ratio. Thermal characteristics of the system are extremely different between a total glass and opaque system. Even though a glazed curtain walls are best expresses the idea of the curtain wall system, it doesn’t satisfy the thermal problems. Opaque systems on the other hand are most efficient. [2]

2.1.1 Thermal qualities
The thermal quality of the window wall system depends on color, characteristics and orientation of the components that create the system. Also meteorological conditions for the local area have major effect on the wall temperature. [2] In addition to wall itself, joints and sealants within the wall system must also be able to resist these temperature differences. Thermal properties can be improved by adding glass layers on the back-side of the panels.

2.1.1.1 Color of the wall components PV cell can be produced in different colors, range of black, blue or brown, etc. Also PV panels can be design in different colors. Visible back layer can be colored so PV panels have combination of PV cells color and back coloring. [3] Like other building material such as frit glass, stone or metal, tinted and conditioned surfaces also give different textures to PV panels.

2.1.1.2 Characteristic of wall components
- Shape, PV panels are produced in various sizes where can be used as different building elements such as different sized rectangular spandrel units, roof tiles, or windows elements. Even though manufactures of the PV offer standard products, they also produce custom-made products to fit in to various building design alternatives with more cost.
- Transparency can be achieved in two different ways. One is to spacing PV cells from a distance each other. Second is to use transparent cells. Transparency on the cell is achieved by the pinholes on the cells. Different density and size of the pinholes give different degrees of transparency. [3]
2.2 Natural Light

Windows are the ideal part of the wall systems to take advantage of natural light. It is important for any kind of building system to admit daylight and provide outside view. Also, the role of windows in energy efficient design is significant. The use of artificial and natural light together gives enormous savings in operational costs. The designer should take full advantage of winter solar radiation and daylight through the window. [2]

Window doesn't have to be 100% clear to take advantage of natural light. There are transparent window materials and transparency gives architects variety of design opportunities. They can create an attractive building skin and also provide the natural light inside of the building without glare problem. There are also transparent PV cells. Transparency in the PV curtain wall can be also given by opaque PV cells with a design strategy. With a distance-replaced cell, shade patterns can be created inside of the building, which change different time of day. [3] The façade area can be densely packed with cells, or more spaced out to give semi-transparent effect. These areas can be below or above the clear glass areas. Several different configurations can be made. (See figure 3).
2.3 Ventilation

It is important to keep the PV temperature low to get better performance. There are various ways to do so. Ventilation gaps can be created in rain screen cladding. Mole ventilation can be combined with the building ventilation. The rule is that the provided gap must be at least 100 mm. This gap also provides space for cabling. (2) Also, with a “stack effect”, natural ventilation behind the PV module can be attained. This creates the airflow behind the PV module. This airflow helps to reduce the PV temperature, which increases the efficiency of the module. [5] This should be considered as a design strategy and the designer should allow air to flow from behind PV modules to maintain high performance. It is also important to avoid unwanted heat gain into the space. This heat can be very valuable during the cold seasons. It can be used directly or recovered by ducting system. [3]

Figure 2: Desktop Radiance 3D image of daylight study of PV wall design by Peter Ellis, Skidmore Owing & Merrill Chicago [7]

Figure 3: Example of PV rain screen-cladding system with an air gap. [3]
2.4 Acoustic

Interruption of outdoor noise is an important problem especially in urban areas. The designer should consider acoustical features in site planning and interior design of the building. Some of the acoustical problems can be avoided if acoustically sensitive functions do not face a noisy site. The basic requirement for noise control is a complete enclosure by heavy, solid material. Openings reduce the effectiveness of the enclosure. Noise reduction can also be achieved by double glazed systems. The space between glass layers should be at least 100 mm (4 inc.) to be really effective. There are also special types of laminated glass for acoustical benefits. [1] Acoustic can be improved by adding glass layers on the back-side of the panels.

3 Economical characteristic of the system

3.1 Cost

The cost effectiveness of the system is as important as the convenience of BIPV product, the building elements and the distributed sources of electrical energy. It can be very valuable to compare the cost of the alternative materials with BIPV system’s cost before making any decision about building envelope materials. In practice sizing and pricing of PV installation is relative. The cost of the system can be calculated according to PV area but also other components of the supporting system, such as balance of system (BOS) and inverters, should be included.

Table 1: Cost compression between traditional cladding materials and PV system. [3] [11]

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<thead>
<tr>
<th>Costs of the conventional wall systems</th>
<th>($/m²)</th>
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<tbody>
<tr>
<td>Cavity wall</td>
<td>90</td>
</tr>
<tr>
<td>Rain screen over cladding</td>
<td>280</td>
</tr>
<tr>
<td>Stone cladding</td>
<td>450</td>
</tr>
<tr>
<td>Double glazed cladding system</td>
<td>560-800</td>
</tr>
<tr>
<td>Granite façade pre-cast concrete cladding</td>
<td>928</td>
</tr>
<tr>
<td>Polish stone cladding</td>
<td>1,200-2,800</td>
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<table>
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<th>Costs of PV cladding systems</th>
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<tbody>
<tr>
<td>Rain screen cladding systems</td>
<td>500-870</td>
</tr>
<tr>
<td>Curtain walling using glass/glass module</td>
<td>1000-1500</td>
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*Based on crystalline silicone technology. Balance of system (BOS) is included.*
Table 1 shows the cost of the different building envelope materials. If comparison is between PV and an expensive façade element, such as polish stone granite, replacement of PV with this material can offset the PV cost. These prices are approximate. Lower system cost can be achieved. The costs of building envelope material such as cavity walls are not significant compared to the cost of PV systems. On the other hand, in an expensive façade system such as polish stone cladding, the cladding cost may equal the cost of PV module and the cost can be offset. So, in the expensive façade system, PV market is already competitive. Also, PV, as different than other expensive cladding material, can return the investment to the building owners (especially for commercial buildings) by increasing in rent. [5]

It shouldn’t be forgotten that PV technology is still a developing technology and PV market is growing very fast. It is most likely that PV cost, will be equivalent to regular building envelope material in the near future.

3.1.1 Photovoltaic curtain-wall system cost

Photovoltaic curtain-wall system includes, PV modules and BOS (Balance of System) components. The BOS components consist of inverters electrical storage, or a grid-metered connection, fault protection, cabling and wiring. These costs along with the cost of integrating design and installation should be included Photovoltaic curtain-wall system cost. When the result is compared with the traditional curtain wall system, it determines the added cost of photovoltaic curtain-wall system. Roughly 45-50% of the PV system costs come from the array, 5-20% from installation, 30-50% from balance of system, power conditioning units, Wiring, switchgear, metering, etc. [3] At the present time, efficiency and cost of the PV system are not very effective. Although according to U.S. Department of Energy research, with government support and better efficiency of the PV cell, PV is expected to be commonly use commercially by the year of 2010. [10]

Application of PV technology is fairly new and still growing. This makes this technology expensive in the present. PV manufactures are improving their technique. Production costs starting to go down. Relatively, PV system component costs are going down too. Installation cost also will go down with market development and more experienced system installer.

Photovoltaic curtain-wall system may have higher labor costs than traditional curtain-wall and other traditional systems especially in the United States. The demand and manufacturing production volumes are lower in United States than Europe. Existing BIPV system projects show high design and final project costs. Also the time and money required for electrical and mechanical engineering and installation methods raise the total cost of system. [9] With growing PV technology, simpler engineering, design and installation methods will help to reduce labor costs of photovoltaic curtain-wall system.

Maintenance cost has a significant role in the cost effectiveness of an investment. System replacements and repairs should be included as part of maintenance cost in the photovoltaic curtain-wall system cost analysis. Periodic
system checks and cleaning may not be that important for the traditional curtain-wall systems but for the Photovoltaic curtain-wall system. They should be made in certain time period and should be a part of maintenance cost. [9]

There is also building permits cost, which required before any construction. It varies for each country.

BIPV systems have utility interconnection cost. Other traditional curtain-wall systems don’t have this cost. Utility interconnection costs are different for each location according to specific requirements determined for different states.

Also there are costs that associated with standards and codes. These apply for all the systems.

For the PV there is also salvage value. Disposal costs can be estimated and included in the analysis. Especially thin film PV technology can generate significant disposal cost. Also for the batteries there is also a disposal cost.

3.2 Economic benefits of PV curtain-wall system, which regular curtain-wall systems do not have:

Benefits that will be getting from PV curtain-wall systems definitely effect decision making. These benefits are usually identified and evaluated based on direct economic impact, indirect economic impact, and qualitative value.

• Direct economic impacts; Photovoltaic curtain-wall system usually affects the construction budget. But electricity that will be generated from this system will effect operating cost that will reduce the budget. Basically photovoltaic curtain-wall system can save the building owner money by reducing construction material and electricity costs, providing education, enhancing power quality and power reliability, and providing tax credits. The entire savings, especially in the long term might be really impressive. [9]

• Indirect economic impacts; each building owner has a value related to strategic goals, business interests, or organizational mission. With the PV curtain-wall system, additional benefits may occur. This can directly effect budgets. There are opportunities to get a credit or value for photovoltaic curtain-wall system technology for environmental emissions reduction from some government organizations. [9]

• There are some benefits of PV curtain-wall systems that cannot be valued with monetarily such as positive image, public perception, or impact on the environment. PV panel systems shouldn’t be considered just as a cladding material. They can have multifunctional role, on the building façade as mentioned above.

3.3 Life Cycle Cost Analyses

For the purpose of designing and PV curtain-wall systems, the LCC method is recommended. With this analysis, the building owner should be able to get current and future costs and also compare the results of another option, [9] such as traditional curtain-wall systems. LCC is the time-adjusted sum of all time-
adjusted costs of a given system over the specified period, and must be compared with the LCC alternative system in order to make an informed choice between them. Basically Photovoltaic curtain-wall system requires a big capital construction cost but no operating fuel cost.

**PV INTEGRATION INTO THE BUILDING DESIGN PROCESS**

Figure 4: Life Cycle Cost Logic (Adapted from Dell’Isola, 1995) [8]

**Conclusion**

Exterior wall gives the building its architectural and esthetic character, and it can also contribute to the structural stiffness of the building frame. Curtain wall systems are prefabricated elements that usually integrated with the exterior of the buildings providing the protective skin. For PV application, facades have great potential. PV can be considered as a cladding material of curtain wall and it can also be an important component of the skin. As such PV could have
significant role in the integral energy strategy of a building as well as environmental aspects. However, PV technology is still a developing technology and cost of the system is still high. Also characteristics of the system are not known by designers and developers. But PV market is growing very fast. It is most likely that PV cost, will be equivalent to regular building envelope material in the near future. Even in today’s market PV can be compatible if compares with expensive cladding systems. PV technology is improving every day. It is important to make this promising technology available and cost effective for the construction industry and building owner.

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References