BIPV FAÇADES RECONSIDERED: MID-RISE AND HIGH RISE APPLICATIONS

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ABSTRACT

Results demonstrate BIPV spandrel applications can contribute in excess of 15% to the annual electricity requirements for highly efficient office buildings throughout major US climate zones. Assuming a 10 story 20,000 square foot floor plate, the maximum contribution provided by BIPV spandrel ranged from 35% to 52% based on the highest spandrel façade coverage and the largest south façade area. In comparison roof mounted PV systems provided a maximum contribution of 10% towards electricity consumption. A BIPV spandrel façade mock-up located in Sacramento, CA provided actual performance data that contributed to the findings. EPA's Target Finder was utilized to provide annual energy consumption data so that the analysis could demonstrate the feasibility of approaching net zero annual energy consumption. While current research reveals the energy production limits associated with their vertical application; the net zero energy goal suggests a reconsideration of BIPV facades.

1. INTRODUCTION

1.1 Significance of the Problem

The American Institute of Architects and the Architecture 2030 Challenge[1] have set a series of progressive milestones over the next nineteen years which culminate in net zero energy buildings by 2030. This voluntary goal is meant for both new and existing buildings, relying on an effective combination of energy efficiency and on-site renewable energy generation. There are of course many challenges to buildings becoming net zero annual energy consumers.

Fortunately costs for renewable energy have been dropping as many products are being mass produced and commoditized. This is especially true for photovoltaic (PV) modules whose selling price is down from $4.25 per Watt ($/W) six years ago to around $2.00/W at the time of this research[2]. When viewed from the perspective of the building construction industry, PV modules used to cost roughly $54 per square foot (/SF) and now cost approximately $25 /SF. It is interesting to compare the cost of PV modules to typical spandrel glazing used in curtainwall building facade applications. On average the cost range for spandrel glazing is roughly $8/SF to $12/SF. If the thirty percent (30%) Federal Investment Tax Credit (ITC) is applied to the selling price of PV modules $25 /SF becomes $18 /SF, which comes closer to the cost of spandrel glazing.

As the total installed cost of PV systems continues to drop there are new opportunities for integrating on-site generation with buildings. One question to be explored in the research is how effective are BIPV spandrel applications in generating on-site energy across a variety of climate types and latitudes so that buildings can approach net zero annual energy consumption?

A Building Integrated Photovoltaic (BIPV) façade mock-up has been constructed in Sacramento, CA using standard size framed mono-crystalline PV modules as spandrel glazing in a curtainwall application. The 1.4 kW BIPV system is seen as a proof of concept to demonstrate that BIPV facades can significantly contribute to reduced utility consumption through on-site energy production. See Figure 1.

Available façade area for PV applications can be quite significant for mid-rise and high-rise buildings. Assuming a 20,000 square foot (SF) floor plate the south facing spandrel area can range from between 1,200 SF to 4,500 SF per floor for a typical mid-rise building. In comparison the available roof area for PV systems may only be 4,000 SF to 10,000 SF based upon perimeter parapet walls, mechanical equipment, elevator machine rooms, and roof access stairways. Refer to Figure 2.

1.2 Climate Selection

In addition to Sacramento, CA the scope of the research also included a review of potential contributions provided by BIPV spandrels in four climate types of the United States. The climate types were represented by the following selected cities: Hot-arid (Phoenix, AZ latitude 33°26'N), Hot-humid (Miami, FL latitude 25°48'N), Temperate (New York, NY latitude 40°47'N), and Cool (Minneapolis, MN latitude 44°53'N).

2. METHODOLOGY

2.1 Research Objective

A major research objective is to demonstrate BIPV spandrel applications can contribute in excess of 15% to the annual electricity needs for highly efficient office buildings throughout major US climate zones.

2.2 Process

At each of the five locations the annual electricity consumption of a highly energy efficient office space type was utilized as the benchmark for establishing the relative benefit provided by various BIPV spandrel configurations. The rationale being that approaching and achieving net zero annual energy consumption requires loads to be minimized and efficient equipment to be utilized even before on-site renewable energy can be effective.

For the study a highly energy efficient building is defined as 70% more efficient than compared to the US commercial building population of similar buildings for that location. The 70% energy reduction target matches the Architecture 2030 Challenge goal for 2015. The estimated annual building energy consumption was established using EPA's Target Finder website (www.energystar.gov/targetfinder). The 70% energy efficiency benchmark is the highest currently available from Target Finder. Target Finder uses information collected from actual energy usage found in the Commercial Building Energy Consumption Survey (CBECS) which was last conducted in 2003 by the US Energy Information Agency.

To obtain energy production data for BIPV spandrel systems a combination of actual and modeled performance was used. For the Sacramento location actual on-site energy production data was collected from the 1.4 kW BIPV façade mock-up. For the other locations the renewable energy production was modeled utilizing PVsyst 5.0 software. The modeled performance was based upon the same PV module and inverter as was used in the actual façade mock-up in order to have comparable results. The actual and modeled performance was then applied to various façade coverages (percentage of spandrel to vision glazing) and to various façade length to width configurations. In addition a roof mounted PV system was modeled in order to assess the effectiveness of the façade BIPV systems. The goal was to create a broad range of results in order to ascertain the relative minimum and maximum effect.

The potential annual PV system energy generation was then merged with building energy consumption data. The resulting net energy from combining consumption and generation is the focus of the research.

2.3 Test Case

The research method examined an office building with the following characteristics:

- 10 stories
- 20,000 SF floor plate
- 14'-0" floor to floor height
- Varying length to width ratios: 1:1, 1:2, 1:3, and 1:4
- Varying spandrel coverage of the total façade: 65%, 75%, 85%, and 100%
- 70% energy efficiency from EPA's Target Finder

3. PARAMETERS

3.1 BIPV Output Performance

During the first stage of investigation, on-site renewable energy generation data was based upon the following parameters:

- PV array tilt angles: 90° for facades, 15° for roofs
- PV array azimuth orientation: 0° facing south
- PV module area: 13.99 SF
- PV module wattage STC: 175 Watts
- PV module power density: 12.51 Watts/SF
- PV module technology: mono-crystalline

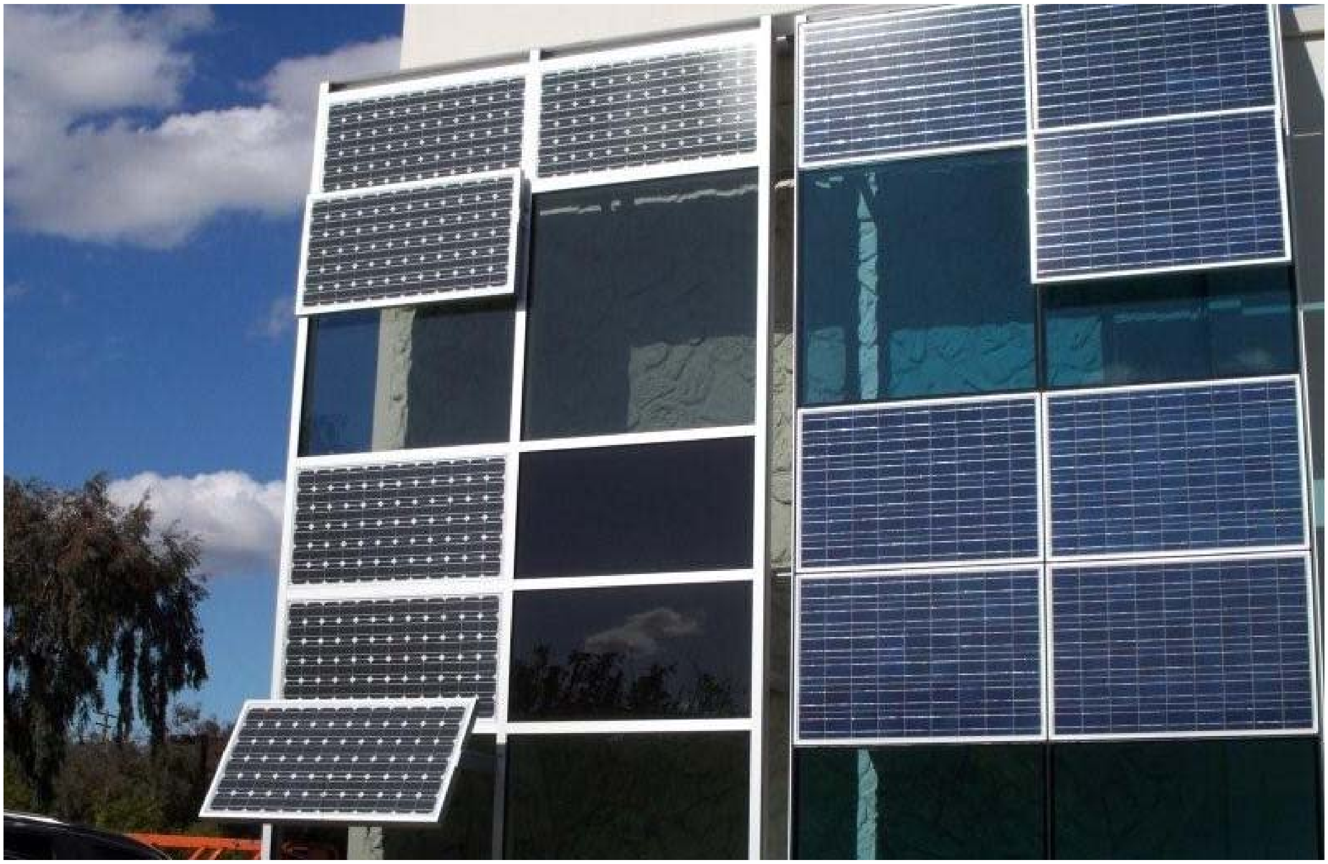

Fig. 1: BIPV façade at Bagatelos Architectural Glass Systems Inc, Sacramento, CA

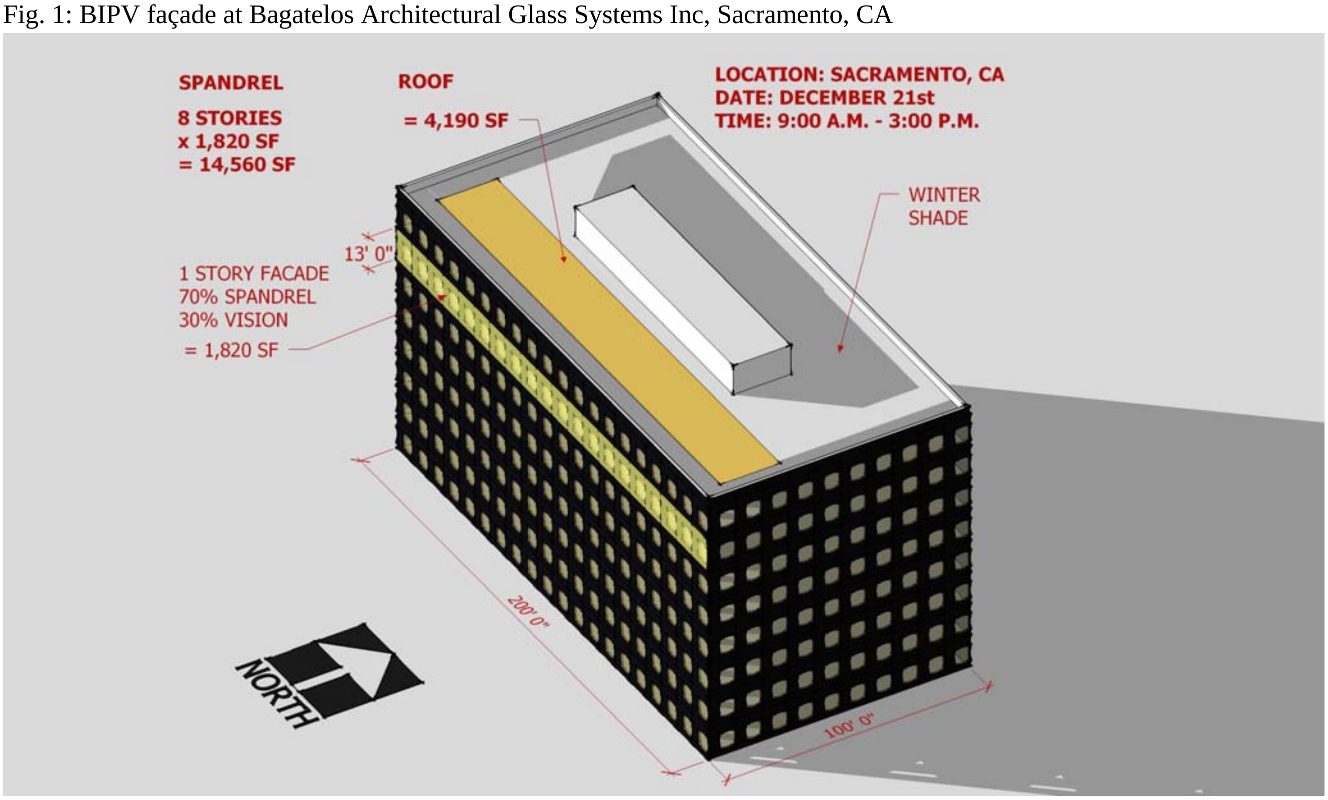

Fig. 2: Illustration comparing potential PV area for roof and façade applications on an 8 story building

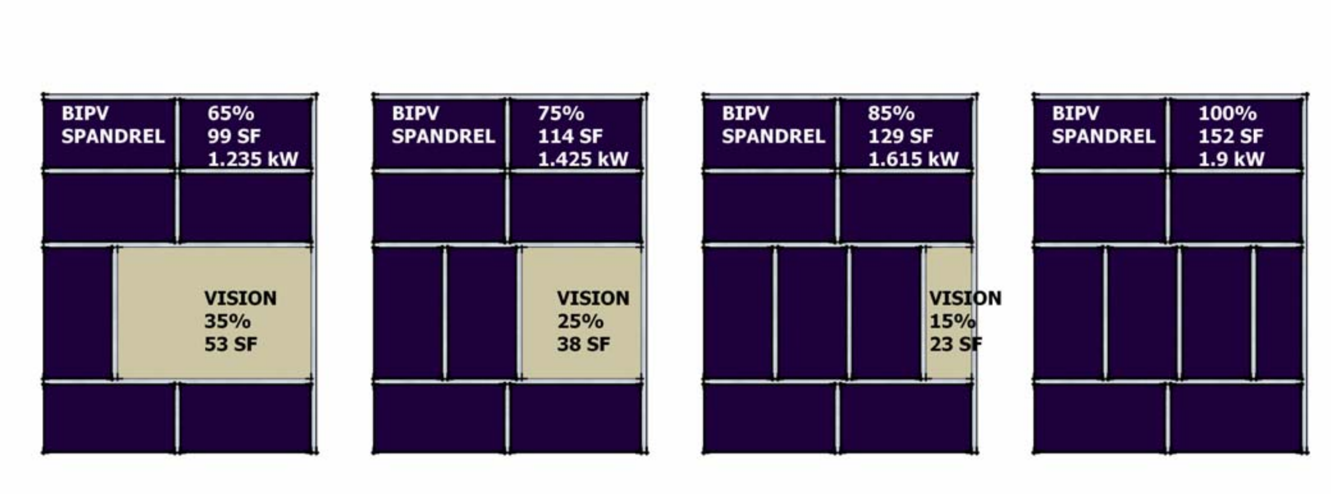

Fig. 3: Variations in percentage of BIPV spandrel and vision glazing.

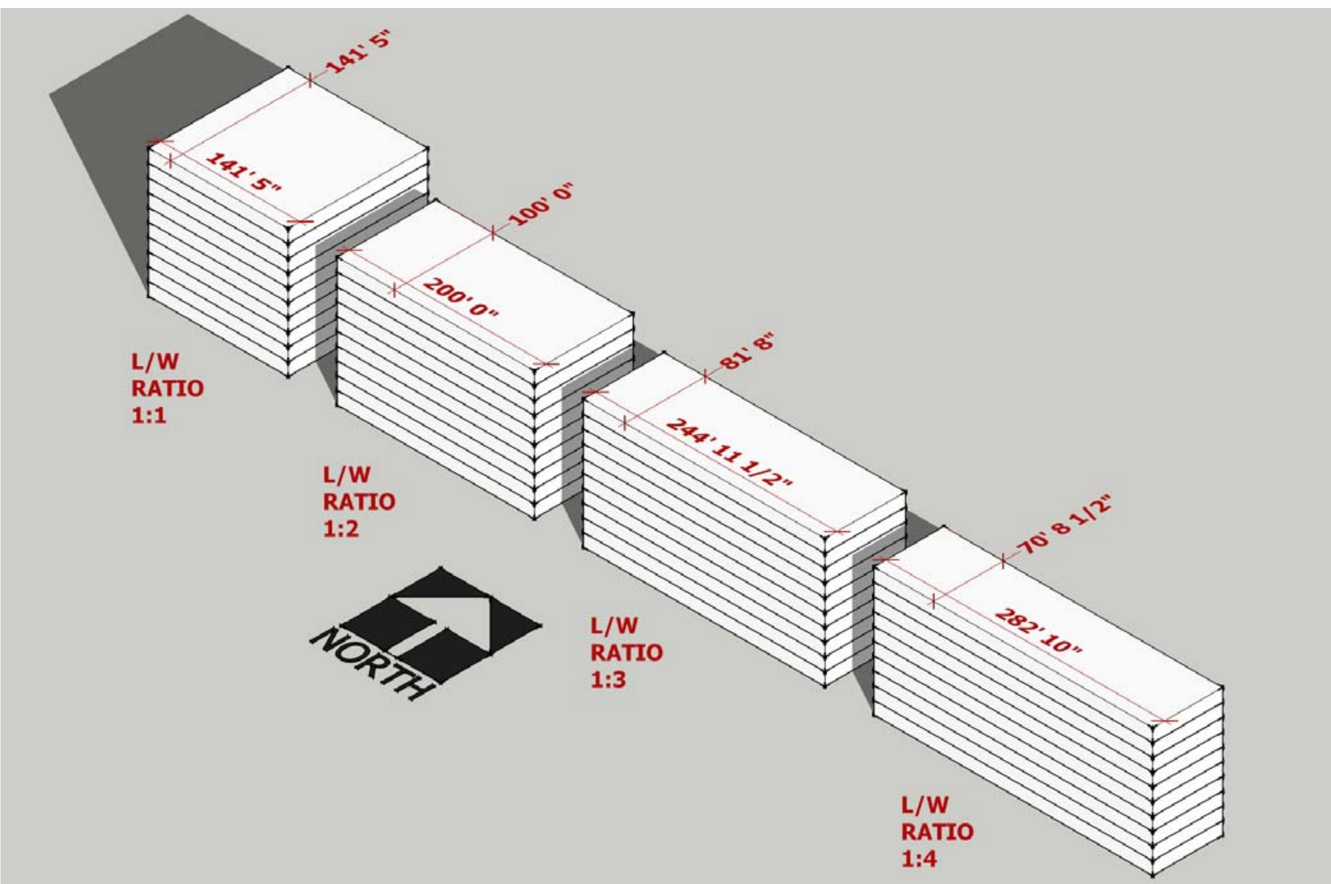

Fig. 4: Variations of the length to width ratio (L/W ratio) for a 20,000 SF floor plate multi-story building.

The generation data was then applied to four BIPV spandrel coverage configurations:

- **Spandrel 65%:** covering 65% of the façade with 35% vision glazing
- **Spandrel 75%:** covering 75% of the façade with 25% vision glazing
- **Spandrel 85%:** covering 85% of the façade with 15% vision glazing
- **Spandrel 100%:** covering 100% of the façade with no vision glazing

Refer to Figure 3 for a visualization of spandrel coverage configurations.

In order to better understand the total south façade area available for BIPV spandrel applications a range of length to width ratios (L/W ratio) was studied. L/W ratio modifies the same building surface area to potentially create more façade area facing south while reducing east and west façade area which has the potential to reduce perimeter loads on HVAC equipment. The range of L/W ratios studied were the following:

- **L/W Ratio 1:1 :** length of south/north façade is equal to east/west façade (square)
- **L/W Ratio 1:2 :** length of south/north façade is 2X the east/west façade (rectangle)
- **L/W Ratio 1:3 :** length of south/north façade is 3X the east/west façade (rectangle)
- **L/W Ratio 1:4 :** length of south/north façade is 4X the east/west façade (rectangle)

3.2 Whole Building Performance

For each city in the study an electricity consumption benchmark was established using Target Finder.
The following parameters were used in Target Finder:

- Zip code: Miami = 33131, Phoenix = 85004, Sacramento = 95814, New York = 10001, Minneapolis = 55402
- Space Type: Office
- Gross Floor Area: 20,000
- Weekly operating hours: 40
- Workers on main shift: 120
- Number of PC's: 120
- Office air-conditioned: 50% or more
- Office heated: 50% or more
- Target Rating:
  100 (70% energy reduction target)
  50 (0% energy reduction target)

4. RESULTS

4.1 BIPV Output Performance

Results indicate PV modules facing south and mounted at a 90° tilt angle have reduced annual energy generation when compared to a 15° tilt angle and the optimum tilt angle for that latitude. The loss of potential energy generation ranged from 46% to 31%. Refer to Figure 5. Note results are reported in energy intensity (kWh/SF/YR) in order to better relate to building industry metrics based on area. It is important to note that for all locations, minimum performance was just slightly below 10 kWh/SF/YR for south facing BIPV spandrel. The analysis shows Phoenix had the highest annual output with Sacramento, Minnesota, New York, and Miami following in order of listing. The unpredictable variation of the output generation results is worthy of further investigation. Refer to Table 1.

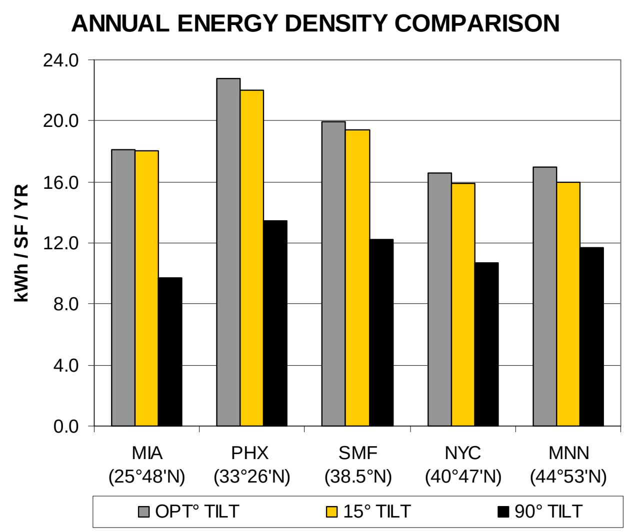

Fig. 5: Results of PV energy output generation.

TABLE 1:
BEST ANNUAL ENERGY INTENSITY FOR 90° TILT

	kWh/SF/YR	% SMALLER
PHX (33°26'N)	**13.47**	
SMF (38.5°N)	12.21	9.3%
MNN (44°53'N)	11.67	13.4%
NYC (40°47'N)	10.70	20.5%
MIA (25°48'N)	9.74	27.7%

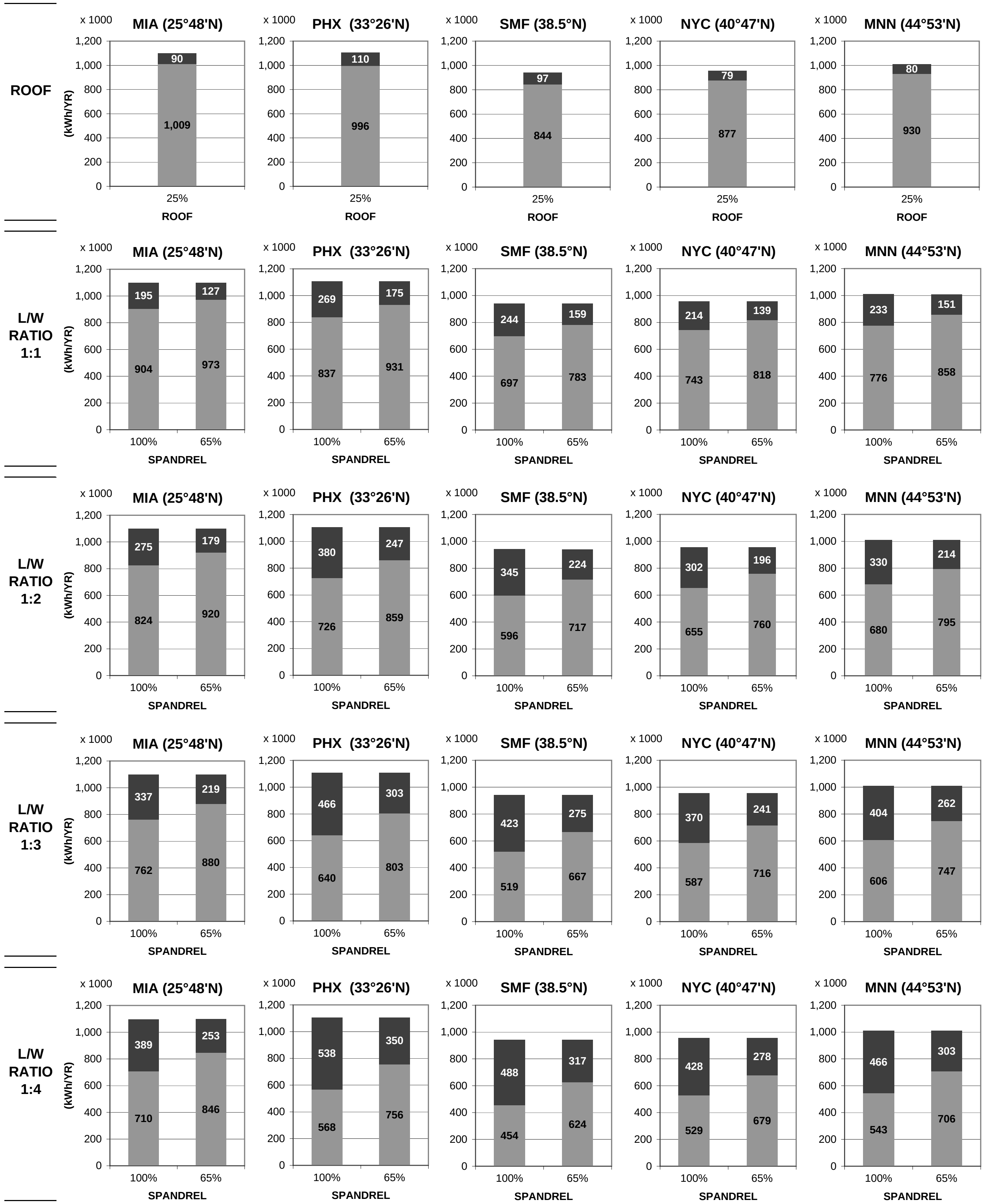

Fig. 6: Analysis of annual PV energy generation and resulting building energy consumption assuming a 10 story 20,000 SF floor plate highly efficient office tower located in cities indicated. The BIPV spandrel coverage on the south facade ranged from 65% to 100%. The PV system coverage on the roof was 25%.

4.2 Whole Building Performance

Research results show the maximum contribution provided by BIPV spandrel ranged from 35% to 52% based on the highest spandrel façade coverage (100%) and based on the L/W ratio 1:4. The minimum contribution provided by BIPV spandrel ranged from 12% to 17% based on the lowest spandrel façade coverage (65%) and based on the L/W ratio 1:1. In comparison roof mounted PV systems provided a maximum contribution of 10% towards electricity consumption. See Figure 6. Sacramento achieved the highest contribution and lowest total electric energy consumption provided by BIPV spandrel. Miami had the lowest contribution and highest total electric energy consumption. Refer to Table 2.

TABLE 2: BEST PERFORMANCE SUMMARY

LOWEST TOTAL ELECTRIC CONSUMPTION W/ NO PV

	kWh/ YR		% HIGHER
SMF (38.5°N)	**941,436**		
NYC (40°47'N)	956,891		1.6%
MNN (44°53'N)	1,009,393		7.2%
MIA (25°48'N)	1,099,097		16.7%
PHX (33°26'N)	1,106,057		17.5%

LOWEST TOTAL ELECTRIC CONSUMPTION W/ PV

	kWh/ YR		% HIGHER
SMF (38.5°N)	**453,515**		
NYC (40°47'N)	529,368		16.7%
MNN (44°53'N)	543,269		19.8%
PHX (33°26'N)	568,014		25.2%
MIA (25°48'N)	709,862		56.5%

HIGHEST PV CONTRIBUTION TO REDUCING ELECTRIC CONSUMPTION

	kWh/ YR	%	% SMALLER
SMF (38.5°N)	**487,922**	**52%**	
PHX (33°26'N)	538,043	49%	3.2%
MNN (44°53'N)	466,123	46%	5.6%
NYC (40°47'N)	427,522	45%	7.1%
MIA (25°48'N)	389,235	35%	16.4%

5. CONCLUSIONS

5.1 BIPV Output Performance

Analysis of the BIPV spandrel energy generation results reveal latitude as being a strong determinant, but not the deciding factor, since lower latitude locations outperformed the rest. When viewing the results for 90° tilt based on loss relative to optimum, the lower latitude locations had the highest drop 47% to 42% as compared to the higher latitude locations with a drop of 37% to 31%. With Phoenix generating the highest amount of energy one can hypothesize that the amount of available direct sunlight throughout the year proved to be the deciding factor. Regardless of latitude and geographic location the investigation revealed that BIPV spandrel can be a significant generator of on-site renewable energy.

5.2 Whole Building Performance

Results demonstrate BIPV spandrel applications can contribute in excess of 15% annual electricity needs for highly efficient office buildings throughout major US climate zones. Results also show that relying on available roof mounted PV systems for tall buildings will not provide as significant on-site renewable energy. While current research reveals the energy production limits associated with their vertical application; the net zero energy goal suggests a reconsideration of BIPV facades. Currently available PV module products can allow building planners, architects, engineers, and contractors the option of employing façades as major energy generators. Potential future studies could include the impact of additional BIPV spandrel on the east and west building facades. Further development of BIPV strategies and products is required in order to create and adapt tall buildings into net zero annual energy consumers.

6. ACKNOWLEDGMENTS

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