NREL/TP-472-7574 • UC Category: 1600 • DE95004032

# Building-Integrated Photovoltaics: A Case Study

Gregory Kiss
Jennifer Kinkead
*Kiss Cathcart Anders Architects, P.C.*

Mahadev Raman
*Ove Arup & Partners New York*

NREL Technical Monitor: Sheila Hayter

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
A national laboratory of the U.S. Department of Energy
Managed by the Midwest Research Institute
for the U.S. Department of Energy
under Contract No. DE-AC36-83CH10093

March 1995

## NOTICE



Available to DOE and DOE contractors from:
Office of Scientific and Technical Information (OSTI)
P.O. Box 62
Oak Ridge, TN 37831
Prices available by calling (615) 576-8401

Available to the public from:
National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

Printed on paper containing at least 50% wastepaper and 10% postconsumer waste

# CONTENTS



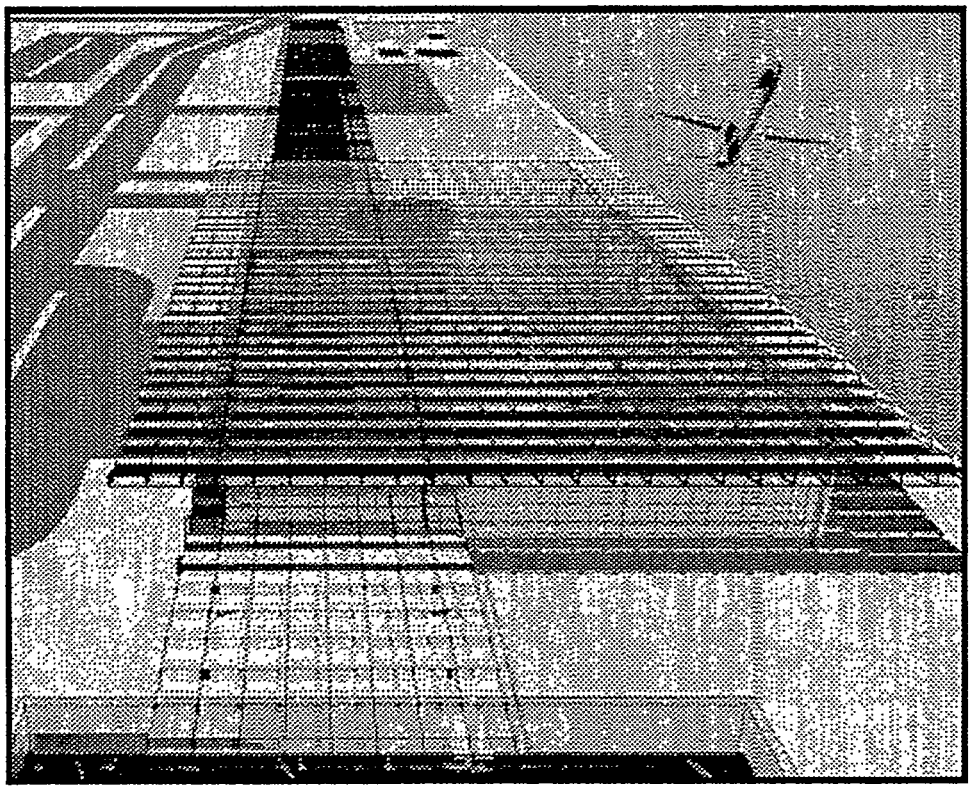


*Fig. 1. Case study building: conference center and pedestrian canopy as seen from hotel roof.*

*Cover page: Conference center at main entry.*

# EXECUTIVE SUMMARY:

## BACKGROUND

In 1992, Kiss Cathcart Anders Architects performed a study for NREL on Building-Integrated Photovoltaics (BIPV) issues as seen from the perspective of the building community. That study included a broad overview of potential BIPV applications in commercial/institutional buildings. Wall, roof, and semi-detached applications were illustrated, and some quantitative analysis of the effects of building geometry on PV output was performed. In general, the purpose of the study was to list major issues and potential applications; by it's nature it asked more questions than it answered.

## SCOPE

This second phase study was commissioned by NREL in 1994 to produce quantitative data on the performance of specific BIPV systems. High value-added applications for BIPV are targeted in medium to high-end commercial/institutional buildings. These building types should offer a good initial market for BIPV products.

## SYSTEMS EVALUATED

In order to limit the number of variables only roof systems are evaluated. The energy performance, construction cost and simple payback for five different BIPV roof options are evaluated in each of six different locations around the US (Oakland, New York, Miami, Phoenix, Chicago and Cincinnati). The roof options include:

1. A single-glazed PV roof using glass-substrate PVs;
2. A double-glazed PV roof with insulating PV modules;
3. A ballasted roof-mounted system;
4. A sawtooth light monitor roof with indirect north daylighting;
5. A sawtooth roof with north light and active heat recovery.

## PV TECHNOLOGIES EVALUATED

Each system was evaluated with three different PV technologies: Crystalline silicon at $4.40/W and 140W/m2 (13W/sf), amorphous silicon at $3/W and 52W/m2 (4.8W/sf), and advanced thin films (for future applications) at $2/W

and 108W/m2 (10W/sf). The first two technologies are currently available; the costs and efficiencies of the third are projections for the future.

## BIPV SYSTEM COSTS AND ENERGY PERFORMANCE

Construction costs and energy benefits of all BIPV roof systems are compared with a reference design (a standard flat, opaque, insulating roof). The reference design has a cost basis of zero; any additional structure, construction materials, PV modules or electrical systems are counted as costs. If the BIPV roof option displaces any of the materials used in the reference design (ie, roof membrane, insulation or metal roof deck), the cost of that material is subtracted from the cost of the BIPV option.

The energy benefits of each BIPV roof system are compared with the reference roof to determine the net effect of each system on building energy consumption. In several of the BIPV options the PV module itself is the building roof; in these cases energy savings or losses due to heat or light transmission through the module are always included in the anlayses. In some of the BIPV systems the PV modules are not integral to daylight or thermal performance; in these cases payback is also analyzed two ways:

1 for the complete system, including all construction costs and all energy benefits, and

2 for the PV system only, including only PV-related costs (modules, wiring, inverters) and using only PV electricity as income.

## LOCATIONS EVALUATED

Oakland, New York, Miami, Phoenix, Chicago and Cincinnati represent a wide range of climate types from temperate cold to subtropical, and an equally wide range of utility rates and construction costs.

## UTILITY RATE ANALYSIS

In each city an applicable utility rate is selected which seems likely to provide the greatest value for power offset by the PV system. Plans with high time of use charges and low demand charges are chosen where available. The actual value of power offset by the PV system is calculated by multiplying the hourly PV output for each day of each month by the rate prevailing at each hour. The resulting total dollar figure is divided by total electrical production for the year to give an average dollar/kWh electrical rate.

## PAYBACK

In the case of the full system analysis (including collateral energy effects), the value of the total energy difference between each option and the base case was divided into the construction cost premium to establish a simple payback. For the PV-only analysis, the value of the electricity generated by the system was divided into the cost of the PV system only. The payback calculations do not take into account tax benefits.

## CONCLUSIONS

•Payback periods range from 14.5 years and up. Of the six locations in the analysis, the best environment for BIPV systems is Oakland, where insolation is good, the climate is mild and energy costs are high. The worst case is Cincinnati, where insolation, climate and energy costs are all less favorable.

•Systems with payback periods of approximately twenty years according to this study) can be cost-effective today. Tax benefits, which are not included in these calculations, can cut payback times significantly, bringing them into the ten-year range. Although the mass market usually requires payback of less than five years, institutions with longer planning horizons can find these applications economical now.

•No one PV technology is most cost effective in all cases. The study indicates that either high efficiency, high cost PVs like single crystal or low efficiency, low cost PVs like amorphous silicon can perform better in the right circumstances. The former technology (high W/m2) is less affected by high area-related balance of system costs, such as glazing framing systems; the latter technology (low $/m2) benefits more from credits from avoided construction materials, such as atrium glass.

•No one BIPV roof system is most cost effective in all cases. Applications offering significant material credits, such as skylights or atriums, usually give the best return. In some cases, systems that combine daylight and thermal benefits with PV can be cost effective even if they are not displacing expensive construction materials.

•This study did not attempt to identify the best possible application for BIPV. Shorter payback periods may be possible with other BIPV systems which offer higher material credits, such as curtain walls, or in other locations with higher utility rates or more favorable climates. It is worth repeating, however, that within the scope of this study cost-effective BIPV applications exist today.

# INTRODUCTION:

In January 1993 Kiss Cathcart Anders Architects (Gregory Kiss and Jennifer Kinkead, investigators) completed a study for the National Renewable Energy Laboratory entitled "Building-Integrated Photovoltaics". Based on the premise that there are many economic advantages to integrating Photovoltaics into building construction, the report was a broad survey of the issues involved in integrating Photovoltaics (PVs) into buildings, seen from the perspective of the building industry. The market for building-integrated products was (and still is) in its infancy. Although advances in PV technologies have made many new applications possible, development of products specifically designed for building use has barely begun.

One of the barriers to the creation of a Building-Integrated Photovoltaic (BIPV) industry is a lack of knowledge about how PV-building products will perform in place, as construction materials as well as PV devices. At present there are few built BIPV projects in the United States from which to gain experience. Most of these have been residential, many of them retrofits to existing houses. In Europe many more BIPV projects have been built, including many residences and a number of advanced, high-visibility commercial and institutional projects.

Our 1993 report concentrated on commercial and institutional building applications because we believe that these building types are the highest value-added applications for PVs, and will therefore be a viable early (and long term) market for BIPV products. In commercial and institutional buildings BIPV materials can be used to replace conventional building materials which cost as much as or more than the PVs; these buildings often have sophisticated envelope and mechanical systems which offer the potential to capture additional daylighting and thermal energy benefits; and their load profiles are well matched to peak sun (and peak electricity rates). The previous report surveyed these and many other issues from the point of view of the design community and the building industry, and while it included a number of schematic system designs and some quantitative analysis, by its nature it raised more questions than it answered.

This report is intended to help answer some of these questions, particularly:

- How would a BIPV system in a medium-sized institutional building perform in terms of the thermodynamic behavior of the building envelope, as well as in terms of electrical output?
- How will these systems be constructed?
- How much will they cost and what will the payback be?

A building is a combination of many complex systems: structural, mechanical, electrical, and others. Changes to the parameters of one system affect the others. An assessment of the performance of a BIPV system as an element of a building skin therefore requires a multidisciplinary approach. We collaborated on this study with Mahadev Raman and Ross Clarke, mechanical and structural engineers respectively, at Ove Arup and Partners New York, a building engineering firm. We began by creating a hypothetical building program, then selecting a basic type of BIPV system (roof or wall) to develop for design and analysis. In setting these initial criteria we relied on our subjective judgment, since an exhaustive analysis of possible building types, programs and sites was beyond the scope of this study. In any case we were not attempting to select the optimum project for PV integration; we were interested in a building that would be in the mid- to high-end of the cost and performance range, and that would have aspects that would be applicable to other projects.

The building type was selected according to the following criteria: that it be a mid-size commercial project in the $10-20 million construction cost range; that it operate primarily during daylight hours; that it be public or semi-public to ensure good visibility for the PV systems; that it have a medium to high level of material finish; and that it be suitable for a BIPV system that could develop significant corollary energy benefits or displace significant construction material costs, or both. Given these parameters, we selected a medium sized conference and convention center as the program.

Among the range of PV-integration options for a convention center, we chose to study integration at the roof of the main exhibition hall. Rooftop BIPV systems offer opportunities for good orientation and collateral energy benefits. In addition, the one-to-one ratio between roof and floor area enabled us to confine

our analysis to a typical square meter of interior space for energy demand and production.

While the building was designed in its entirety in English units to establish a scale for the project and to provide peak electrical demand numbers for use in utility rate analysis, all other analyses, including thermal performance, construction cost and payback, were performed on a square meter basis.

# BUILDING DESCRIPTION:

The case study building is a conference center designed to support medium-sized conferences and exhibitions for 300 to 500 persons at a time. The total building floor area is 6,700 m2 gross (72,000sf).

Note that the site diagram *(Fig 2)* shows a larger program which includes a hotel and pedestrian/parking structure, all PV-integrated. This case study focuses exclusively on the conference center. The renderings illustrating the report (cover page, Figs. 1, 3, 6, 30) depict a sawtooth roof system with light monitors. The sawtooth roof system is illustrated to give a general sense of the the architectural quality of a combined PV/daylight structure. The other BIPV roof systems were also analyzed and are illustrated with diagrams, sections and detail perspectives in the *BIPV Options* and *Cost Analysis* sections.

For the purpose of the energy balance analysis, occupancy is projected from 9am-7pm daily. Standard internal environmental criteria apply for temperature, humidity and lighting (Appendix A outlines these criteria and other building load assumptions in more detail). The building is projected to have a peak demand of ≤500kW and is thus considered a medium-scale commercial utility user.

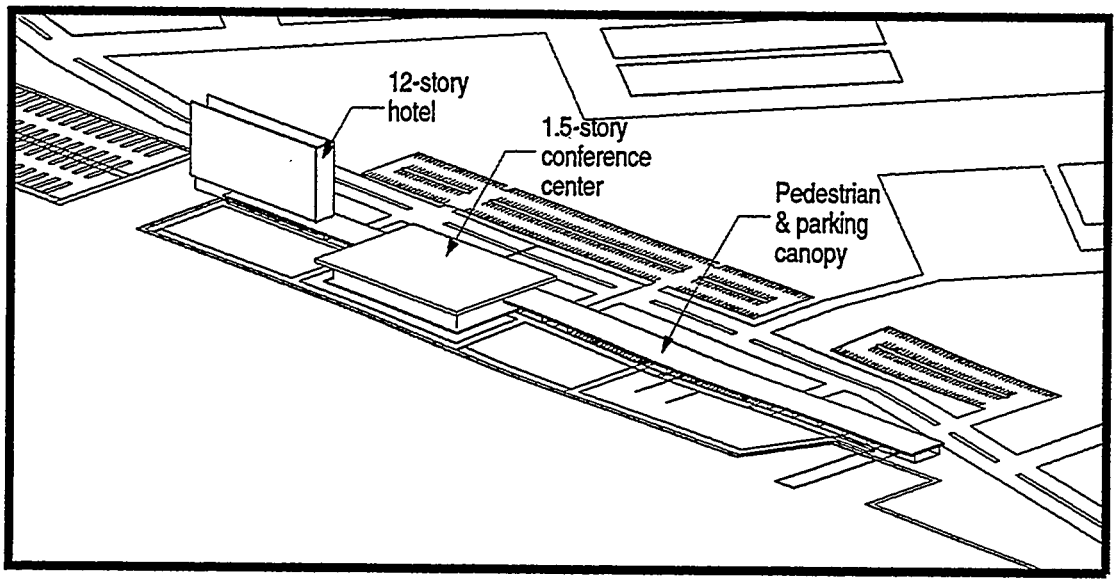



*Fig 2. Case study building and surrounding site.*

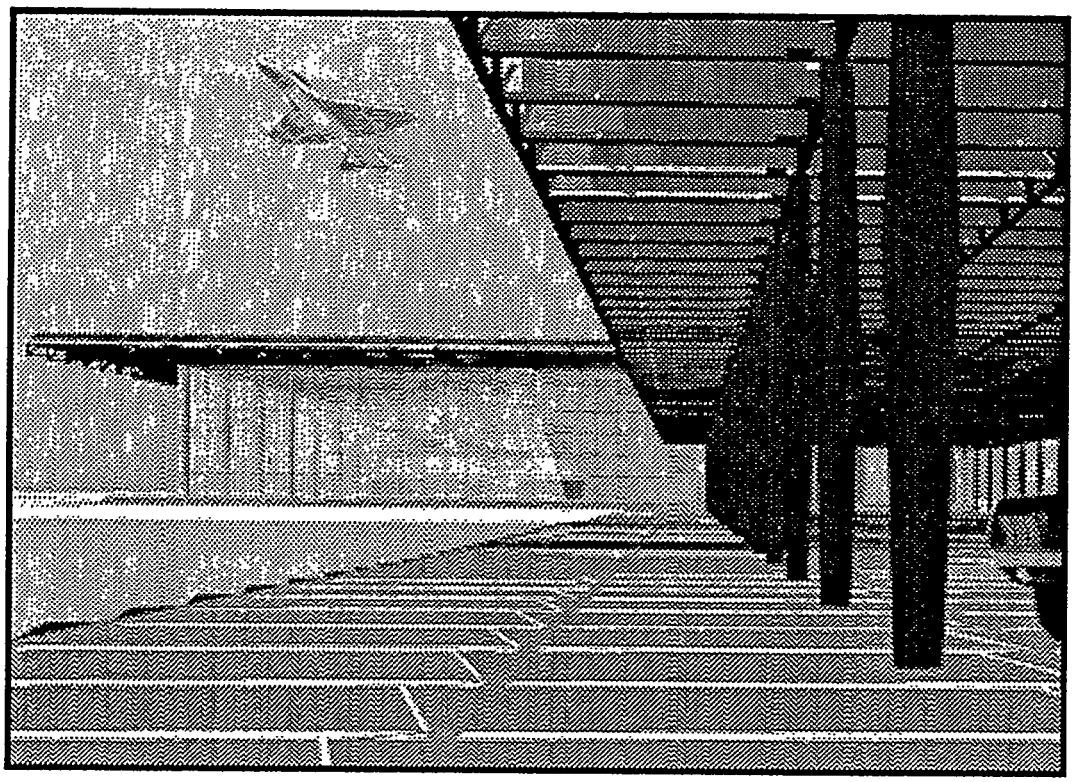


*Fig 3. Conference center as seen from below parking canopy.*

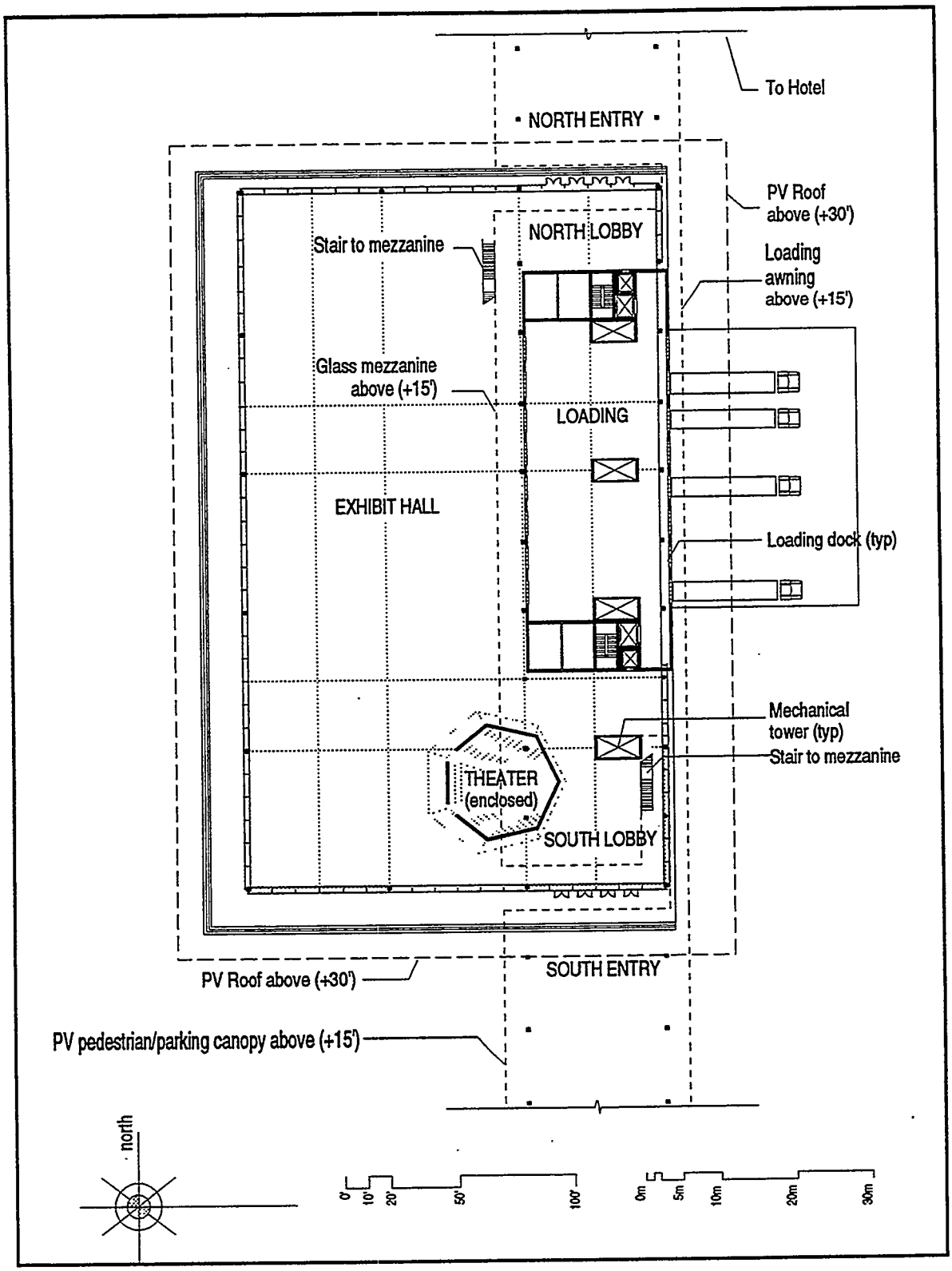



*Fig 4. Conference center ground floor plan.*

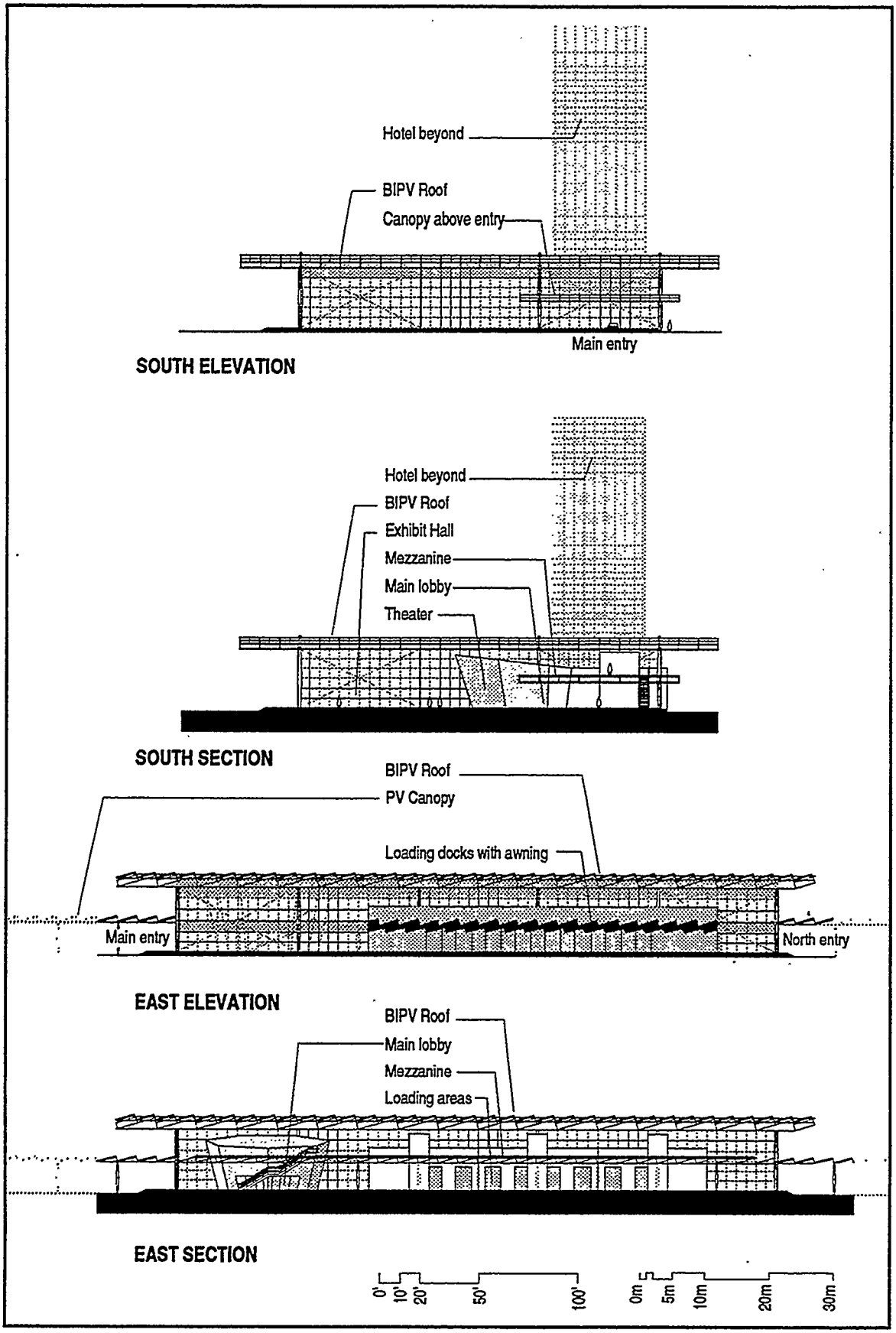



*Fig 5. Conference center elevations and sections.*

## BIPV SYSTEM TYPE

The external surfaces of a building have many functions: they keep out the weather, provide security and keep heat out (or in). A BIPV system adds another role to this program: generating power. A building surface can usually be classified as a roof or a wall, with significant differences in function, construction, and thermal and solar loadings. For the sake of clarity, we chose to design and analyze exclusively a roof-type BIPV system.

The choice of the conference center program influenced this decision in favor of a roof system. BIPV wall systems generally have a higher potential than roofs to displace costly building materials, but they suffer PV output losses due to relatively poor orientation. There is also relatively little wall area in most conference and convention centers: they are usually one story structures featuring a large exhibition and meeting space, creating a high roof to floor area ratio. In this case we felt that a roof system would have good PV performance, good potential for collateral energy benefits, and important significance as an architectural element. A roof system also has the advantage of being easy to analyze on a per square meter basis, making the results applicable to a wide range of building sizes.

A conference center is frequently built in conjunction with other facilities, and our site diagram *(Fig 2)* shows an adjacent hotel. The hotel is articulated as a tall thin slab, with maximum east/west exposure, ideal for BIPV curtain wall applications. Although we did not analyze the hotel in detail for this study, it plays a role in the economic analyses of the conference center. Since the hotel would not be energy self-sufficient from its own PV skin, it serves as a built-in customer for any surplus power produced by the conference center. As a rule, it generally does not pay to produce a surplus of PV power, since present policy in the US provides a low return on power sold back to the utilities. Our payback analyses assume the full retail peak cost of electricity is avoided by the PV system at all times.

Once the building program and site were selected, the project was designed to a level of detail sufficient for the schematic thermal and cost analyses which follow.

# BIPV SYSTEM OPTIONS

We identified five BIPV roof systems and analyzed each to determine its overall impact on the building's energy balance. A conventional flat opaque roof design served as the basis for comparison. This analysis was performed in six different climates. Construction cost estimates of each system were prepared, and the simple payback was calculated by dividing the construction cost premium by energy savings multiplied by local electrical rate.

The principal function of a roof is to keep out the precipitation and, secondarily, to moderate radiation (heat and light) between the interior and exterior environment. By selectively allowing light in and heat in or out, the roof can reduce building loads by supplementing or replacing lighting and heating/cooling systems. We attempted to find roof configurations that served as many functions as possible at a minimum construction cost premium. Since PVs should capture as much direct sunlight as possible, they can easily be combined with clerestory glazing which captures only indirect light. PVs on glass substrates (the majority of large-area PV modules suitable for building integration are on glass substrates) can also be made semi-transparent, and can be designed to pass some direct sunlight into a space while producing electricity. The heat that PVs create heat as they convert sunlight to electricity can be used or discarded as required.

The five BIPV roof configurations included two using direct-transmission semi-transparent PV roofs, two in a roof monitor (sawtooth) configuration with indirect light gain, and one flat opaque PV roof-mounted array. The latter system was based on the standard flat roof (the reference design for energy and cost calculations), with a gravity-mounted (ballasted) PV array above the roof membrane. This system is roof-mounted as opposed to roof-integrated, in that the PVs serve no function as a construction material: they do not form a weathering surface or serve other architectural functions.

In all the BIPV systems the PVs had the same orientation: 15° tilt, azimuth southwest (see *Utility Rate Analysis* for a discussion of the effects of orientation on PV output).

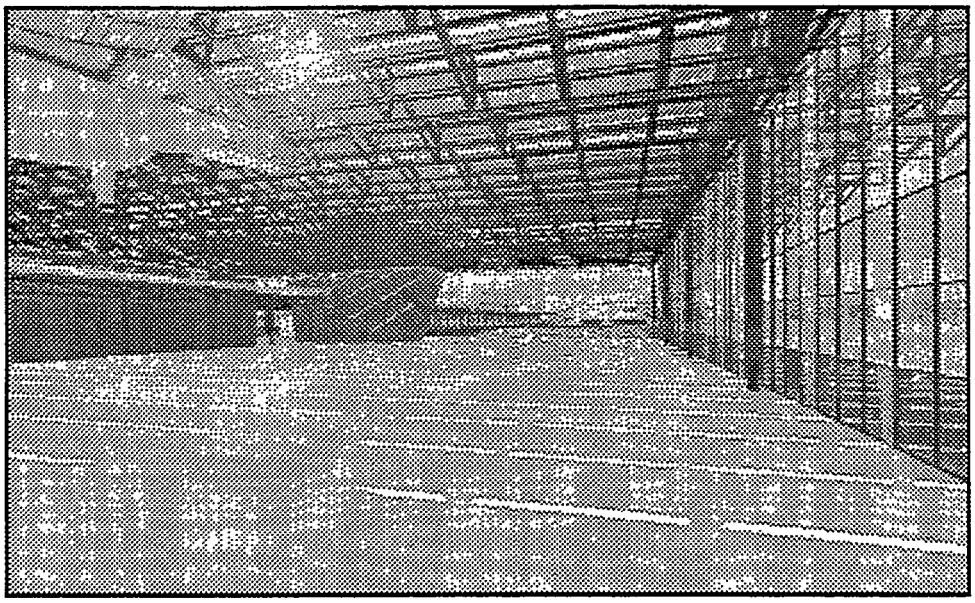


*Fig 6. Conference center exhibition hall.*

## OPTION 1: SEMI-TRANSPARENT PV ROOF

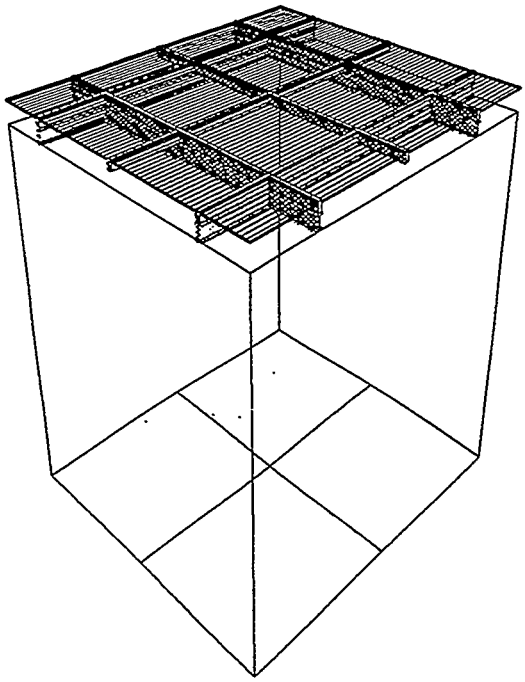


*Fig 7. Option 1 partial roof illustration. Note: all PV output analyzed at 15° tilt.*

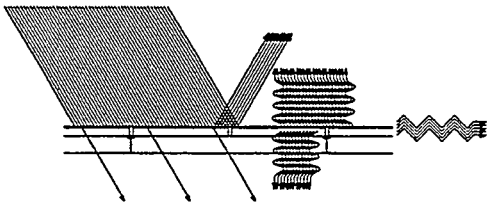


*Fig 8. Option 1 energy balance diagram (see Fig 21 for labels and quantities).*

**SUMMARY:**

- **Poor thermal performance results in building energy consumption more than twice that of better insulated alternatives.**
- **Wide extremes of building loads requires oversized HVAC systems, increasing capital cost.**

This system is similar to large-area skylights, with semi-transparent modules in aluminum frames. Existing thin film technologies can produce glass-encapsulated modules that are ≈5% transparent. With additional scribing or patterning of the modules the transparency can be increased to 15% or 20% or beyond, although the module efficiency decreases in proportion to the transparent area. Other existing technologies where single crystal or polycrystalline cells are laminated between glass sheets also offer flexible degrees of transparency. A 5% transparent roof over a large area is sufficient for most daylighting purposes: bright sunlight is approximately 100,000 lux, which will transmit 5,000 lux to the interior, much more than the standard artificial lighting range of 500-1,000 lux. On a cloudy day 10,000 lux exterior will be transmitted through as 500 lux, at the low end of standard illumination levels.

Standard laminated glass-to-glass modules have poor thermal performance. A 5% transparent module has a low shading coefficient (a measure of direct radiation transmitted) but a high U-value (a measure of thermal conductivity). Because of the high U-value, building energy costs are high. There are wide extremes of heating and cooling requirements, which affects operating costs and requires an oversized HVAC system to handle the loads. The direct daylighting scheme may have a tendency to overlight the space on sunny days and underlight it on cloudy days, when supplemental artificial lighting may be required.

## OPTION 1A: SEMI-TRANSPARENT SINGLE GLAZED PV ATRIUM

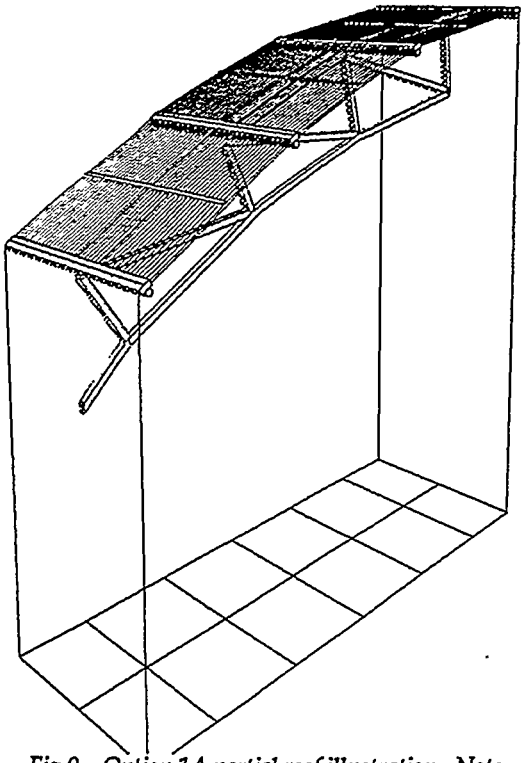


*Fig 9. Option 1A partial roof illustration.. Note: all PV output analyzed at 15° tilt.*

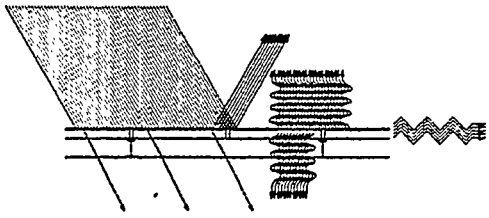


*Fig 10. Option 1A energy balance diagram (see Fig 21 for labels and quantities).*

This option is similar to Option 1 in PV output and daylight and thermal performance. For cost estimation, this system is compared to the base case of an atrium roof, where skylight framing, laminated glass, and exposed architectural support structure are present.

When this system is considered for applications where an atrium exists or is planned, the daylight and thermal properties are not an issue- atria are often semiconditioned spaces - and a material credit is given for the cost of displacing tinted laminated atrium glass.

**SUMMARY:**

- **Lowest installed cost due to simple installation and good material credit.**
- **Poor thermal performance may not be a factor in some climates or in cases where atrium space is not fully conditioned**

## OPTION 2: SEMI-TRANSPARENT DOUBLE GLAZED PV ROOF

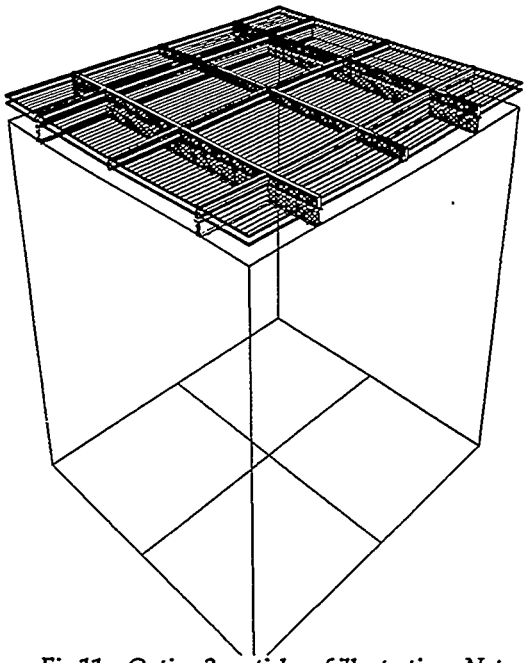


*Fig 11. Option 2 partial roof illustration. Note all PV output analyzed at 15° tilt.*

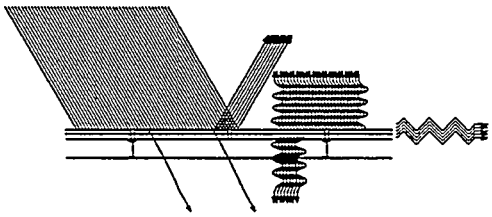


*Fig 12. Option 2 energy balance diagram (see Fig 21 for labels and quantities).*

This system is similar to Option 1, with the substitution of high-performance double glazed PV lites for the single glazed versions. The laminated PV module is bonded to an inner lite with a spacer 13mm (0.5") thick. The cavity can be air or argon filled, and a low-E coating can be applied to the second lite to further improve the energy performance.

This option has much better energy performance than Option 1, and better overall energy performance than for an opaque insulated roof due to the daylighting contributions. (see Energy Performance Evaluations, p. 19)

Direct light transmittance is somewhat lower for this scheme than for Option 1, since the additional glazing layer absorbs more light. However, the potential for over-lighting and under-lighting, and the reliance on artificial lighting for cloudy days in winter, are still present in this scheme.

**SUMMARY:**

- **Good overall energy performance despite low thermal insulation value, due to daylighting contribution.**
- **Tendency to over-and under-light space below; supplemental lighting may be required on cloudy days.**
- **Insulated Glazing PV unit not yet available as product; potentially expensive.**

## OPTION 2A: SEMI-TRANSPARENT DOUBLE GLAZED PV ATRIUM

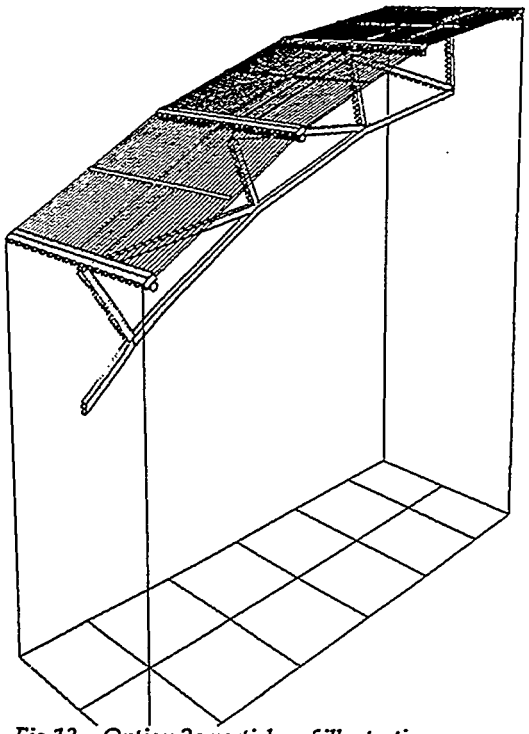


*Fig 13. Option 2a partial roof illustration.*

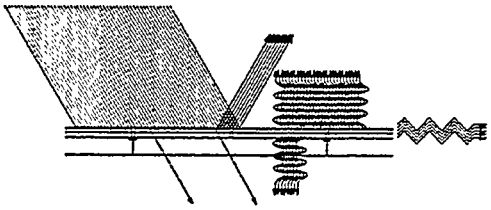


*Fig 14. Option 2a energy balance diagram (see Fig 21 for labels and quantities).*

This option is similar to Option 2, for applications where an atrium exists or is planned. For cost estimation, this system is compared to the base case of an atrium roof, where skylight framing, laminated double-glazing, and exposed architectural support structure are present.

It is important to note that an insulated PV-glazed atrium will not provide as much daylight as conventional glazing, which is roughly comparable to unfiltered sunlight. The light levels in this kind of space would be more like a shaded outdoor space, which would be more than adequate for most purposes and indeed would be more comfortable than a conventional atrium for extended occupation. The amount of light admitted to a space can be controlled by mixing PV with conventional glazing or by specifying PV with a custom transparency. In the cost analysis (see following section) a relatively high material credit is given for the cost of displacing insulated atrium safety glass.

**SUMMARY:**

- **Similar to Option 2, with a higher material credit.**
- **Replaces a traditional atrium roof.**
- **Not as much daylight as traditional atriums - would be a more comfortable environment to occupy for long periods.**
- **Much more energy efficient than a traditional atrium roof.**

## OPTION 3: FLAT BALLASTED ROOF ARRAY

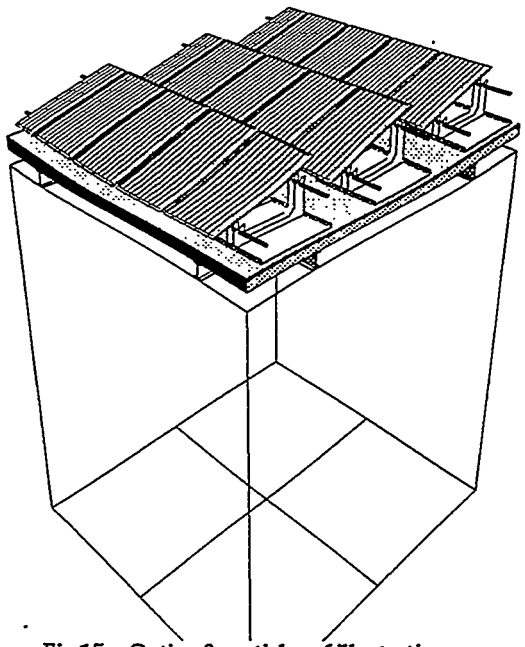


*Fig 15. Option 3 partial roof illustration.*

This is a conventional flat commercial roof: steel structure, steel deck, rigid insulation (Metric U 0.3; english R28.4), membrane roofing, with PVs installed on ballasted trays above the membrane.

This system is simple to install and does not penetrate the roof membrane, but several limitations exist:

•Seismic codes may not permit a system that is not physically restrained from lateral movement.

•The weight of the system (in excess of 10-15psf over the PV area) exceeds the load bearing capacity of many commercial roofs, which are typically designed to minimum structural criteria.

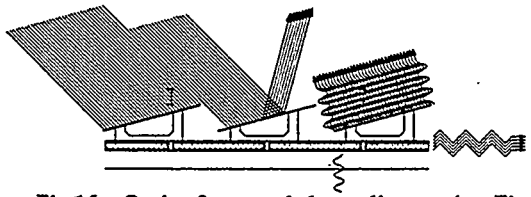


*Fig 16. Option 3 energy balance diagram (see Fig 21 for labels and quantities).*

The costs of the structure and installation should be low, but the system does not gain any material credits by displacing other construction materials, and has no daylighting and limited thermal energy benefits: the value of the shading to the reference roof design is approximately U 0.2, which yields energy reductions from 0.45 - 1.2kWh/m2/yr ($0.08 - 0.11/m2/yr).

**SUMMARY:**

- **Simple installation, avoids roof penetrations.**
- **Potentially low cost.**
- **No material credits or daylight/thermal benefits.**
- **May have limited applicability due to code problems.**

Due to the ease of installation and minimal disruption to the building envelope, this system is well suited for retrofit applications, although rooftop equipment, parapets and other obstructions may significantly limit available rooftop areas.

## OPTION 4: PV ROOF MONITORS

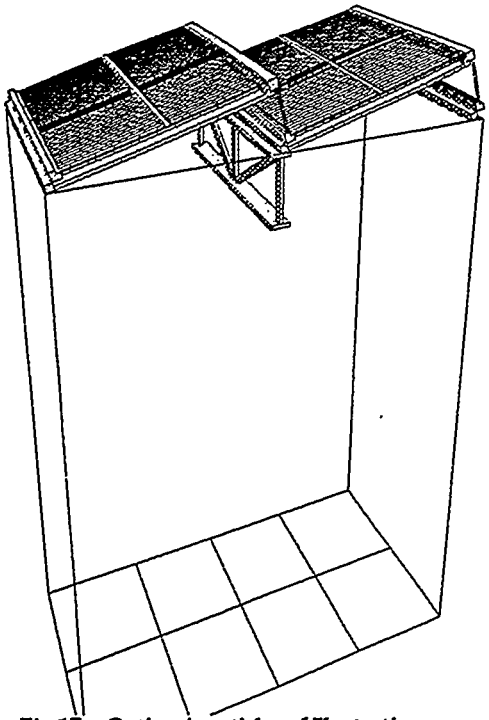


*Fig 17. Option 4 partial roof illustration.*

This is a variation of the traditional industrial light monitor sawtooth roof system. The benefits of indirect natural light have been apparent to artists and industrialists alike: diffuse, variable, and free, it has psychological benefits that go beyond the light provided.

The north-facing clerestory glazing is complemented by PVs on the opaque south facing side of the roof monitor. The increased slope given the PVs when compared to other large area flat roofs has benefits because of higher output per unit area of PV, and also has better drainage and less dirt buildup. The sawtooth can also create problems with snow accumulation and ponding of water: these issues must be carefully studied in each case.

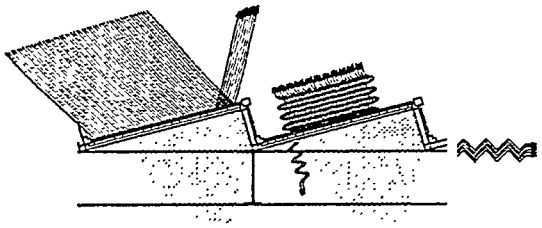


*Fig 18. Option 4 energy balance diagram (see Fig 21 for labels and quantities).*

The PV can be insulated with inexpensive materials, giving the roof system as a whole a higher insulating value than any transparent system could have. Opaque or glass substrate PVs can be used. For glass modules, a shingled mounting method that relies partly on overlaps and flashing techniques might be used instead of conventional pressure plate systems; or other substrates such as plastic or sheet metal can be used instead. Interlocking plastic shingle sub-substrate systems have been developed by a number of manufacturers, although these add an extra element to the product. Metal substrate PVs can be used directly as a building material; like glass, sheet metal is already a building material. Formed into pans, modules of this type can be used as sheet metal for standing seam, flat seam or batten seam roofing.

**SUMMARY:**

- **Medium to high construction cost.**
- **Very good energy performance.**
- **Tilt on PVs and clerestories provides reliable drainage and helps keep modules clean.**

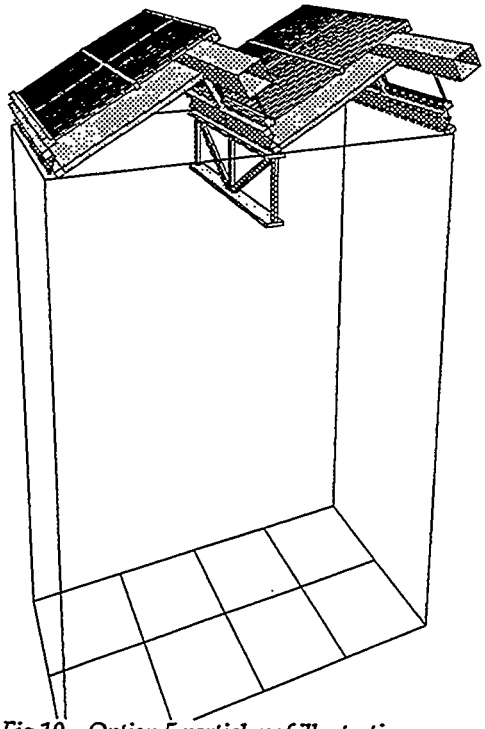


*Fig 19. Option 5 partial roof illustration.*

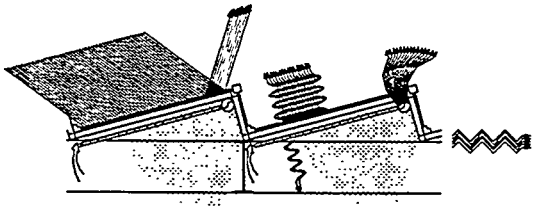


*Fig 20. Option 5 energy balance diagram (see Fig 21 for labels and quantities).*

SUMMARY:

- Best energy performance.
- System is most effective if all the heat captured can be used without requiring long-term thermal storage.
- High construction costs.
- Active systems require maintenance and repair, increasing life cycle cost.

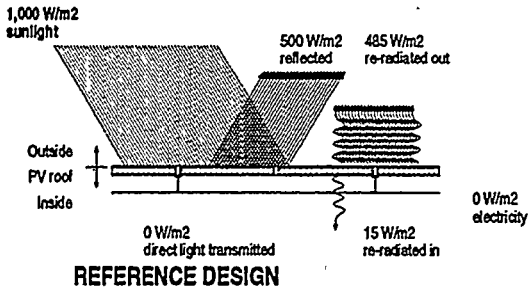
## OPTION 5: PV ROOF MONITORS WITH ACTIVE HEAT RECOVERY

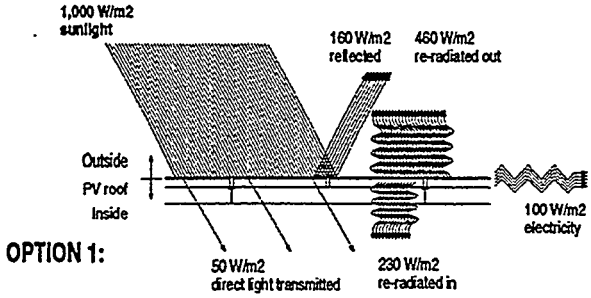
This variation of Option 4 has the most ambitious energy agenda of all the schemes: recovery of as much of the PV heat buildup as possible via a dedicated ventilation system. This entails constructing a second insulated layer below the single-glazed PVs. The airspace within is vented at the top into a duct which feeds into the building HVAC system, or can be vented to the outside when there is no need for the heat. The heat removal also cools the PVs, which decreases thermal degradation of PV output, and reduces thermal stresses on the modules.

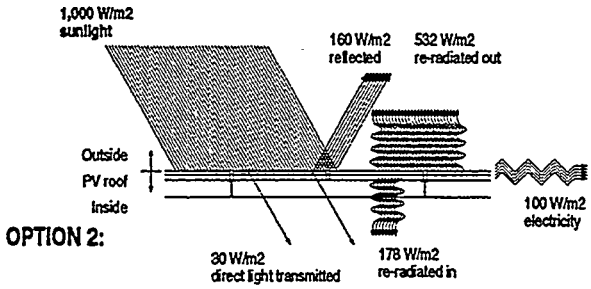
The biggest drawback with this system approach is the limited need for heating in most commercial buildings in the US. In Oakland, the system yields 20x the total heating requirement of the building. Even in Chicago, the coldest climate we evaluated, the system produces 3x the total building heat requirements. If a use were available for all the heat collected, (for an industrial process use or pool water heating, for example), thermal storage might be required to make the heat available at times other than peak sun.

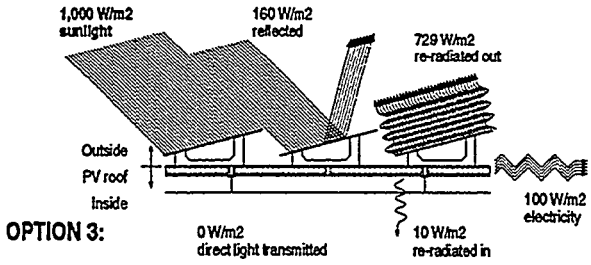
A solution to this problem would be to apply this system to only as much of the building's roof surface as necessary to generate a usable amount of heat. It could be easily combined with an Option 4 roof for this purpose.

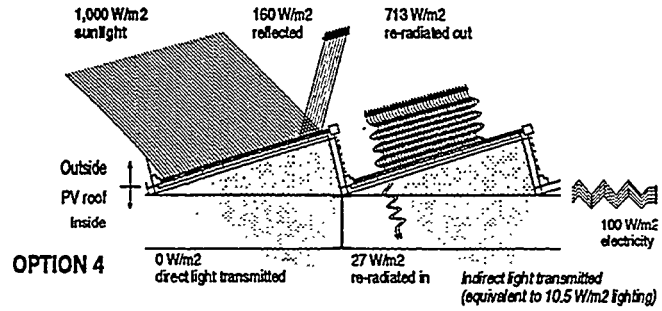
*Fig 21. Energy Balance Diagram Summary.*

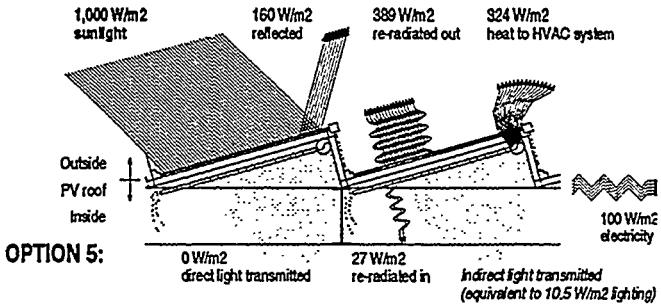



Note: these diagrams depict the energy balance of the roof systems under direct radiation (daylight) only. The energy balance analyses in the next section take into account the full range of daily and annual weather conditions.

# ENERGY PERFORMANCE EVALUATIONS

For each of the BIPV roof options, building load data was calculated from a building energy balance model developed by Mahadev Raman at Ove Arup & Partners New York. We evaluated each roof option for its effect on the total building energy use in six different locations in the continental United States. These locations were chosen to represent a range of climate types as follows:

| | |
|---|---|
| Oakland | Temperate/coastal/warm |
| New York (Long Island) | Temperate/coastal/cold |
| Phoenix | Temperate/arid |
| Miami | Subtropical |
| Chicago/Cincinnati | Temperate/continental |

The effect of each roof system on typical building HVAC and lighting loads was calculated, taking into account:

- Gains from direct and indirect radiation
- Thermal transmittance in and out by conduction
- Offset electrical and thermal loads due to reduced artificial lighting.

The overall energy performance was compared to the reference roof design: flat, insulated dark colored with a U-value (metric) of 0.3 (R28.4 in english units).

The energy consumption of the test building for each roof option in each climate is shown in charts 1-7 on the following pages. The analyses show that Option 1 has poor energy performance in all climates, especially in climates with extremes of hot and cold, due to the poor insulating value of single glazing.

Option 2 (insulated glass roof) has better thermal energy performance than the conventional reference design in every climate except Phoenix, indicating that the daylighting and (to a lesser extent) the useful thermal gains through the glass more than offset it's lesser insulating value. Option 3 has very slightly better thermal performance due to the reduction in heat gain from the shading of the roof. Options 4 and 5 have significantly better energy performance than the reference design in every case.

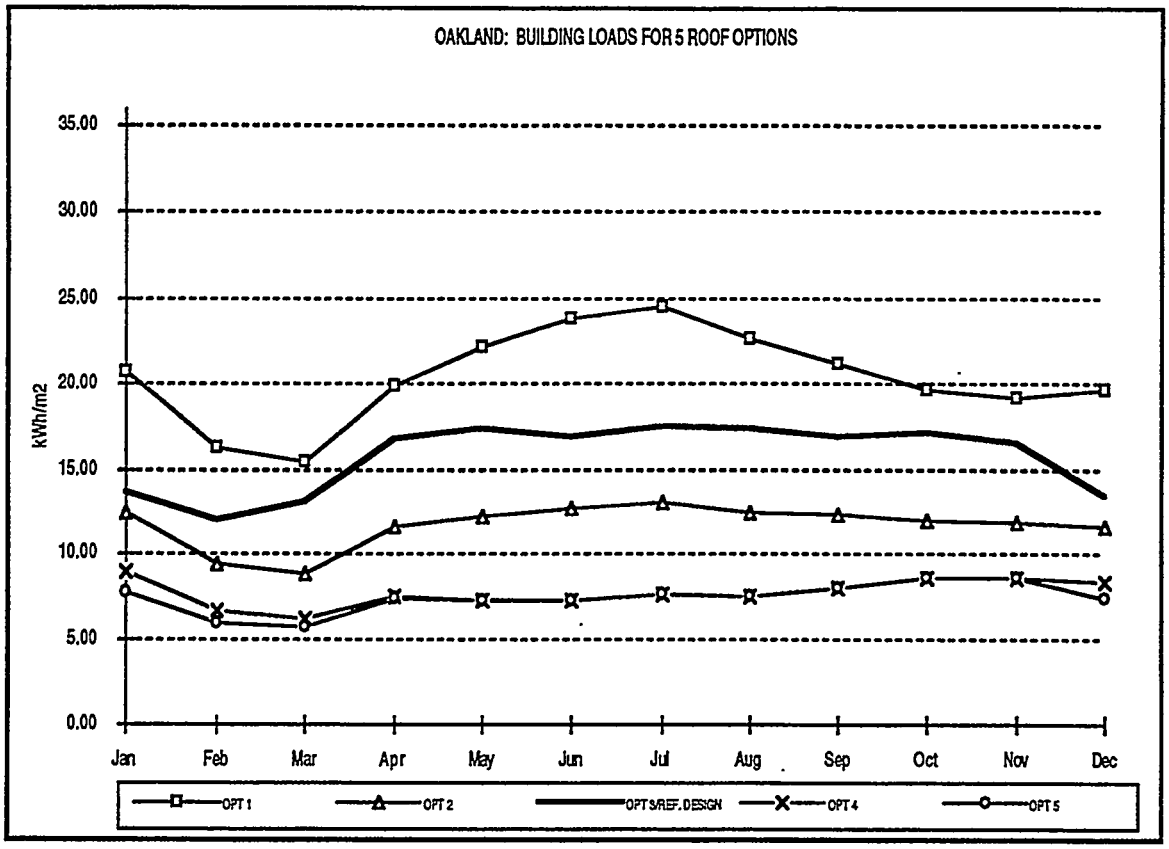



*Chart 1. Energy performance for Oakland, California.*

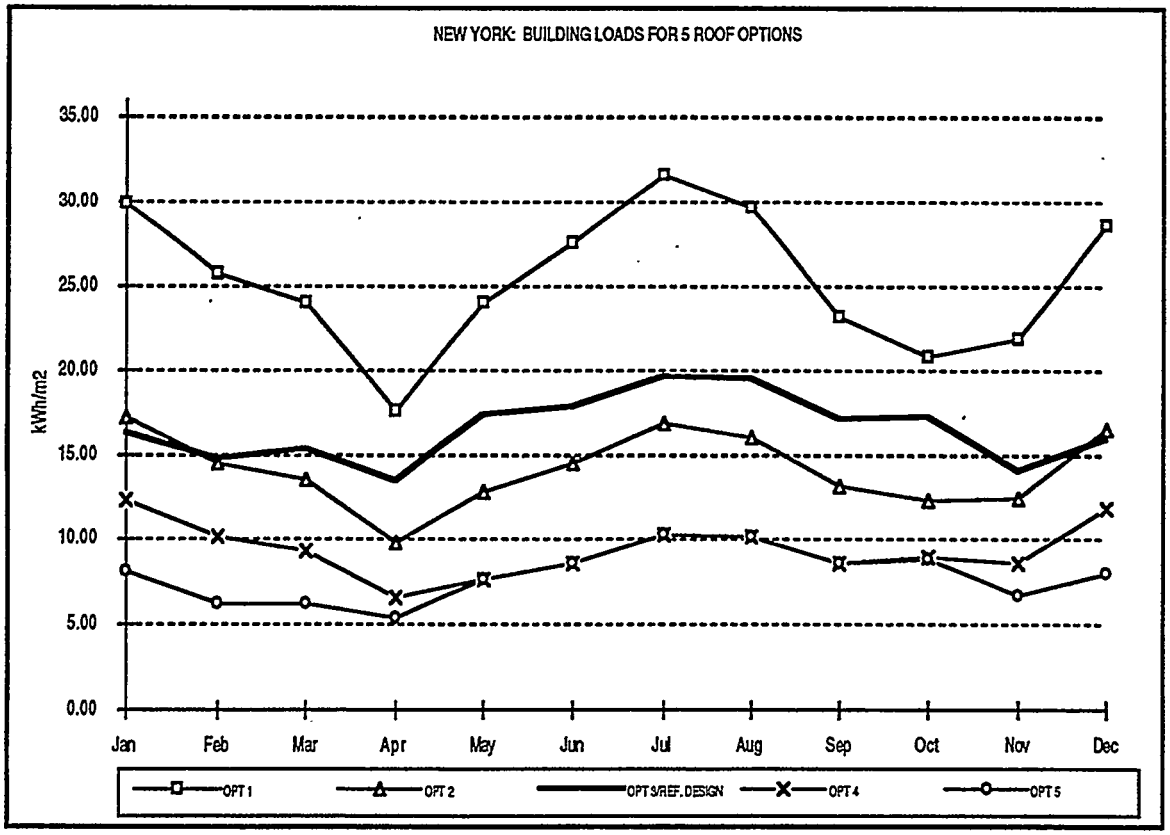



*Chart 2. Energy performance for New York City, New York.*

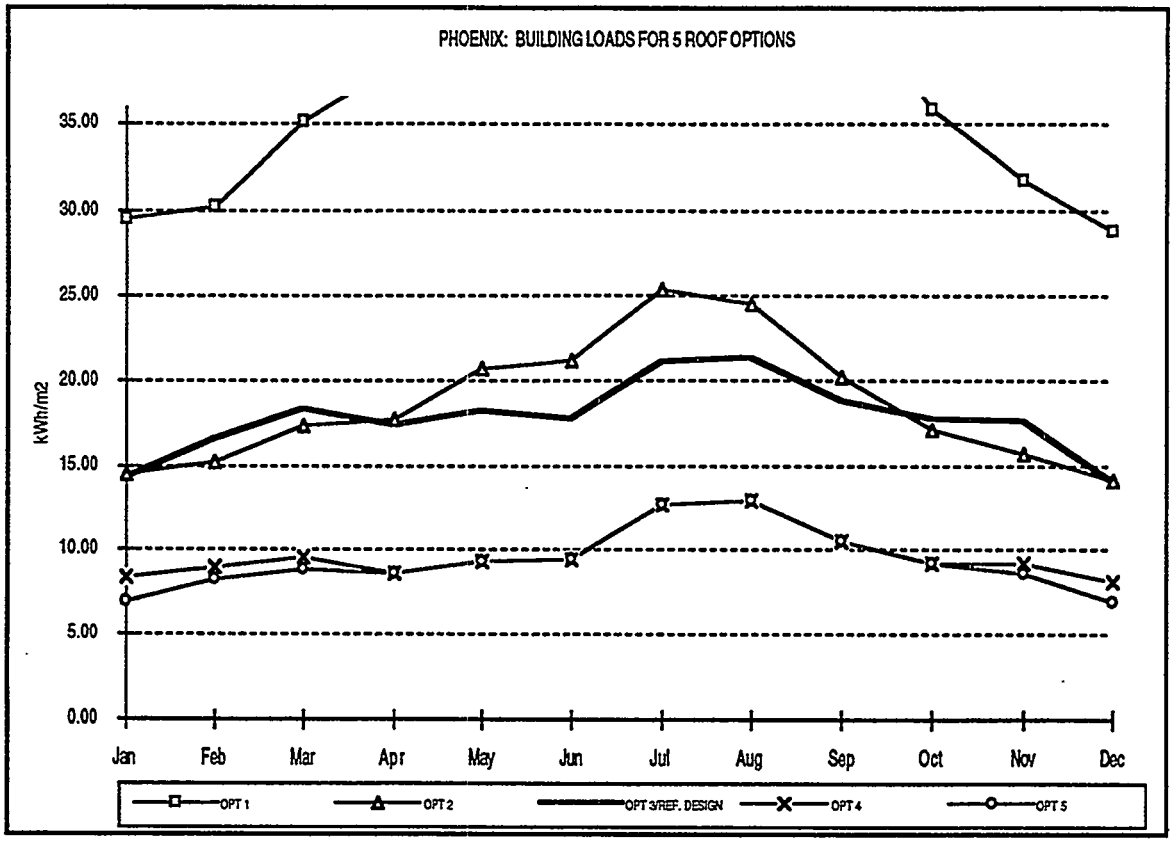



*Chart 3. Energy performance for Phoenix, Arizona (extreme data for Option 1 not depicted on graph).*

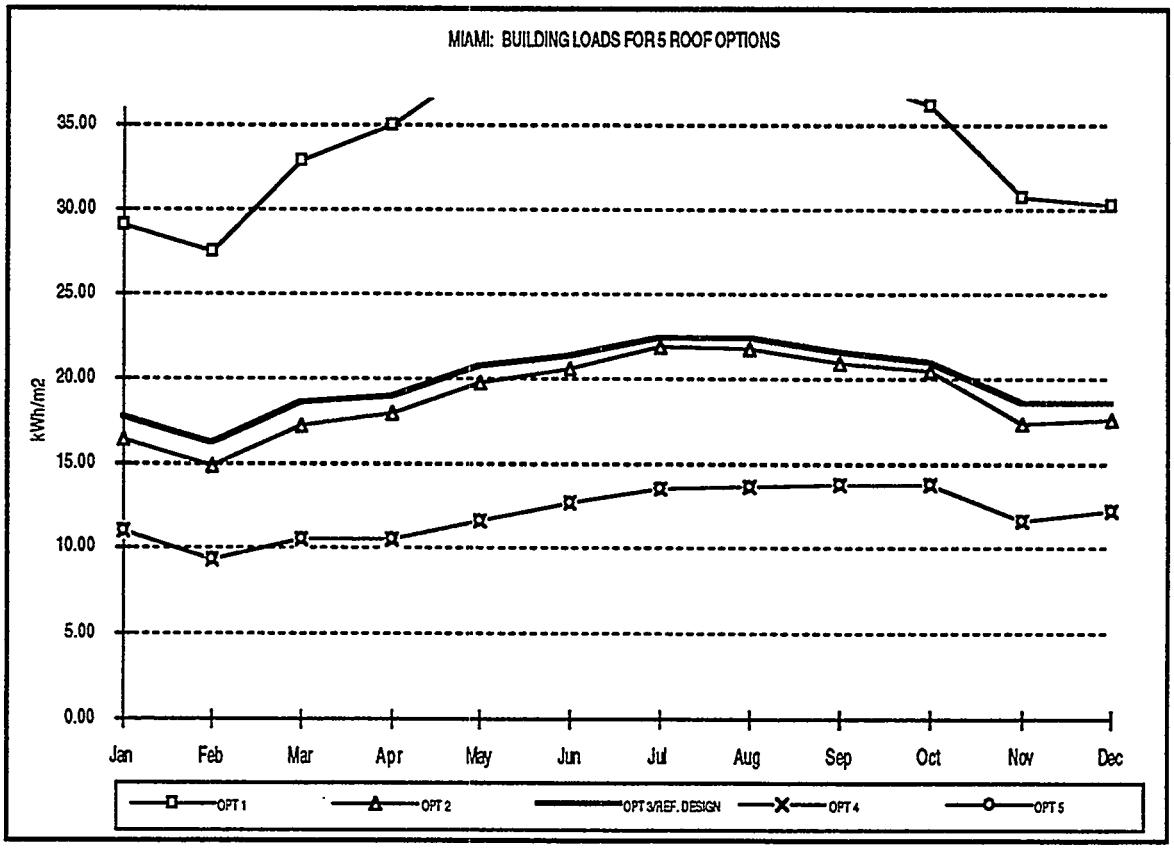



*Chart 4. Energy performance for Miami, Florida (extreme data for Option 1 not depicted on graph).*

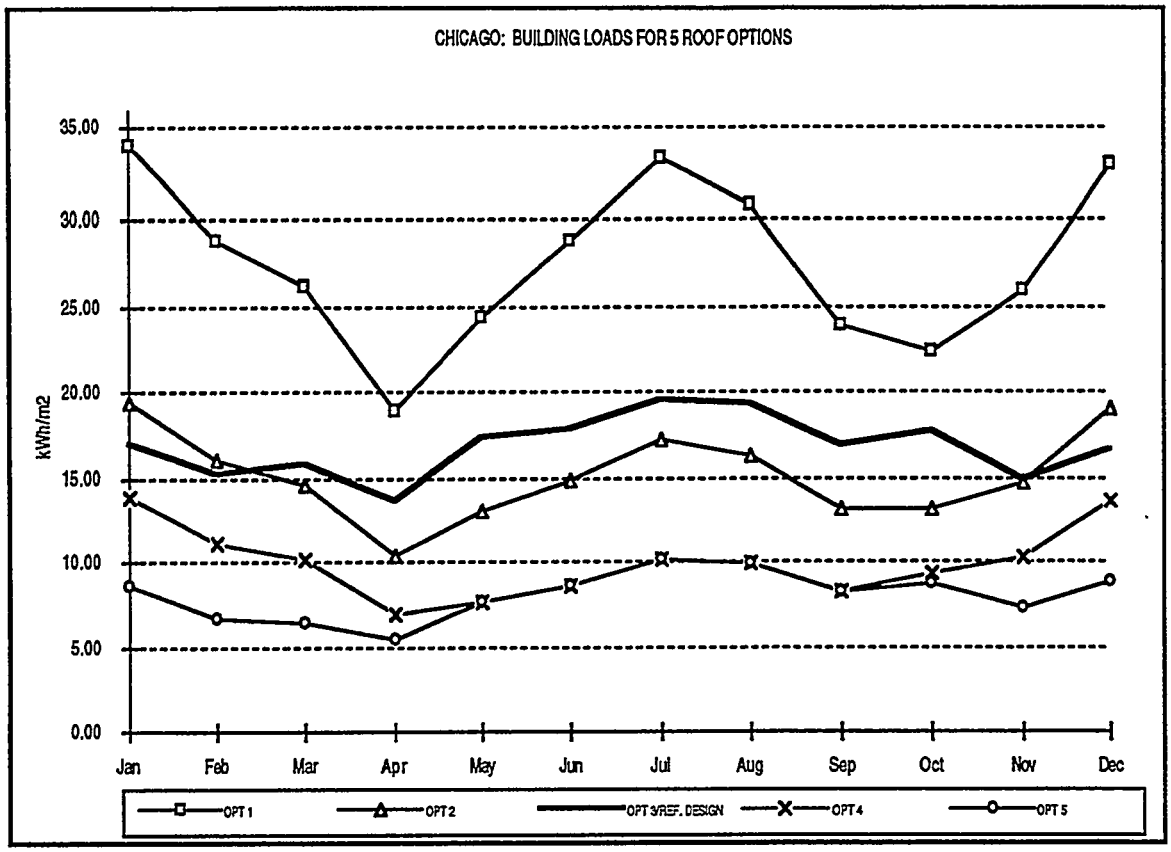



*Chart 5. Energy performance for Chicago, Illinois.*

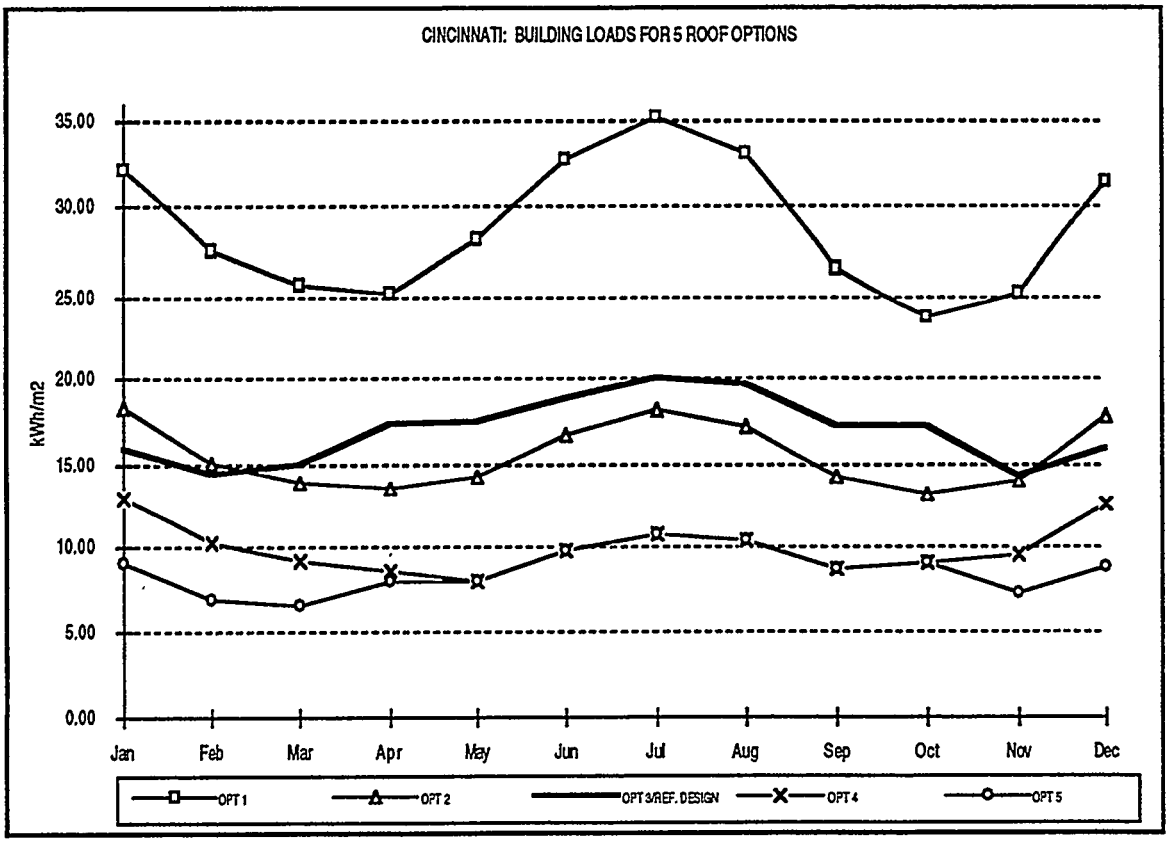



*Chart 6. Energy performance for Cincinnati, Ohio.*

# PV PERFORMANCE CALCULATIONS

In addition to the building load calculations, PV performance for each of the options was modeled using PV-F Chart software. PV output was calculated for each of the five BIPV options, in each of the six cities, for each of three PV technologies. The parameters are summarized as follows:

**PV Technology**

| Type | Efficiency | Temperature coefficient |
|---|---|---|
| PV1 | 13% | .0043(1/°C) |
| PV2 | 5.2% | .0027(1/°C) |
| PV3 | 10% | .0035(1/°C) |

**Option-specific temperature parameters**

Different construction systems will cause the PVs to operate at different temperatures. All PVs lose efficiency at higher temperatures. The temperature coefficient above is the rate at which the module efficiency linearly decreases with temperature. Since the construction of each option affects the operating temperature of the modules, this factor further affects the total performance of each system.

| Option | Cell operating temperature (°C above ambient) |
|---|---|
| 1 | +23.0° |
| 2 | +26.6° |
| 3 | +18.3° |
| 4 | +35.7° |
| 5 | +19.5° |

Other parameters were constant for all options. All options were evaluated at a 15° altitude tilt. Various azimuth angles were evaluated (see Utility rate analysis.)

PV output was evaluated on an hourly basis for use in the utility rate calculations (see appendix D).

# COST ANALYSIS

This section estimates the cost premium of each roof option over the cost of a conventional flat non-PV roof. The conventional roof includes steel structure, metal deck, rigid insulation, and membrane roofing (see Fig. 22). Detailed breakdowns of the costs of each option are presented in subsequent tables. Basic assumptions concerning construction and PV technology are as follows:

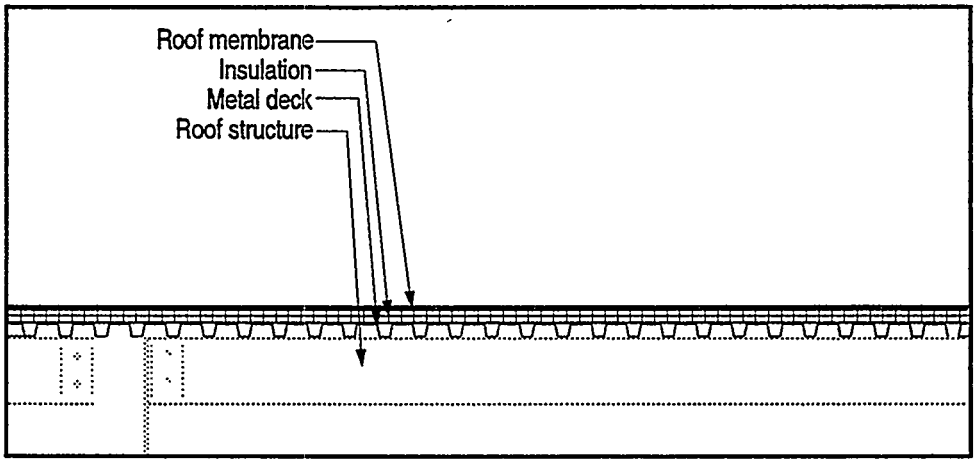



*Fig 22. Section through typical bay, Reference Design*

- Construction costs include any additional structure, insulation, roofing materials, glazing and sprinklers, beyond what is included in the reference roof.
- Costs of construction materials used in the standard roof that are replaced by a BIPV material are deducted from the cost of the BIPV system.
- PV system costs include modules, fabrication of insulating units (where applicable), aluminum framing to support the modules in a watertight seal (where applicable), wiring, and power conditioning.

- Three different PV technologies are evaluated, ranging from high-efficiency, high-cost/W to low-efficiency, low cost/W:

| | | |
|---|---|---|
| **PV1:** Crystalline Silicon | 140W/m2 | $4.40/W |
| *Source: Arthur D Little report 6/94.* | | |
| **PV2:** Amorphous Silicon | 52W/m2 | $3.00/W |
| *Source: Advanced Photovoltaics Systems, Inc., 1994.* | | |
| **PV3:** High-efficiency thin-film (CIS, CdTe) | 108W/m2 | $2.00/W |
| *Source: Energy Photovoltaics, Inc. Projected price for 1996-97.* | | |

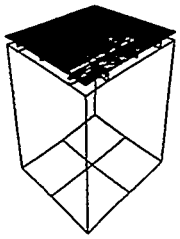
PV1 and PV2 represent currently available technologies. PV3 cost/performance figures may be available in the near future using any number of technologies under development. PV3 projections are included because any significant construction project currently in planning stages may not be constructed for several years, at which point the new technologies, or improved versions of existing technologies, may be available.

Table 1 summarizes the construction costs of each option with each of the three PV technologies. (see Payback Analysis for a discussion of the implications of costs) For options 4 and 5, the costs and benefits are evaluated in three ways:

- As a daylight/thermal system only, including all construction costs associated with daylighting and/or thermal energy systems, but no PV-related costs. The payback analysis includes benefits (or costs) associated with daylighting and thermal performance only.
- As a PV system only. To isolate the costs and payback of the PV system, construction costs associated with daylighting and thermal systems are not included, as are any energy savings (or costs) produced by these systems. Only PV income is used.
- As a complete system, including all construction costs associated with daylighting and/or thermal energy systems. In the payback analysis, all benefits (or costs) associated with daylighting and thermal performance are included with PV income.

| Costs: Full system | | PV1 | | PV2 | | PV3 |
|---|---|---|---|---|---|---|
| | $/m2 | $/W | $/m2 | $/W | $/m2 | $/W |
| OPTION 1 | $1,115.34 | $7.97 | $463.71 | $8.97 | $610.28 | $5.67 |
| OPTION 1a | $863.30 | $6.17 | $211.68 | $4.10 | $358.25 | $3.33 |
| OPTION 2 | $1,338.16 | $9.56 | $686.53 | $13.29 | $833.10 | $7.74 |
| OPTION 2a | $897.97 | $6.42 | $246.34 | $4.77 | $392.91 | $3.65 |
| OPTION 3 | $1,102.22 | $7.88 | $450.59 | $8.72 | $597.16 | $5.55 |
| OPTION 4 | $1,149.86 | $8.22 | $498.24 | $9.64 | $644.80 | $5.99 |
| OPTION 5, 5a | $1,424.67 | $10.18 | $773.05 | $14.96 | $919.61 | $8.54 |
| Daylight+Thermal Only | | | | | | |
| OPTION 4 | $136.77 | NA | $136.77 | NA | $136.77 | NA |
| OPTION 5, 5a | $235.80 | NA | $235.80 | NA | $235.80 | NA |
| PV system only | | | | | | |
| OPTION 4 | $1,013.09 | $7.24 | $361.46 | $7.00 | $508.03 | $4.72 |
| OPTION 5, 5a | $1,188.87 | $8.50 | $537.24 | $10.40 | $683.81 | $6.35 |

*Table 1. A summary of the system costs (construction plus PV integration) for each of the five roof options, for each of the three different PV technologies.*



## OPTION 1 CONSTRUCTION COSTS

| | | PV1 | | PV2 | | PV3 | |
|---|---|---|---|---|---|---|---|
| | | $/m2 | $/W | $/m2 | $/W | $/m2 | $/W |
| 1 | Additional roof structure | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 2 | | | | | | | |
| 3 | PV system costs: | | | | | | |
| 4 | PV modules | $615.72 | $4.40 | $155.01 | $3.00 | $215.29 | $2.00 |
| 5 | | | | | | | |
| 6 | PV framing | $215.29 | $1.54 | $215.29 | $4.17 | $215.29 | $2.00 |
| 7 | PV wiring | $34.88 | $0.25 | $34.88 | $0.68 | $34.88 | $0.32 |
| 8 | Other indirect | $55.97 | $0.40 | $20.67 | $0.40 | $43.06 | $0.40 |
| 9 | Power Conditioning | $111.95 | $0.80 | $41.33 | $0.80 | $86.11 | $0.80 |
| 10 | | $1,033.80 | $7.39 | $467.17 | $9.04 | $594.62 | $5.52 |
| 11 | Material credits: | | | | | | |
| 12 | Roofing | ($21.53) | ($0.15) | ($21.53) | ($0.42) | ($21.53) | ($0.20) |
| 13 | Insulation | ($20.88) | ($0.15) | ($20.88) | ($0.40) | ($20.88) | ($0.19) |
| 14 | Metal Deck | ($21.53) | ($0.15) | ($21.53) | ($0.42) | ($21.53) | ($0.20) |
| 15 | | ($63.94) | ($0.46) | ($63.94) | ($1.24) | ($63.94) | ($0.59) |
| 16 | | | | | | | |
| 17 | Subtotal | $969.86 | $6.93 | $403.23 | $7.80 | $530.68 | $4.93 |
| 18 | Markup (15%) | $145.48 | $1.04 | $60.48 | $1.17 | $79.60 | $0.74 |
| 19 | **Total system** | **$1,115.34** | **$7.97** | **$463.71** | **$8.97** | **$610.28** | **$5.67** |

*Table 2. Detailed breakdown of Option 1 cost calculations.*

**TABLE NOTES:**

6. **PV framing.** Aluminum extrusion skylight system. *Source: DeaMor, Inc. 1994*

7. **PV wiring.** $37.67/m2 ($3.50/sf) PV area allowance. Could be significantly less: assuming modules are connected in series of six (a-Si modules @ 40V ea for a 240V system) with snap together connectors in the series string, conduit is needed only for wiring between strings and for home runs to the inverter. In the test building, this should require approx. 1m conduit/10m2 PV area, or $10.00/m2 @ $10/m wiring cost allowance.

8. **Other indirect.** Engineering, permits, shipping, insurance, project management. *Source: AD Little 6/94.*

9. **Power conditioning.** Source: various industry reports. This figure should be conservative for a system of over 100kW. APS-Fairfield data suggest a cost of under $0.60/W for a system this size.

12. **Roofing credit.** 55 mil EPDM fully adhered membrane. *Source: Devcon Construction Inc., 1994.*

13. **Insulation.** Phenolic foam board 2 layers x 1.75", (R28.4) *Source: RS Means Construction Cost Data 1993.*

14. **Metal deck.** *Source: Devcon Construction Inc., 1994.*

SECTION

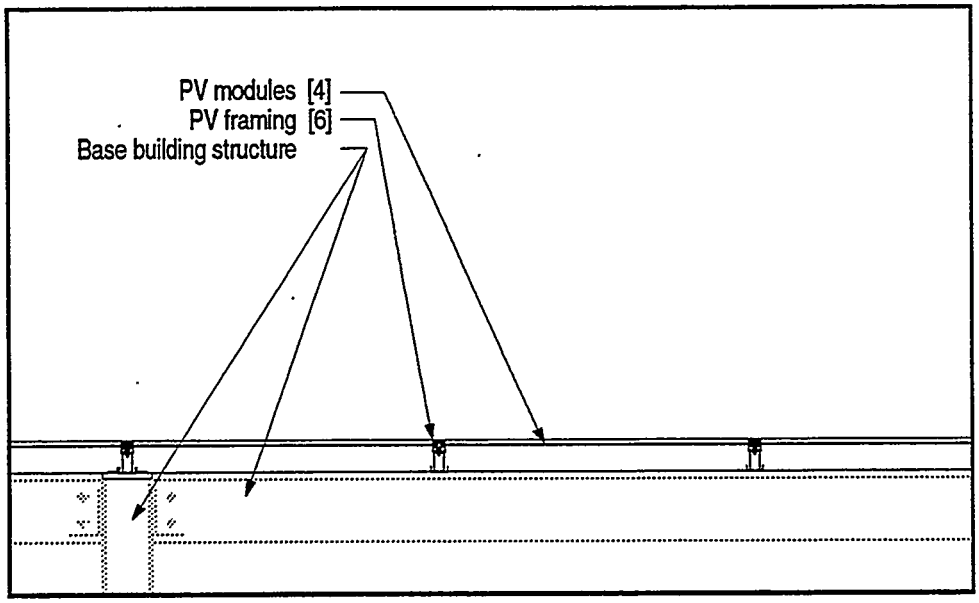
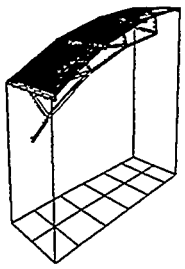



*Fig 23. Section through typical bay, Option 1*



## OPTION 1A CONSTRUCTION COSTS

| | | PV1 | | PV2 | | PV3 | |
|---|---|---|---|---|---|---|---|
| | | $/m2 | $/W | $/m2 | $/W | $/m2 | $/W |
| 1 | Additional roof structure | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 2 | | | | | | | |
| 3 | PV system costs: | | | | | | |
| 4 | PV modules | $615.72 | $4.40 | $155.01 | $3.00 | $215.29 | $2.00 |
| 5 | | | | | | | |
| 6 | PV framing | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 7 | PV wiring | $34.88 | $0.25 | $34.88 | $0.68 | $34.88 | $0.32 |
| 8 | Other indirect | $55.97 | $0.40 | $20.67 | $0.40 | $43.06 | $0.40 |
| 9 | Power Conditioning | $111.95 | $0.80 | $41.33 | $0.80 | $86.11 | $0.80 |
| 10 | | $818.51 | $5.85 | $251.88 | $4.88 | $379.33 | $3.52 |
| 11 | Material credits: | | | | | | |
| 12 | Roofing | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 13 | Insulation | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 14 | Glazing | ($67.81) | ($0.48) | ($67.81) | ($1.31) | ($67.81) | ($0.63) |
| 15 | | ($67.81) | ($0.48) | ($67.81) | ($1.31) | ($67.81) | ($0.63) |
| 16 | | | | | | | |
| 17 | Subtotal | $750.70 | $5.36 | $184.07 | $3.56 | $311.52 | $2.89 |
| 18 | Markup (15%) | $112.60 | $0.80 | $27.61 | $0.53 | $46.73 | $0.43 |
| 19 | **Total system** | **$863.30** | **$6.17** | **$211.68** | **$4.10** | **$358.25** | **$3.33** |

*Table 3. Detailed breakdown of Option 1a cost calculations.*

TABLE NOTES:

**Option 1A and 2A are referenced to an atrium roof design, including skylight framing, glazing and exposed structure.**

7. **PV wiring.** $37.67/m2 ($3.50/sf) PV area allowance. Could be significantly less: assuming modules are connected in series of six (a-Si modules @ 40V ea for a 240V system) with snap together connectors in the series string, conduit is needed only for wiring between strings and for home runs to the inverter. In the test building, this should require approx. 1m conduit/10m2 PV area, or $10.00/m2 @ $10/m wiring cost allowance.

8. **Other indirect.** Engineering, permits, shipping, insurance, project management. *Source: AD Little 6/94.*

9. **Power conditioning.** Source: various industry reports. This figure should be conservative for a system of over 100kW. APS-Fairfield data suggest a cost of under $0.60/W for a system this size.

12, 13. **Material credits.** Since this option is identical to option 1 except that it is being compared to atrium roof construction, credits for the flat roof components are not used.

14. **Glazing.** Credit for 1/4" laminated, tinted glass.

SECTION

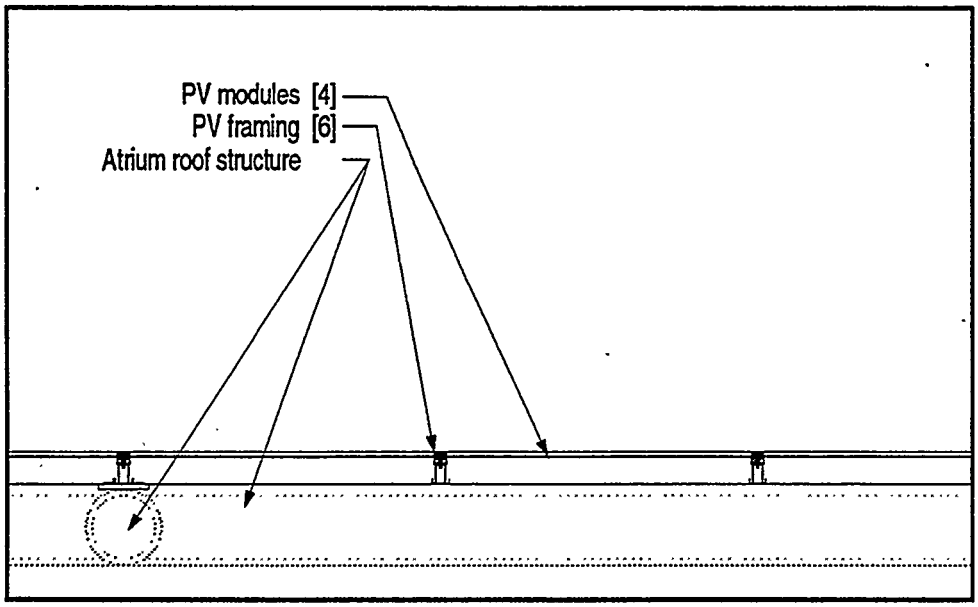
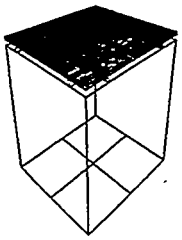



*Fig 24. Section through typical bay, Option 1a*



## OPTION 2 CONSTRUCTION COSTS

| | | PV1 | | PV2 | | PV3 |
|---|---|---|---|---|---|---|
| | $/m2 | $/W | $/m2 | $/W | $/m2 | $/W |
| 1 Additional roof structure | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 2 | | | | | | |
| 3 PV system costs: | | | | | | |
| 4 PV modules | $615.72 | $4.40 | $155.01 | $3.00 | $215.29 | $2.00 |
| 5 IG unit fabrication | $193.76 | $1.38 | $193.76 | $3.75 | $193.76 | $1.80 |
| 6 PV framing | $215.29 | $1.54 | $215.29 | $4.17 | $215.29 | $2.00 |
| 7 PV wiring | $34.88 | $0.25 | $34.88 | $0.68 | $34.88 | $0.32 |
| 8 Other indirect | $55.97 | $0.40 | $20.67 | $0.40 | $43.06 | $0.40 |
| 9 Power Conditioning | $111.95 | $0.80 | $41.33 | $0.80 | $86.11 | $0.80 |
| 10 | $1,227.56 | $8.77 | $660.93 | $12.79 | $788.37 | $7.32 |
| 11 Material credits: | | | | | | |
| 12 Roofing | ($21.53) | ($0.15) | ($21.53) | ($0.42) | ($21.53) | ($0.20) |
| 13 Insulation | ($20.88) | ($0.15) | ($20.88) | ($0.40) | ($20.88) | ($0.19) |
| 14 Metal Deck | ($21.53) | ($0.15) | ($21.53) | ($0.42) | ($21.53) | ($0.20) |
| 15 | ($63.94) | ($0.46) | ($63.94) | ($1.24) | ($63.94) | ($0.59) |
| 16 | | | | | | |
| 17 Subtotal | $1,163.62 | $8.32 | $596.99 | $11.55 | $724.43 | $6.73 |
| 18 Markup (15%) | $174.54 | $1.25 | $89.55 | $1.73 | $108.67 | $1.01 |
| 19 **Total** | **$1,338.16** | **$9.56** | **$686.53** | **$13.29** | **$833.10** | **$7.74** |

*Table 4. Detailed breakdown of Option 2 cost calculations.*

TABLE NOTES:

5. **IG unit fabrication.** $18.00/sf: Assumes $21.50/sf for insulating glazing unit with 1/4" float and 1/4" laminate glass less $3.50/sf for replacing 1/4" float glass with PV.

6. **PV framing.** Aluminum extrusion skylight system. *Source: DeaMor, Inc. 1994*

7. **PV wiring.** $37.67/m2 ($3.50/sf) PV area allowance. Could be significantly less: assuming modules are connected in series of 6 (a-Si modules @ 40V ea for a 240V system) with snap together connectors in the series string, conduit is needed only for wiring between strings and for home runs to the inverter. In the test building, this should require approx. 1m conduit/10m2 PV area, or $10.00/m2 @ $10/m wiring cost allowance.

8. **Other indirect.** Engineering, permits, shipping, insurance, project management. *Source: AD Little 6/94.*

9. **Power conditioning.** This figure should be conservative for a system of over 100kW. APS-Fairfield data suggest a cost of under $0.60/W for a system this size.

12. **Roofing credit.** 55 mil EPDM fully adhered membrane. *Source: Devcon Construction Inc., 1994.*

13. **Insulation.** Phenolic foam board 2 layers x 1.75", (R28.4) *Source: RS Means Construction Cost Data 1993.*

14. **Metal deck.** *Source: Devcon Construction Inc., 1994.*

SECTION

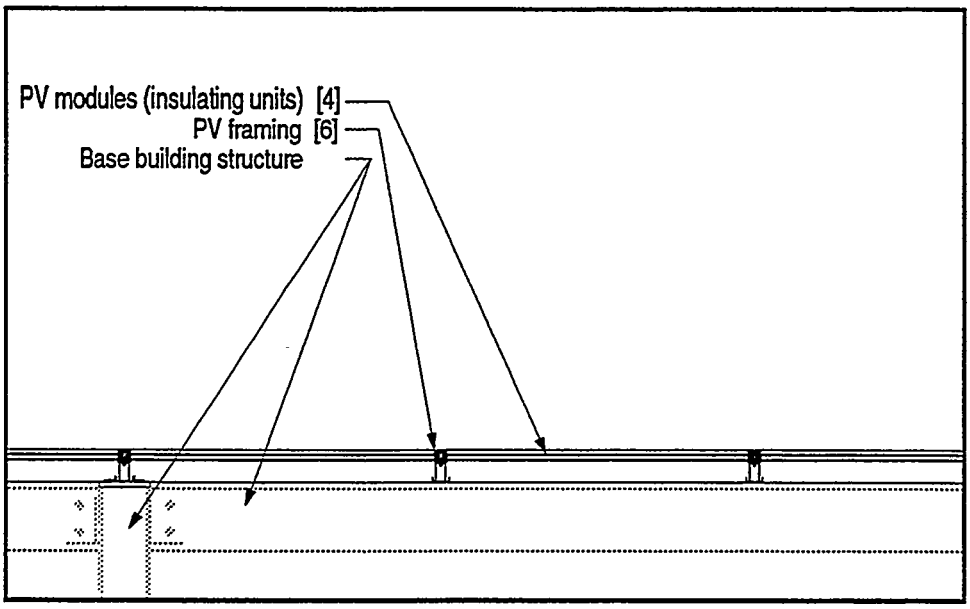
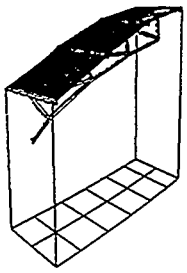



*Fig 25. Section through typical bay, Option 2*



## OPTION 2A CONSTRUCTION COSTS

| | | PV1 | | PV2 | | PV3 | |
|---|---|---|---|---|---|---|---|
| | | $/m2 | $/W | $/m2 | $/W | $/m2 | $/W |
| 1 | Additional roof structure | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 2 | | | | | | | |
| 3 | PV system costs: | | | | | | |
| 4 | PV modules | $615.72 | $4.40 | $155.01 | $3.00 | $215.29 | $2.00 |
| 5 | Lg. area encaps. (IG units) | $193.76 | $1.38 | $193.76 | $3.75 | $193.76 | $1.80 |
| 6 | PV framing | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 7 | PV wiring | $34.88 | $0.25 | $34.88 | $0.68 | $34.88 | $0.32 |
| 8 | Other indirect | $55.97 | $0.40 | $20.67 | $0.40 | $43.06 | $0.40 |
| 9 | Power Conditioning | $111.95 | $0.80 | $41.33 | $0.80 | $86.11 | $0.80 |
| 10 | | $1,012.27 | $7.23 | $445.64 | $8.63 | $573.09 | $5.32 |
| 11 | Material credits: | | | | | | |
| 12 | Roofing | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 13 | Insulation | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 14 | Glazing | ($231.43) | ($1.65) | ($231.43) | ($4.48) | ($231.43) | ($2.15) |
| 15 | | ($231.43) | ($1.65) | ($231.43) | ($4.48) | ($231.43) | ($2.15) |
| 16 | | | | | | | |
| 17 | Subtotal | $780.84 | $5.58 | $214.21 | $4.15 | $341.66 | $3.17 |
| 18 | Markup (15%) | $117.13 | $0.84 | $32.13 | $0.62 | $51.25 | $0.48 |
| 19 | **Total** | **$897.97** | **$6.42** | **$246.34** | **$4.77** | **$392.91** | **$3.65** |

*Table 5. Detailed breakdown of Option 2a cost calculations.*

### TABLE NOTES:

**Option 1A and 2A are referenced to an atrium roof design, including skylight framing, glazing and exposed structure.**

7. **PV wiring.** $37.67/m2 ($3.50/sf) PV area allowance. Could be significantly less: assuming modules are connected in series of 6 (a-Si modules @ 40V ea for a 240V system) with snap together connectors in the series string, conduit is needed only for wiring between strings and for home runs to the inverter. In the test building, this should require approx. 1m conduit/10m2 PV area, or $10.00/m2 @ $10/m wiring cost allowance.

8. **Other indirect.** Engineering, permits, shipping, insurance, project management. *Source: AD Little 6/94.*

9. **Power conditioning.** This figure should be conservative for a system of over 100kW. APS-Fairfield data suggest a cost of under $0.60/W for a system this size.

11. **Material credits.** Since this option is identical to option 2 except that it is being compared to atrium roof construction, credits for the flat roof components are not used.

14. **Glazing.** Credit for 1" double glazing, 1/4" float, 1/4" wire glass.

SECTION

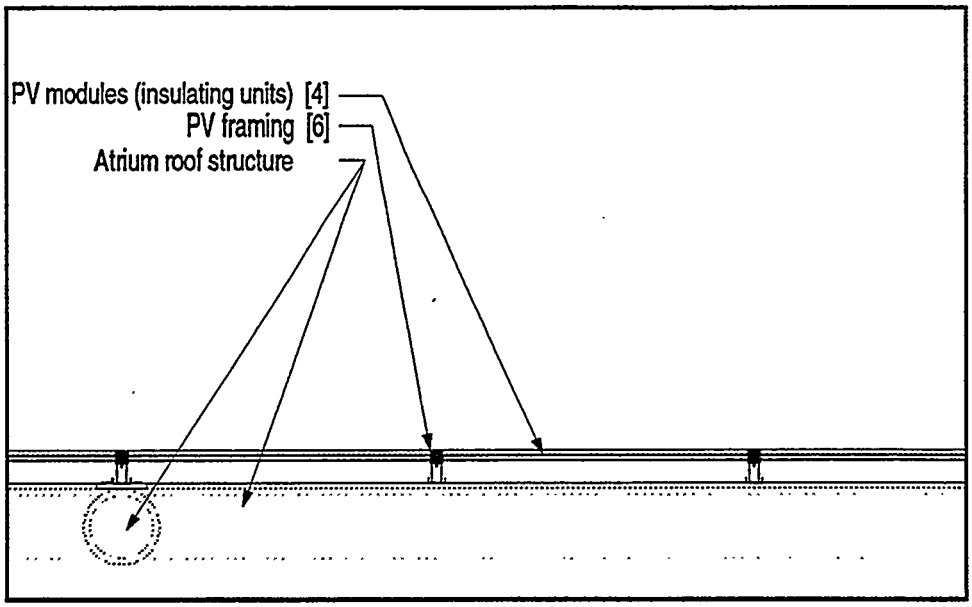
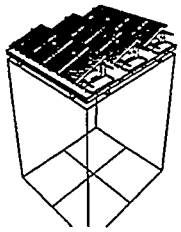



*Fig 26. Section through typical bay, Option 2a*



## OPTION 3 CONSTRUCTION COSTS

| | | PV1 | | PV2 | | PV3 | |
|---|---|---|---|---|---|---|---|
| | | $/m2 | $/W | $/m2 | $/W | $/m2 | $/W |
| 1 | Ballasted roof structure | $139.94 | $1.00 | $139.94 | $2.71 | $139.94 | $1.30 |
| 2 | | | | | | | |
| 3 | PV system costs: | | | | | | |
| 4 | PV modules | $615.72 | $4.40 | $155.01 | $3.00 | $215.29 | $2.00 |
| 5 | | | | | | | |
| 6 | PV wiring | $34.88 | $0.25 | $34.88 | $0.68 | $34.88 | $0.32 |
| 7 | Other indirect | $55.97 | $0.40 | $20.67 | $0.40 | $43.06 | $0.40 |
| 8 | Power Conditioning | $111.95 | $0.80 | $41.33 | $0.80 | $86.11 | $0.80 |
| 9 | | $958.45 | $6.85 | $391.82 | $7.58 | $519.27 | $4.82 |
| 10 | | | | | | | |
| 11 | Material credits: | | | | | | |
| 12 | | | | | | | |
| 13 | | | | | | | |
| 14 | None | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 15 | | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 16 | | | | | | | |
| 17 | Subtotal | $958.45 | $6.85 | $391.82 | $7.58 | $519.27 | $4.82 |
| 18 | Markup (15%) | $143.77 | $1.03 | $58.77 | $1.14 | $77.89 | $0.72 |
| 19 | **Total** | **$1,102.22** | **$7.88** | **$450.59** | **$8.72** | **$597.16** | **$5.55** |

*Table 6. Detailed breakdown of Option 3 cost calculations.*

**TABLE NOTES:**

1. **Ballasted roof structure.** Uses $1.00/W for crystalline installation ($140/m2). *Source: AD Little 6/94.*

6. **PV Wiring.** $37.67/m2 ($3.50/sf) PV area allowance. Could be significantly less: assuming modules are connected in series of 6 (a-Si modules @ 40V ea for a 240V system) with snap together connectors in the series string, conduit is needed only for wiring between strings and for home runs to the inverter. In the test building, this should require approx. 1m conduit/10m2 PV area, or $10.00/m2 @ $10/m wiring cost allowance.

7. **Other indirect.** Engineering, permits, shipping, insurance, project management. *Source: AD Little 6/94.*

8. **Power conditioning.** Source: various industry reports. This figure should be conservative for a system of over 100kW. APS-Fairfield data suggest a cost of under $0.60/W for a system this size.

SECTION

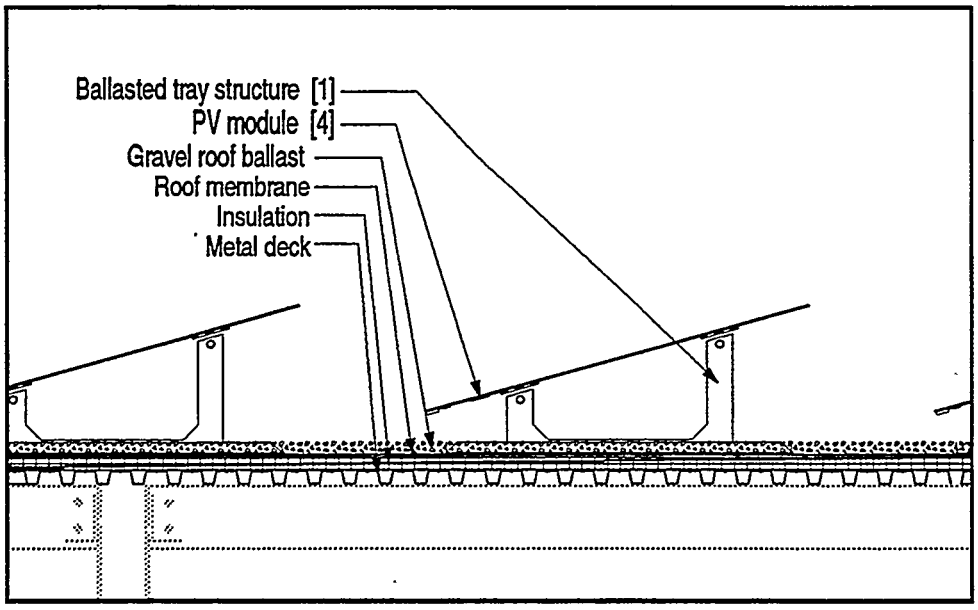
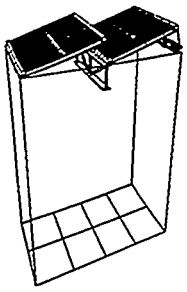



*Fig 27. Section through typical bay, Option 3*



## OPTION 4 CONSTRUCTION COSTS

| | | PV1 | | PV2 | | PV3 | |
|---|---|---|---|---|---|---|---|
| | | $/m2 | $/W | $/m2 | $/W | $/m2 | $/W |
| 1 | Additional roof structure | $32.28 | $0.23 | $32.28 | $0.62 | $32.28 | $0.30 |
| 2 | | | | | | | |
| 3 | PV system costs: | | | | | | |
| 4 | PV modules | $615.72 | $4.40 | $155.01 | $3.00 | $215.29 | $2.00 |
| 5 | Module subframe | $62.43 | $0.45 | $62.43 | $1.21 | $62.43 | $0.58 |
| 6 | | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 7 | PV wiring | $34.88 | $0.25 | $34.88 | $0.68 | $34.88 | $0.32 |
| 8 | Other indirect | $55.97 | $0.40 | $20.67 | $0.40 | $43.06 | $0.40 |
| 9 | Clerestory Glazing | $77.50 | $0.55 | $77.50 | $1.50 | $77.50 | $0.72 |
| 10 | Add. sprinklers | $9.15 | $0.07 | $9.15 | $0.18 | $9.15 | $0.09 |
| 11 | Power Conditioning | $111.95 | $0.80 | $41.33 | $0.80 | $86.11 | $0.80 |
| 12 | | $999.88 | $7.15 | $433.25 | $8.39 | $560.70 | $5.21 |
| 13 | Material credits: | | | | | | |
| 14 | | | | | | | |
| 15 | None | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 16 | | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 17 | Subtotal | $999.88 | $7.15 | $433.25 | $8.39 | $560.70 | $5.21 |
| 18 | Markup (15%) | $149.98 | $1.07 | $64.99 | $1.26 | $84.10 | $0.78 |
| 19 | **Total: All** | **$1,149.86** | **$8.22** | **$498.24** | **$9.64** | **$644.80** | **$5.99** |
| 20 | **Total: PV only** | **$1,013.09** | **$7.24** | **$361.46** | **$7.00** | **$508.03** | **$4.72** |
| 21 | **Total: Daylight only** | **$136.77** | **NA** | **$136.77** | **NA** | **$136.77** | **NA** |

*Table 7. Detailed breakdown of Option 4 cost calculations.*

TABLE NOTES:

1. **Additional roof structure.** tube steel framing to form sawtooth roof profile.*Source: Devcon Construction Inc., 1994.*

5. **Module subframe.** Steel channel support structure for 2'-6" x 5'-0" modules. *Source: Bell Products.*

7. **PV wiring.** $37.67/m2 ($3.50/sf) PV area allowance. Could be significantly less: assuming modules are connected in series of six (a-Si modules @ 40V ea for a 240V system) with snap together connectors in the series string, conduit is needed only for wiring between strings and for home runs to the inverter. In the test building, this should require approx. 1m conduit/10m2 PV area, or $10.00/m2 @ $10/m wiring cost allowance.

8. **Other indirect.** Engineering, permits, shipping, insurance, project management. *Source: AD Little report 6/94.*

9. **Clerestory glazing.** Insulated glazing at $344/m2 for clerestory area. *Source: Devcon Construction Inc., 1994.*

10. **Additional sprinklers.** Sprinkler heads required to cover volumes of sawtooth roof. *Source: Devcon Construction Inc., 1994.*

11. **Power conditioning.** This figure should be conservative for a system of over 100kW. APS-Fairfield data suggest a cost of under $0.60/W for a system this size.

20 **PV Only.** Sum of lines: 4+5+7+8+11.

21 **Daylight Only.** Sum of lines: 1+9+10+14+15.

SECTION

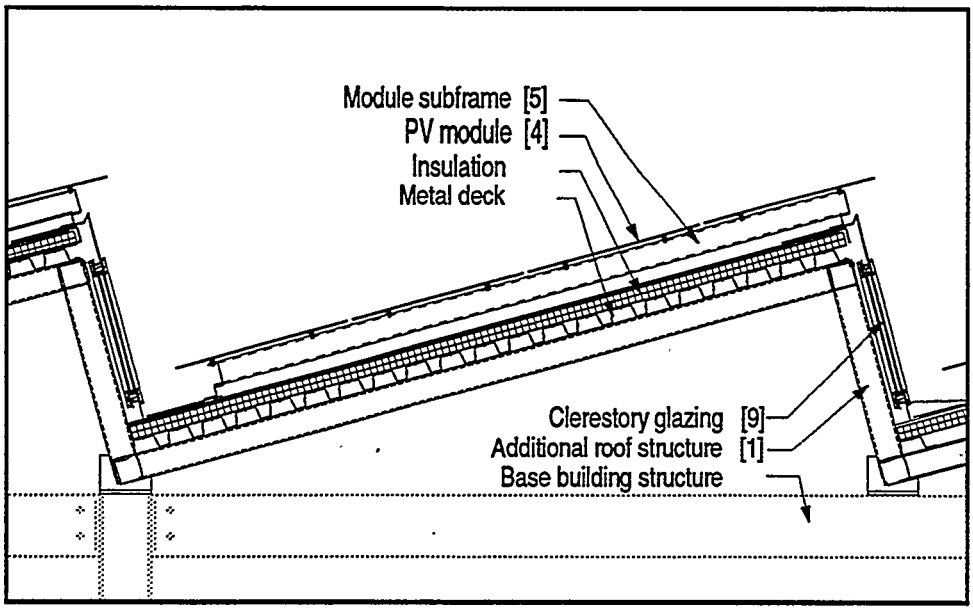
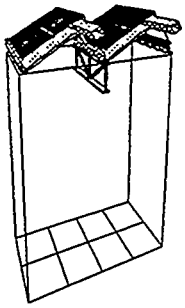



*Fig 28. Section through typical bay, Option 4*



## OPTION 5 CONSTRUCTION COSTS

| | | PV1 | | PV2 | | PV3 |
|---|---|---|---|---|---|---|
| | $/m2 | $/W | $/m2 | $/W | $/m2 | $/W |
| 1 Additional roof structure | $32.28 | $0.23 | $32.28 | $0.62 | $32.28 | $0.30 |
| 2 | | | | | | |
| 3 PV system costs: | | | | | | |
| 4 PV modules | $615.72 | $4.40 | $155.01 | $3.00 | $215.29 | $2.00 |
| 5 PV framing | $215.29 | $1.54 | $215.29 | $4.17 | $215.29 | $2.00 |
| 6 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 7 PV wiring | $34.88 | $0.25 | $34.88 | $0.68 | $34.88 | $0.32 |
| 8 Other indirect | $55.97 | $0.40 | $20.67 | $0.40 | $43.06 | $0.40 |
| 9 Clerestory Glazing | $77.50 | $0.55 | $77.50 | $1.50 | $77.50 | $0.72 |
| 10 Liner Panel | $21.53 | $0.15 | $21.53 | $0.42 | $21.53 | $0.20 |
| 11 Heat recovery, therm. stor. | $64.59 | $0.46 | $64.59 | $1.25 | $64.59 | $0.60 |
| 12 Add. sprinklers | $9.15 | $0.07 | $9.15 | $0.18 | $9.15 | $0.09 |
| 13 Power Conditioning | $111.95 | $0.80 | $41.33 | $0.80 | $86.11 | $0.80 |
| 14 | $1,238.85 | $8.85 | $672.21 | $13.01 | $799.66 | $7.43 |
| 15 Material credits: | | | | | | |
| 16 Roofing | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 17 Metal Deck | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 18 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 19 Subtotal | $1,238.85 | $8.85 | $672.21 | $13.01 | $799.66 | $7.43 |
| 20 Markup (15%) | $185.83 | $1.33 | $100.83 | $1.95 | $119.95 | $1.11 |
| **21 Total: All** | **$1,424.67** | **$10.18** | **$773.05** | **$14.96** | **$919.61** | **$8.54** |
| **20 Total: PV only** | **$1,188.87** | **$8.50** | **$537.24** | **$10.40** | **$683.81** | **$6.35** |
| **21 Total: Daylight + Thermal** | **$235.80** | **NA** | **$235.80** | **NA** | **$235.80** | **NA** |

*Table 8. Detailed breakdown of Option 5 cost calculations.*

**TABLE NOTES:**

1. **Additional roof structure.** tube steel framing to form sawtooth roof profile. *Source: Devcon Construction Inc., 1994.*

5. **PV framing.** Aluminum extrusion skylight system. *Source: DeaMor, Inc. 1994*

7. **PV wiring.** $37.67/m2 ($3.50/sf) PV area allowance. Could be significantly less: assuming modules are connected in series of six (a-Si modules @ 40V ea for a 240V system) with snap together connectors in the series string, conduit is needed only for wiring between strings and for home runs to the inverter. In the test building, this should require approx. 1m conduit/10m2 PV area, or $10.00/m2 @ $10/m wiring cost allowance.

8. **Other indirect.** Engineering, permits, shipping, insurance, project management. *Source: AD Little report 6/94*

9. **Clerestory glazing.** Insulated glazing at $344/m2 for clerestory area. *Source: Devcon Construction Inc., 1994.*

10. **Liner panel.** Cost of plywood liner to create airspace behind PV modules.

11. **Heat recovery HVAC, thermal storage.** Budget price for ductwork, controls, thermal mass storage system. *Source: Ove Arup & Partners New York*

12. **Additional sprinklers.** Sprinkler heads required to cover volumes of sawtooth roof. *Source: Devcon Construction Inc., 1994.*

13. **Power conditioning.** This figure should be conservative for a system of over 100kW. APS-Fairfield data suggest a cost of under $0.60/W for a system this size.

20 **PV Only.** Sum of lines: 4+5+7+8+11.

21 **Daylight +Thermal.** Sum of lines: 1+9+10+14+15.

SECTION

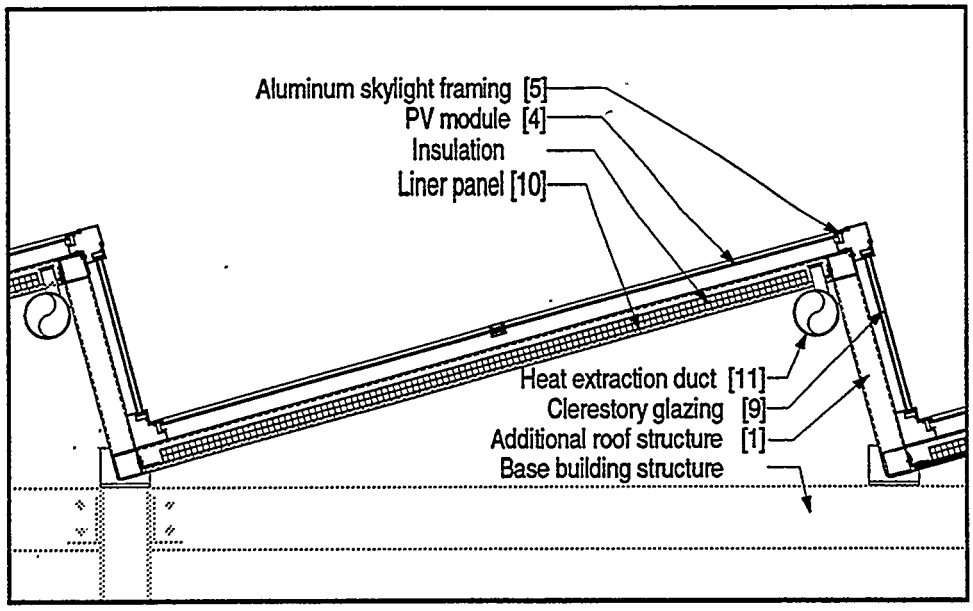



*Fig 29. Section through typical bay, Option 5*

# UTILITY RATE ANALYSIS

To obtain a payback period for each system, the costs obtained in the preceding section are divided by the value of energy savings and PV income. Since the thermal performance and PV output of each system was determined for each of the six test cities, the actual value of PV electricity was calculated for each location and used as the basis for the payback calculation. (see Appendix D for detailed calculations of average utility rates.)

We used utility rate data compiled by Casazza, Schultz & Associates for the Gas Research Institute, entitled "Electric and Gas Rates for the Residential, Commercial and Industrial Sectors: 1993". In each location a rate was found which was applicable to a commercial customer with a peak demand of ≤500kW. When there was more than one applicable rate, the rate that appeared to yield the best return based on maximum time-of-use energy rates were selected (we did not evaluate every rate available).

One exceptional rate was evaluated, a LILCO small commercial (<7kW demand) rate in New York. This rate (noted as New York 2) provides exceptionally high peak energy charges, and gives an idea of the high end of the rates smaller commercial or residential users might find in certain parts of the country.

To obtain the most accurate value of avoided electricity, PV performance was modeled on an hourly basis for each climate using PV-F Chart software. The PV production for each hour of the day for each month was multiplied by the electric rate prevailing at that hour, taking into account time-of-use charges, demand charges, seasonal variations, surcharges, energy cost adjustments and taxes. Demand charges were offset by 20% of the capacity of the PV system, which would be minimum output for most PV systems during cloudy days. The total cost of electricity for the year was then divided by the total kilowatt-hours produced by the PVs to obtain the average offset electric cost.

These evaluations were performed for three different array orientations: South, 45° West of South, and West. (see "PV Orientation Effects on Average Electric Rate" below.)

## DEMAND CHARGE ANALYSIS

Table 9 summarizes the average rate in $/kWh for four different levels of PV demand credit. Note that the Oakland and New York 2 rates are energy charges only and have no demand component.

| | % Demand Credit | | | |
|---|---|---|---|---|
| | 0% | 20% | 60% | 100% |
| Oakland | $0.1753 | $0.1753 | $0.1753 | $0.1753 |
| New York 1 | $0.1258 | $0.1306 | $0.1402 | $0.1499 |
| New York 2 | $0.2727 | $0.2727 | $0.2727 | $0.2727 |
| Phoenix | $0.0878 | $0.0897 | $0.0935 | $0.0972 |
| Miami | $0.1091 | $0.1158 | $0.1291 | $0.1424 |
| Chicago | $0.0604 | $0.0727 | $0.0975 | $0.1223 |
| Cincinnati | $0.0470 | $0.0561 | $0.0742 | $0.0924 |

*Table 9. PV demand credit levels for different locations.*

Although it is not in the scope of this report, there may be cases where storage to achieve greater demand savings is cost-effective. In Chicago, for example, the effective value of PV electricity is more than doubled by capturing 100% demand credit. The additional value is $0.0619/kWh/year.

Almost all the commercial utility rates we examined had a demand charge component. Energy-charge-only rates are common in residential rate plans, less common in small commercial rates, and rare in medium-large commercial rates. In general, the lower the demand charge component of a rate, the higher the value of PV power.

## PV ORIENTATION EFFECTS ON AVERAGE ELECTRIC RATE

The following three charts illustrate the effects of array orientation on PV electric value. Although annual PV output from a West-facing array (90°) was typically lower than output from a South-facing and Southwest-facing array (*Chart 7*), a 90° orientation produced an equivalent or better overall electric rate (*Chart 8*) as a result of higher utility rates in the latter part of the day. The average annual PV value was calculated by multiplying the average electric rate by the PV power produced (*Chart 9*). The payback analyses which follow use the 45° orientation for producing the best overall income.

Detailed PV output and electrical rate calculations are listed in Appendix D.

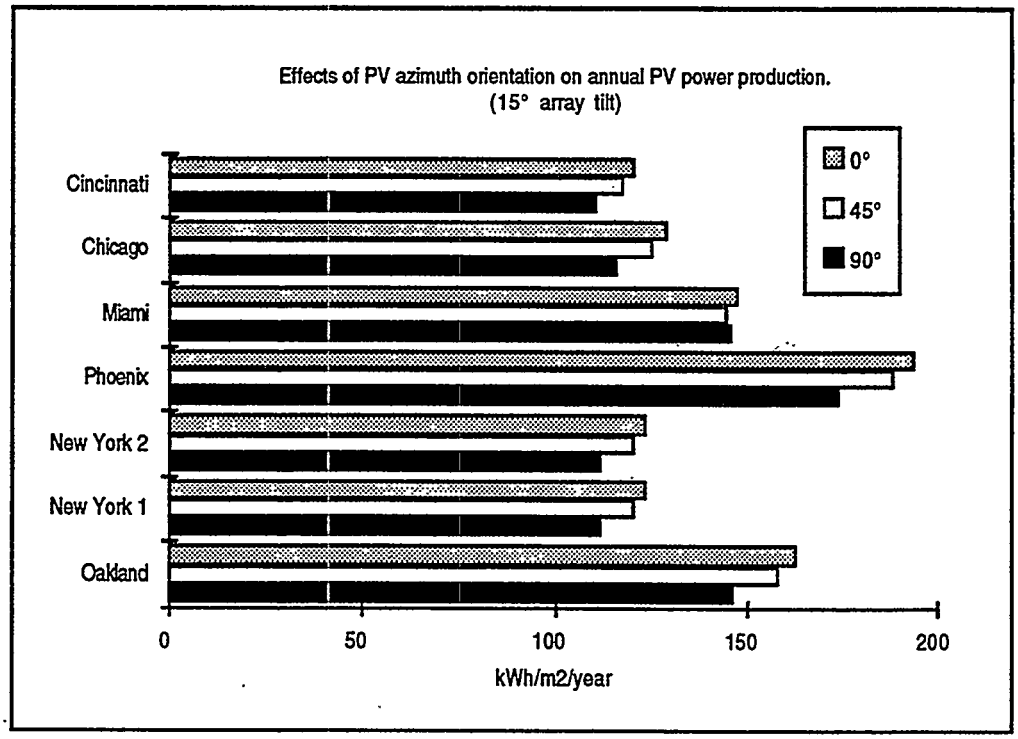



*Chart 7. Annual PV power production for three different array orientations.*

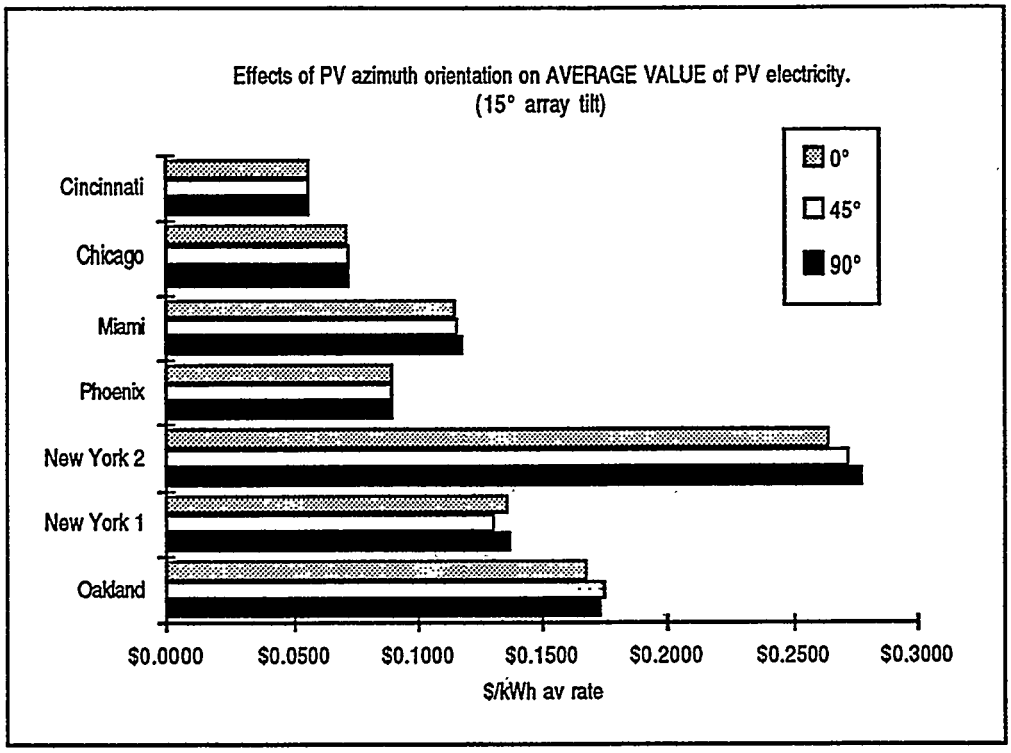



*Chart 8. Average PV electric value for three different array orientations.*

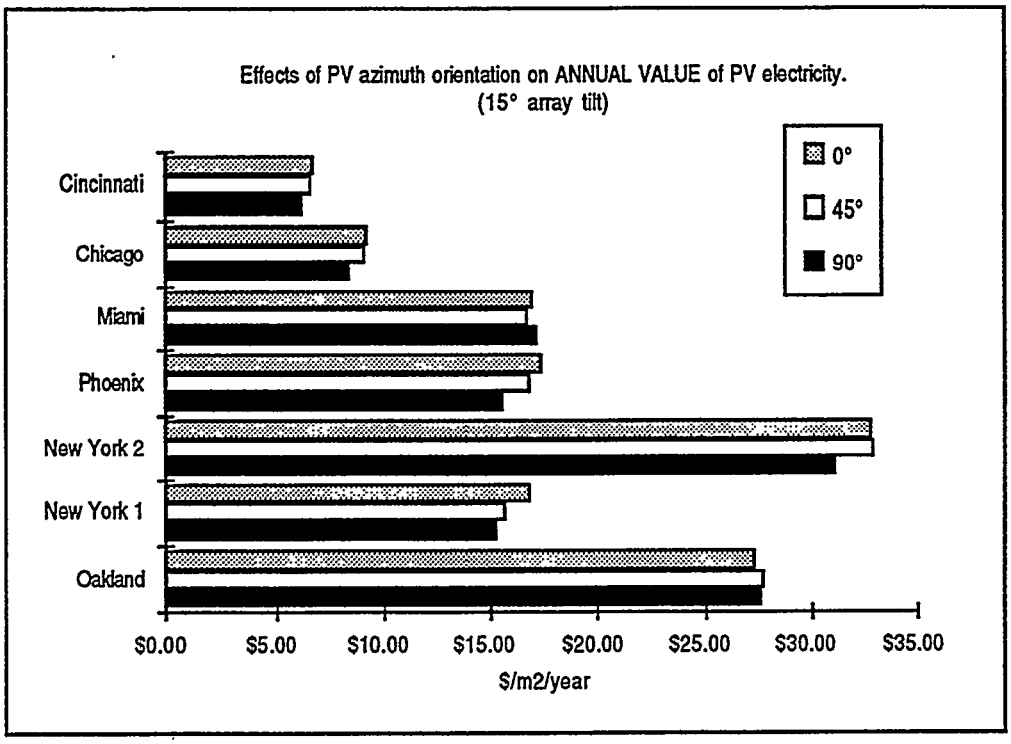



*Chart 9. Annual PV value (PV power x average PV electric value) for three different array orientations.*

# PAYBACK ANALYSIS - PARAMETERS

To assess the relative economic value of the options, a simple payback was calculated for each system in each climate for the three PV technologies. For Options 4 and 5, a PV system-only payback was calculated since the daylight/thermal benefits of these designs are not an integral product of the PV modules. The payback calculations are:

$$\text{Simple Payback, years (full system)} = \frac{\text{(Construction+ PV Cost, \$/m2) x (Const. Cost Location Factor)}}{\text{(PV + daylight + thermal, kWh/m2/yr) x (Av. elect rate, \$/kWh)}}$$

$$\text{Simple Payback, years (PV only)} = \frac{\text{(PV System Cost, \$/m2) x (Const. Cost Location Factor)}}{\text{(PV, kWh/m2/yr) x (Av. elect rate, \$/kWh)}}$$

More sophisticated economic models would give a better picture of the actual value of the systems analyzed. We made no attempt to include life cycle costs such as maintenance, cleaning, insurance or any other additional operating costs. We also did not attempt present value calculations.

Some other assumptions are worth noting:

1. Some of the system costs may be high for a project of this size (see cost calculations section, particularly in regard to power conditioning and wiring costs), although the markup of 15% for the PV system costs may be higher in cases with multiple subcontractors.
2. No escalation was calculated for electric rates.
3. A demand credit of 20% was given for the PV system. In some cases, a higher demand credit may apply.
4. Tax credits were not factored into payback. For corporate building owners with tax liabilities, these savings could substantially cut the effective cost of the PV systems. A 10% federal renewable energy tax credit, combined with an accelerated five year depreciation of the system costs, can cut the system cost by more than 40%. Other state and Federal credits and subsidies may apply.
5. The effects of incorporating PV system costs into a building mortgage have not been considered.

The overall effect of these factors could cut the payback times shown by half or more.

# PAYBACK ANALYSIS - SUMMARY

Tables 10 and 11 summarize the simple payback period calculated in years for each of the systems. For each option, the best payback of the two currently available PV technologies (PV1 and PV2) is highlighted in boldface.

| Payback, PV Only | | Oakland | New York 1 | New York 2 | Phoenix | Miami | Chicago | Cincinnati |
|---|---|---|---|---|---|---|---|---|
| OPTION 1 | *PV1* | **35.68** | **72.65** | **34.79** | **47.15** | **45.74** | **100.54** | **124.02** |
| | *PV2* | 36.84 | 75.38 | 36.10 | 47.84 | 46.54 | 104.32 | 128.55 |
| | *PV3* | 25.30 | 51.63 | 24.72 | 33.14 | 32.19 | 71.46 | 88.10 |
| OPTION 1a | *PV1* | 27.62 | 56.24 | 26.93 | 36.50 | 35.41 | 77.82 | 96.00 |
| | *PV2* | **16.82** | **34.41** | **16.48** | **21.84** | **21.25** | **47.62** | **58.68** |
| | *PV3* | 14.85 | 30.31 | 14.51 | 19.45 | 18.90 | 41.95 | 51.71 |
| OPTION 2 | *PV1* | **43.30** | **87.99** | **42.14** | **57.30** | **55.52** | **121.84** | **150.26** |
| | *PV2* | 54.96 | 112.31 | 53.78 | 71.43 | 69.44 | 155.51 | 191.59 |
| | *PV3* | 34.86 | 71.04 | 34.02 | 45.72 | 44.37 | 98.37 | 121.25 |
| OPTION 2a | *PV1* | 29.05 | 59.05 | 28.27 | 38.45 | 37.25 | 81.76 | 100.83 |
| | *PV2* | **19.72** | **40.30** | **19.30** | **25.63** | **24.92** | **55.80** | **68.74** |
| | *PV3* | 16.44 | 33.51 | 16.04 | 21.56 | 20.92 | 46.39 | 57.18 |
| OPTION 3 | *PV1* | **34.74** | **70.92** | **33.96** | **45.83** | **44.53** | **98.07** | **121.01** |
| | *PV2* | 35.44 | 72.63 | 34.78 | 45.97 | 44.77 | 100.47 | 123.82 |
| | *PV3* | 24.45 | 50.00 | 23.94 | 31.98 | 31.11 | 69.15 | 85.28 |
| OPTION 4 | *PV1* | 33.74 | 68.24 | 32.68 | 44.82 | 43.29 | 94.63 | 116.63 |
| | *PV2* | **29.51** | **60.11** | **28.78** | **38.43** | **37.28** | **83.31** | **102.59** |
| | *PV3* | 21.78 | 44.20 | 21.17 | 28.64 | 27.73 | 61.29 | 75.50 |
| OPTION 5,5a | *PV1* | **37.62** | **76.74** | **36.75** | **49.64** | **48.21** | **106.13** | **130.95** |
| | *PV2* | 42.36 | 86.78 | 41.56 | 54.97 | 53.52 | 120.06 | 147.97 |
| | *PV3* | 28.08 | 57.41 | 27.49 | 36.75 | 35.73 | 79.41 | 97.92 |

*Table 10 A summary matrix of simple payback periods for all possible PV roof option, PV system cost/benefits only (See Appendix D for detailed payback tables for each option).*

| Payback, Full system | | Oakland | New York 1 | New York 2 | Phoenix | Miami | Chicago | Cincinnati |
|---|---|---|---|---|---|---|---|---|
| OPTION 1 | *PV1* | **52.55** | **295.81** | **141.65** | negative | negative | **533.09** | **2,426.02** |
| | *PV2* | 138.10 | negative | negative | negative | negative | negative | negative |
| | *PV3* | 44.09 | 1,280.41 | 613.14 | negative | negative | negative | negative |
| OPTION 1a | *PV1* | 27.62 | 56.24 | 26.93 | 36.50 | 35.41 | 77.82 | 96.00 |
| | *PV2* | **16.82** | **34.41** | **16.48** | **21.84** | **21.25** | **47.62** | **58.68** |
| | *PV3* | 14.85 | 30.31 | 14.51 | 19.45 | 18.90 | 41.95 | 51.71 |
| OPTION 2 | *PV1* | 35.29 | **74.43** | **37.56** | **61.91** | **53.37** | **110.12** | **137.67** |
| | *PV2* | **35.19** | 77.20 | 40.80 | 85.31 | 62.81 | 122.57 | 155.50 |
| | *PV3* | 27.03 | 57.75 | 30.03 | 50.97 | 42.45 | 86.87 | 108.98 |
| OPTION 2a | *PV1* | 29.05 | 59.05 | 28.27 | 38.45 | 37.25 | 81.76 | 100.83 |
| | *PV2* | **19.72** | **40.30** | **19.30** | **25.63** | **24.92** | **55.80** | **68.74** |
| | *PV3* | 16.44 | 33.51 | 16.04 | 21.56 | 20.92 | 46.39 | 57.18 |
| OPTION 3 | *PV1* | **34.67** | **70.67** | **33.84** | 45.60 | 44.30 | **97.74** | **120.50** |
| | *PV2* | 35.25 | 71.98 | 34.47 | **45.41** | **44.20** | 99.63 | 122.53 |
| | *PV3* | 24.38 | 49.77 | 23.83 | 31.77 | 30.90 | 68.85 | 84.81 |
| OPTION 4 | *PV1* | **25.37** | 47.70 | 22.84 | 35.52 | 31.74 | 69.86 | 83.79 |
| | *PV2* | 17.92 | **32.34** | **15.49** | **25.86** | **21.97** | **48.98** | **57.74** |
| | *PV3* | 16.55 | 30.85 | 14.77 | 23.33 | 20.58 | 45.59 | 54.42 |
| OPTION 5 | *PV1* | 33.85 | 59.57 | 28.53 | 45.42 | 42.79 | 84.53 | 105.38 |
| | *PV2* | **33.36** | **52.80** | **25.28** | **44.97** | **41.37** | **76.22** | **95.63** |
| | *PV3* | 26.30 | 45.07 | 21.58 | 35.26 | 33.01 | 64.26 | 80.24 |

*Table 11 A summary matrix of simple payback periods for all possible PV roof options, full system cost/benefits. (See Appendix D for detailed payback tables for each option).*

# PAYBACK ANALYSIS-DISCUSSION

Payback period is a function of a large number of variables, some specific to each roof option, some to location, some to PV technology. Depending on the project, it may be necessary to evaluate a BIPV installation according to one or more of these criteria:

1. Location
   - PV output (insolation)
   - Electrical rate
   - Construction cost location factor
   - Building energy requirements (climate)
2. BIPV Option
   - Cost (Construction cost minus material credit)
   - Thermal performance
   - Daylight performance
   - PV performance (a function of PV module temperature)
3. PV technology
   - Cost ($/W)
   - Efficiency (W/m2)
   - Temperature coefficient (%efficiency/°C)

## LOCATION

Of the three categories, location has the greatest effect on payback, with the best area averaging more than 3.5 times better than the worst. The effect of location on payback is consistent for each BIPV system: Oakland always has the shortest payback, followed by Miami, Phoenix, New York, Chicago, and Cincinnati *(see Chart 10)*. As discussed in the previous section, we included one exceptional case: in New York, a time-of-use rate for small commercial customers with demand too small to qualify for our reference building (less than 7kWp). Using this rate, the shortest payback of all is achieved, despite the lowest insolation and the highest construction costs.

In general, Oakland has a favorable balance of mild climate, high electrical rates, and high insolation. Phoenix, which has the highest insolation by far, has a hot climate and moderate electrical rates which lengthen the payback periods. At the other end of the range, Cincinnati has the lowest electrical rate, the second-lowest insolation, and significant heating and cooling seasons.

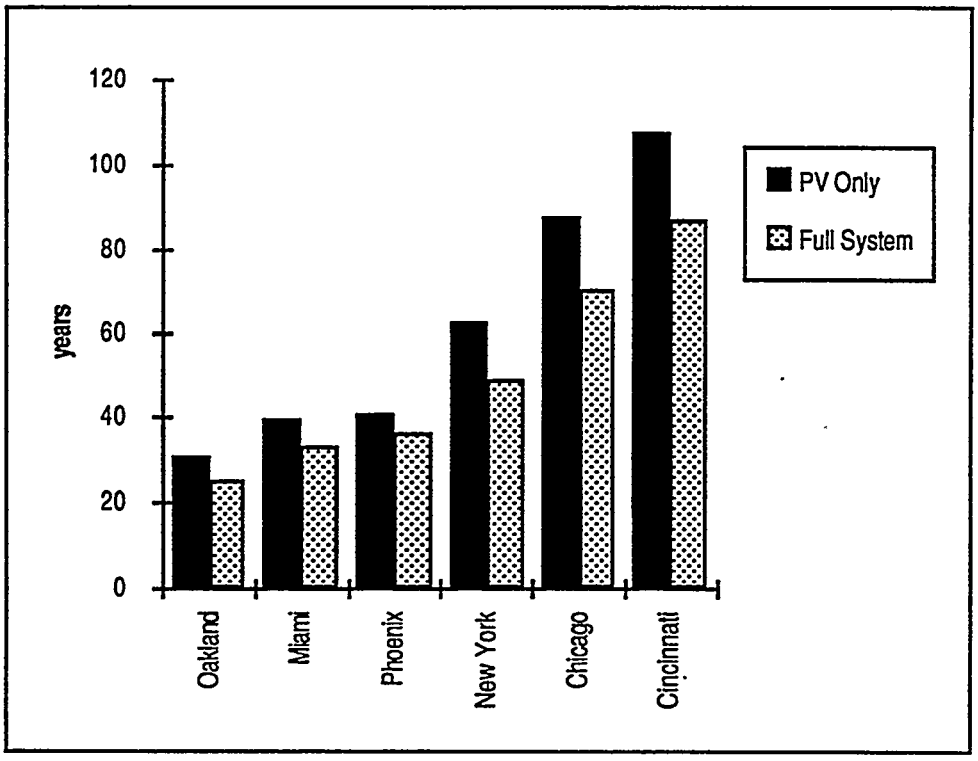



*Chart 10. Average payback by location, all options, all PV technologies.*

It is important to note that the paybacks shown in Chart 10 are averages for all BIPV options and PV technologies. In each location, the shortest payback achieved was approximately 60% of the average. Given any significant tax savings related to the PV system (see above, p. 44), full system payback periods of less than 20 years could be possible in all the locations except Chicago and Cincinnati.

### BIPV OPTION

The pattern is not as consistent when payback is evaluated according to BIPV roof option. The range between the best and worst cases on average is less than a factor of two. In most cases, Options 1a and 2a - the "atrium" options - are most cost-effective. Unlike all the other options, which are compared with a conventional flat roof, these systems are compared with the specialized and costly construction of atria: they have the highest material credit and lowest additional construction costs, and no daylight or thermal benefits.

Options 1 and 2 are identical in construction and energy performance to Options 1a and 2a, but are compared with the standard flat roof. They perform poorly, due to the high extra cost of skylight framing systems and low material credit

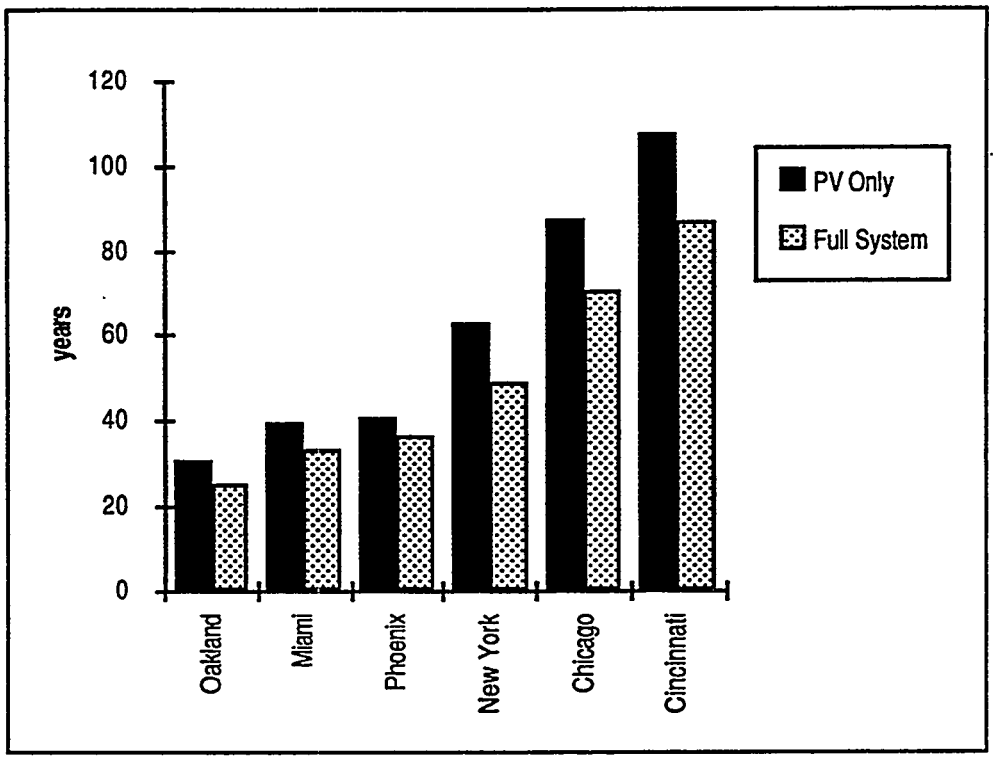



*Chart 11. Average payback by option, all climates, all PV technologies.*

for the conventional roof system and poor thermal performance. Option 1 is omitted from payback calculations because the very poor thermal performance results in extremely long or negative payback periods.

The roof options which rely most on collateral energy benefits (Options 4, 5, 5a), show the greatest improvement in payback when analyzed as a full system. We found that the active heat recovery of Option 5 is not generally cost-effective compared with the Option 4, which has the same indirect daylighting strategy but less expensive construction due to the absence of ductwork and a double-layer skin. Since more heat is generated in all cases with Option 5 than is needed for building space heating, this system is inherently inefficient. Option 5a, which is identical to Option 5 except that it is assumed that all available heat is used, approaches Option 4 in payback time.

The ballasted roof-mounted system (Option 3) shows moderately long payback in all cases, since it has additional construction costs, no material credit and no significant collateral energy benefits.

The cost analyses reveal that many of the construction-related items cost as

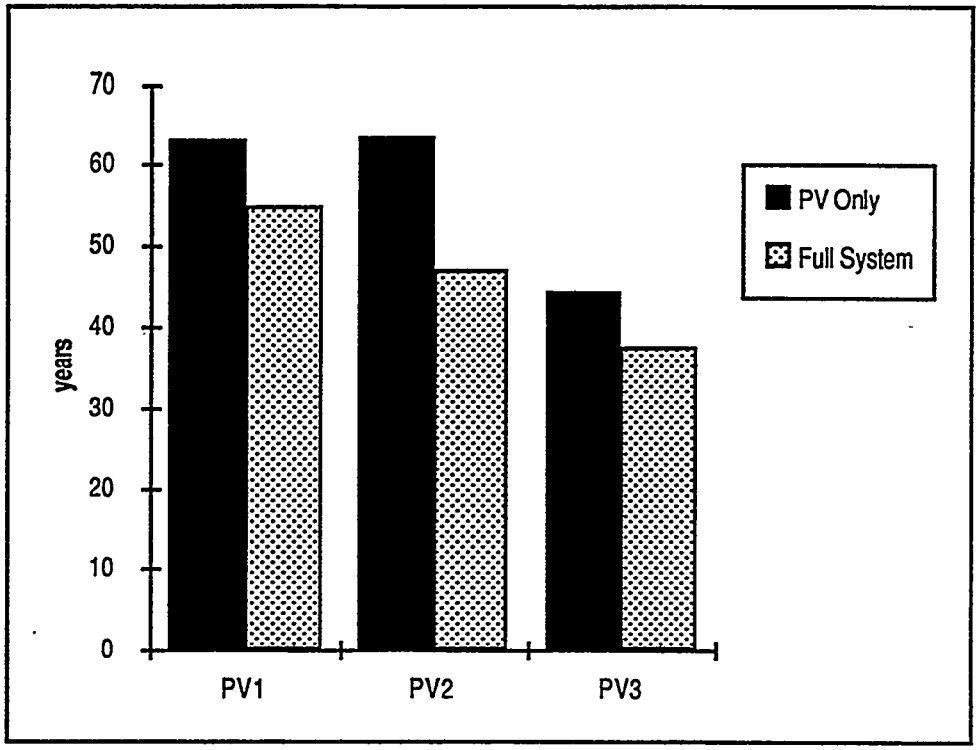



*Chart 12. Average payback by PV technology, all locations, all options.*

much or more than the PV modules. As PV costs decline, the cost/area of PVs becomes comparable to certain construction costs: PV1 is now $615/m2, PV3 is projected to be $215/m2. Skylight framing costs $215/m2, double glazing costs $231/m2. As PV costs drop, the costs of related systems become more significant, and the value of material credits becomes greater. In the future, the reduction of PV-related construction costs will be increasingly important.

## PV TECHNOLOGY.

The three PV technologies evaluated are most cost-effective in very specific conditions. We have identified the three technologies as Crystalline silicon (PV1), amorphous silicon (PV2) and advanced thin-film, CIS or CdTe (PV3). The analysis is primarily on the basis of their cost and efficiency, although the effects of operating temperature on efficiency is taken into account for each material. Other properties of these devices - aesthetics, long-term stability, toxic materials or heavy metals - may significantly affect their viability as building materials, but are not considered in this report.

In all cases evaluated, PV3 systems have the shortest payback. Since PV3 materials are not presently available (although they may be within the next few

| | Option2 | PV1 | | PV2 | | PV3 | |
|---|---|---|---|---|---|---|---|
| | | $/m2 | $/Wp | $/m2 | $/Wp | $/m2 | $/Wp |
| 1 | PV module | $615.72 | $4.40 | $155.01 | $3.00 | $215.29 | $2.00 |
| 2 | Area-independent costs | $167.92 | $1.20 | $62.00 | $1.20 | $129.17 | $1.20 |
| 3 | Area-dependent costs | $443.92 | $3.17 | $443.92 | $8.59 | $443.92 | $4.12 |
| 4 | Material Credit | ($63.94) | ($0.46) | ($63.94) | ($1.24) | ($63.94) | ($0.59) |
| 5 | Total with markup & location factor | $1,533.98 | $10.96 | $793.09 | $15.35 | $959.73 | $8.92 |
| 6 | Value of PV output | $35.14 | $0.25 | $14.20 | $0.27 | $27.17 | $0.25 |
| 7 | Value of daylight/thermal benefits | $8.33 | $0.06 | $8.33 | $0.16 | $8.33 | $0.08 |
| 8 | Total benefit | $43.47 | $0.31 | $22.54 | $0.44 | $35.50 | $0.33 |
| 9 | Simple Payback | 35.29 | | 35.19 | | 27.03 | |

| | Option2a | PV1 | | PV2 | | PV3 | |
|---|---|---|---|---|---|---|---|
| | | $/m2 | $/Wp | $/m2 | $/Wp | $/m2 | $/Wp |
| 10 | PV module | $615.72 | $4.40 | $155.01 | $3.00 | $215.29 | $2.00 |
| 11 | Area-independent costs | $167.92 | $1.20 | $62.00 | $1.20 | $129.16 | $1.20 |
| 12 | Area-dependent costs | $228.63 | $1.63 | $228.63 | $4.42 | $228.63 | $2.12 |
| 13 | Material Credit | ($231.43) | ($1.65) | ($231.43) | ($4.48) | ($231.43) | ($2.15) |
| 14 | Total with markup & location factor | $1,020.99 | $7.30 | $280.09 | $5.42 | $446.73 | $4.15 |
| 15 | Value of PV output | $35.14 | $0.25 | $14.20 | $0.27 | $27.17 | $0.25 |
| 16 | Value of daylight/thermal benefits | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 17 | Total benefit | $35.14 | $0.25 | $14.21 | $0.28 | $27.17 | $0.25 |
| 18 | Simple Payback | 29.05 | | 19.72 | | 16.44 | |

*Table 12. Area-dependent and Area-independent cost and income components. Sample for options 2, 2a, Oakland location factors.*

years), an interesting comparison can be made between PV1 and PV2.

In general, PV1, high-cost, high-efficiency modules are best suited to installations where the rest of the area-dependent balance of system costs are high and area-dependent benefits are low. Table 12 uses the examples of options 2 and 2a to illustrate the relative value of area-dependent and area-independent costs to different PV technologies. The area-dependent costs (framing, insulated glazing unit fabrication, wiring) are worth $3.17/W for PV1, and $8.59/W for PV2, well over twice as much (lines 3 and 12). Conversely, the area-dependent income (credit for displaced construction materials and daylight/thermal benefits) are worth proportionally more for PV2 than PV1 (lines 4, 7, 13, 16).

Ultimately, the best payback times are achieved with the lowest cost/watt modules, although there are many situations where area-dependent balance of system costs will make high-cost/high-efficiency modules worthwhile. Building-integrated applications tend to favor the former, while standalone systems can justify the latter.

# PAYBACK ANALYSIS - CHARTS

The following six charts illustrate the payback periods from Tables 11 and 12, sorted by PV Technology. The data is presented in two ways: Full System (all costs and all types of energy benefits) and PV System Only (no construction costs for daylight & thermal systems, and no daylight/thermal benefits for Options 4, 5, and 5a).

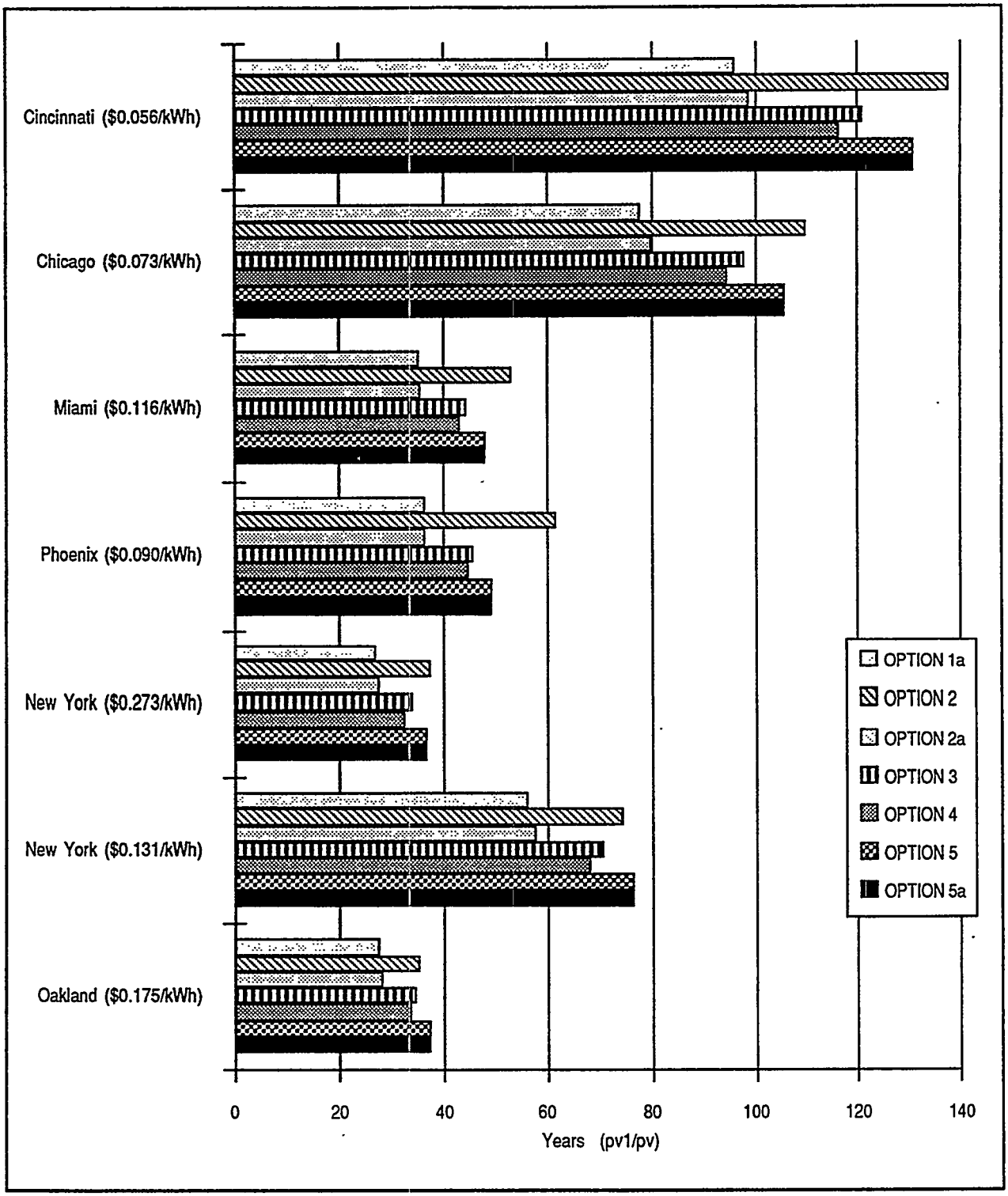



*Chart 13. PV1 Payback, PV System Only (140W/m2, $4.40/W).*

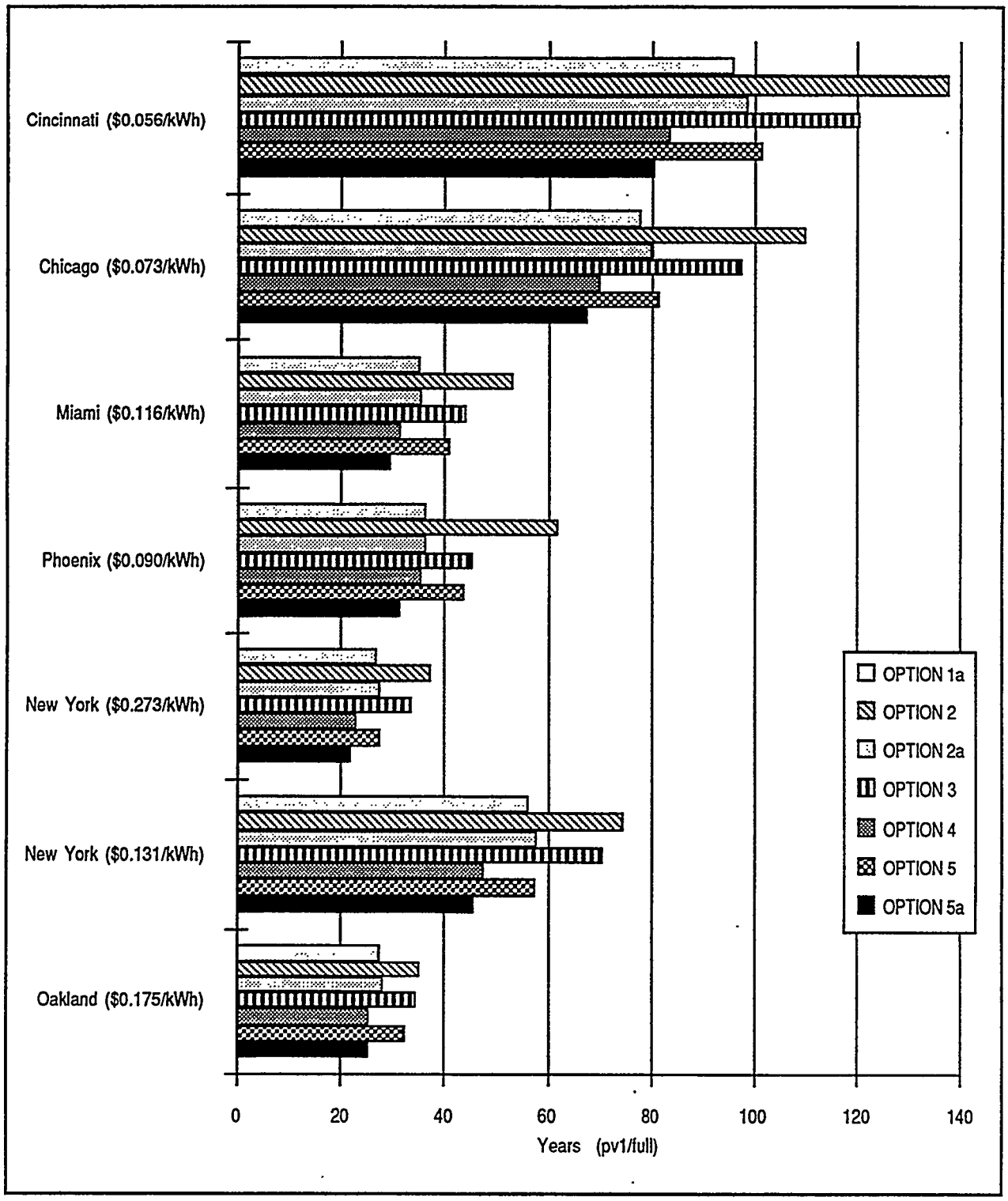



*Chart 14. PV1 Payback, Full System (140W/m2, $4.40/W). Includes daylight and thermal costs & benefits.*

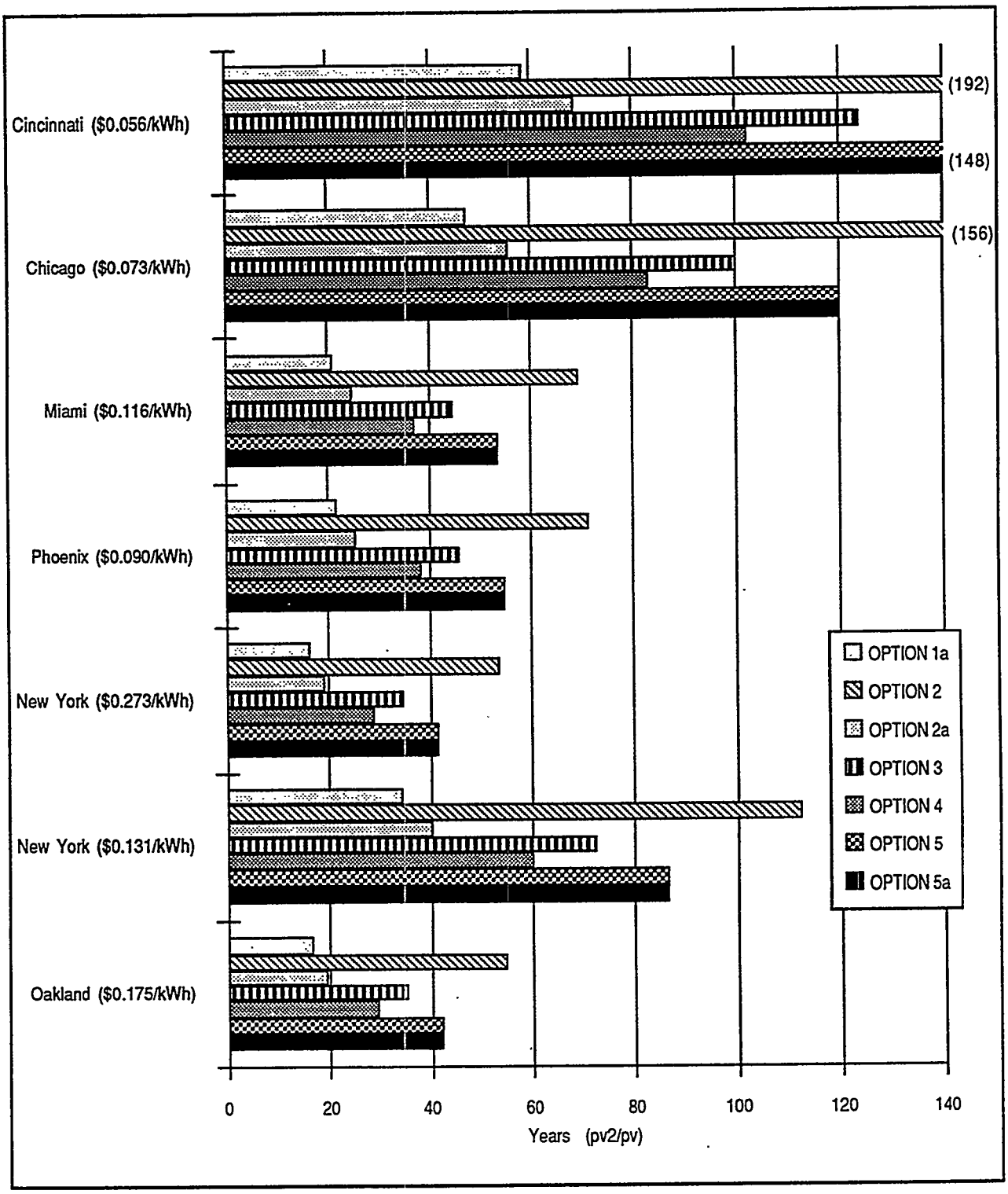



*Chart 15. PV2 Payback, PV System Only (52W/m2, $3.00/W).*

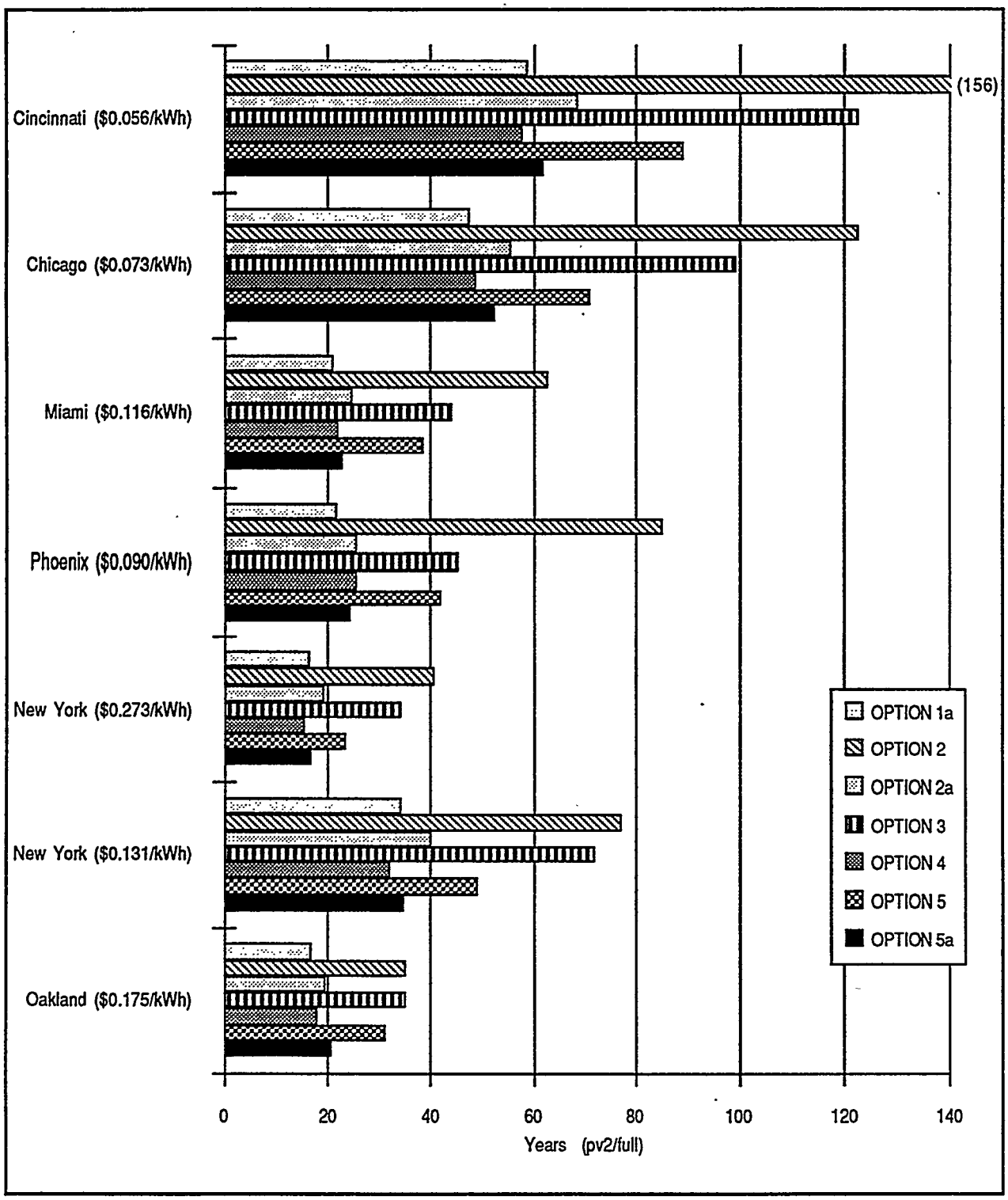



*Chart 16. PV2 Payback, Full System (52W/m2, $3.00/W). Includes daylight and thermal costs & benefits.*

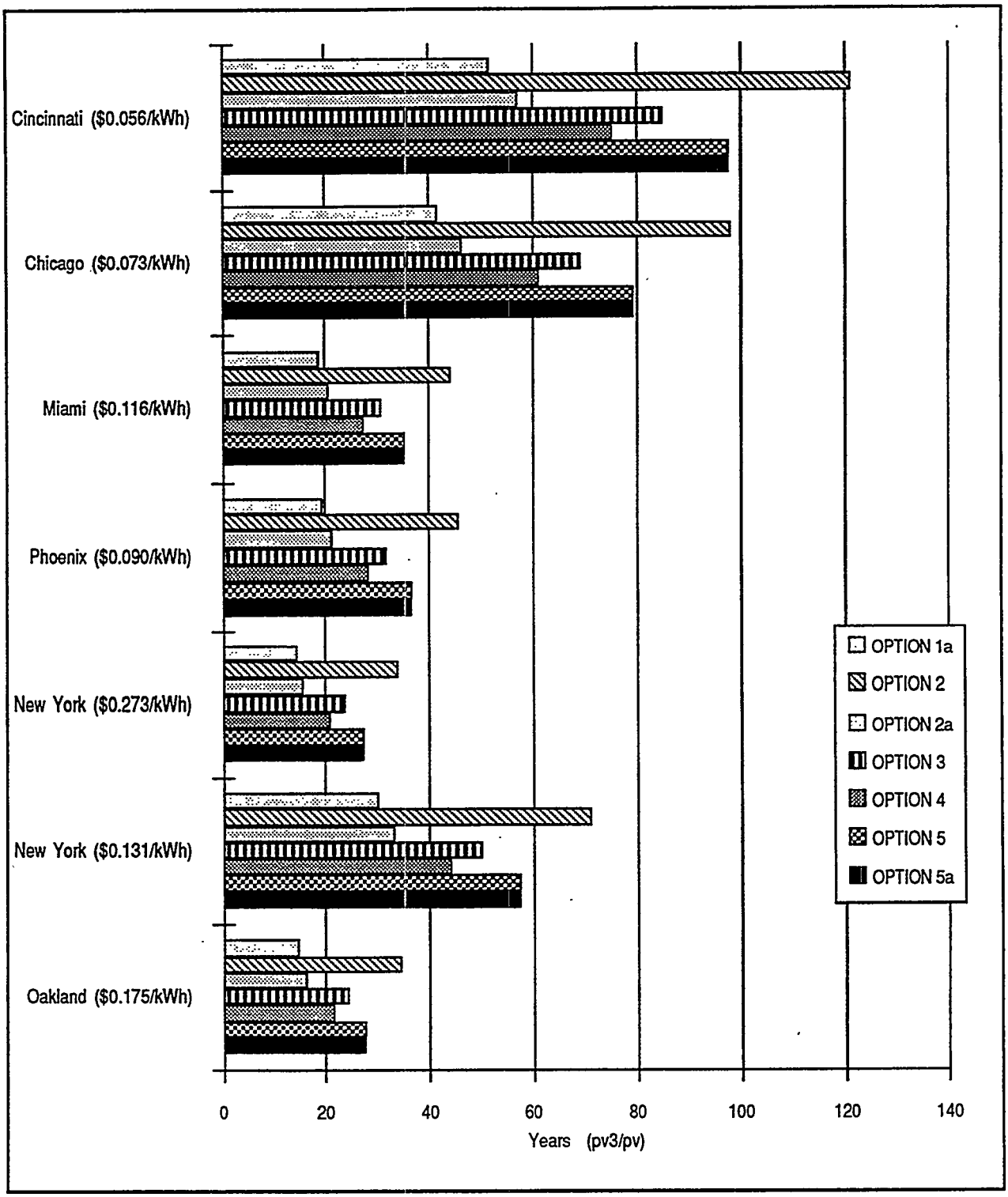



*Chart 17. PV3 Payback, PV System Only (108W/m2, $2.00/W).*

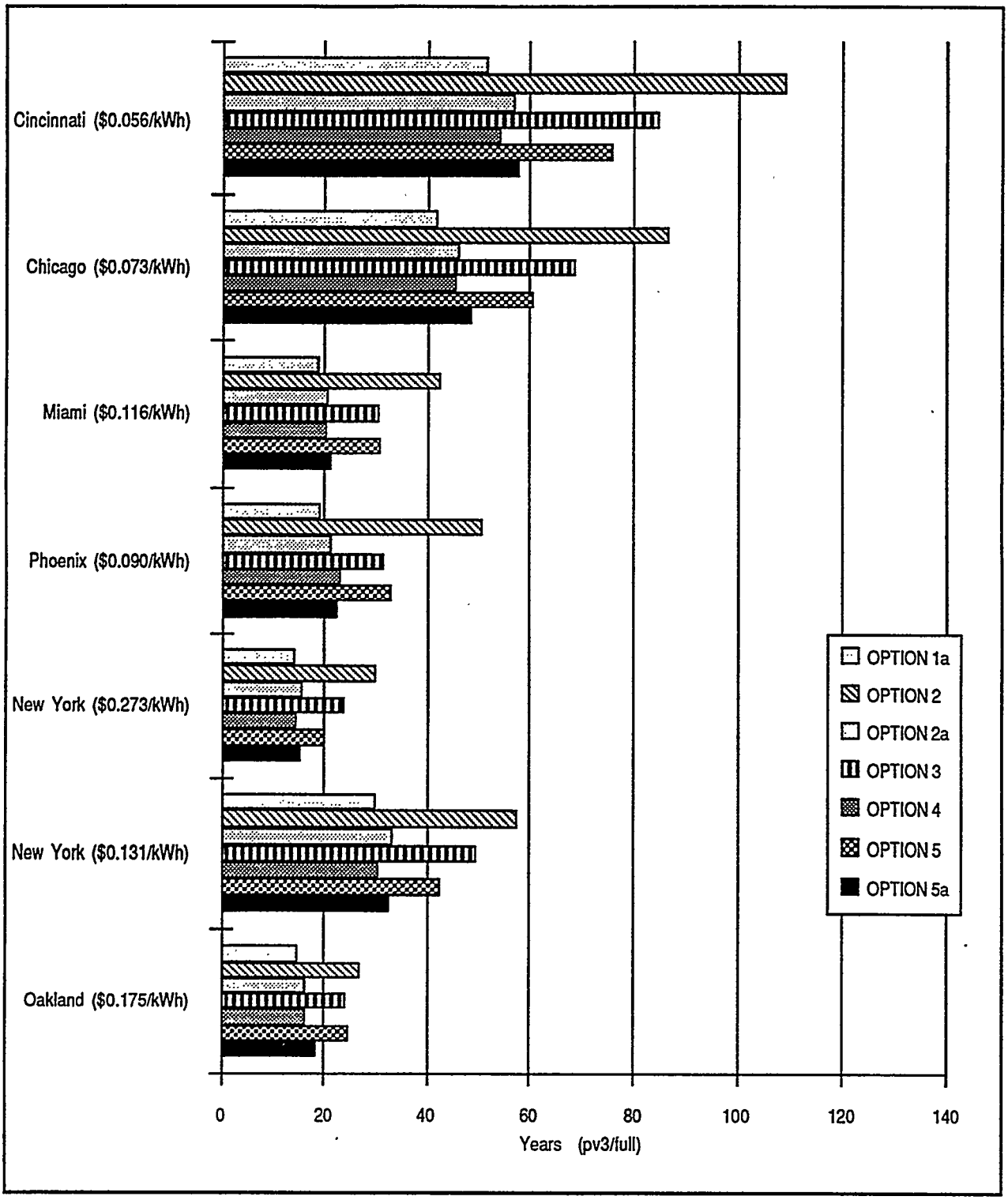



*Chart 18. PV3 Payback, Full System (108W/m2, $2.00/W). Includes daylight and thermal costs & benefits.*

# CONCLUSIONS:

- Some BIPV roof systems are economical today. With present day technologies and utility rates, several of the systems analyzed show pre-tax payback of 20 years or less; with tax savings included these payback periods could be less than 10 years.

- There is no existing PV technology that is best suited for all BIPV roof applications. With current technologies and prices, low efficiency and low *$/m2* PVs like amorphous silicon show a better return in cases where *area-dependent costs* (skylight framing systems, insulated glazing unit fabrication) are low and/or *area-dependent benefits* (construction material credits, daylighting and thermal benefits) are high. Conversely, high efficiency and high *$/W* PVs like crystalline silicon are better able to absorb area-dependent costs, and gain less by area-dependent benefits.

- The best payback on a PV-only basis (ignoring collateral energy benefits) is from installations such as atriums with high material credit and low additional construction cost.

- Direct rooftop integration, where the PV module serves as the weather barrier for the roof, is not presently cost effective in cases other than atrium applications. The value of the material credit for conventional roofing materials is too low to offset the considerable costs of the framing systems required to accommodate large-area glass-substrate modules. Price reductions in these systems, or the development of other cost-competitive integrated roofing systems (such as PV metal roofing or PV tiles), could make direct integration viable in a much broader range of roof types.

- The value of PV can be significantly enhanced by collateral energy benefits. In most commercial buildings, these benefits will be mostly from daylighting - thermal benefits are unlikely to be as great - for commercial buildings heating loads are a small portion of energy used. In cases where all the available thermal energy can be utilized, as in industrial processes with a large makeup air requirement, a very good payback can be achieved.

- The viability of BIPV roof installations varies greatly with location. The combination of climate, insolation and electric rates in Oakland result in pay-back periods over three times as short as those in Cincinnati.

- Advances in PV technology will significantly improve the economics of BIPV systems. The better economics of lower cost/higher efficiency modules is clearly shown in the progression from PV1 to PV3. Most experts agree that costs and efficiencies better than PV3 eventually will be achieved.

- As the costs of PV technologies drop, the relative value of other construction systems (skylight framing, wiring) will increase. Any decrease in the costs of these systems will become more important to the cost effectiveness of the BIPV system as a whole. Conversely, the value of material credits for displaced construction materials will increase.

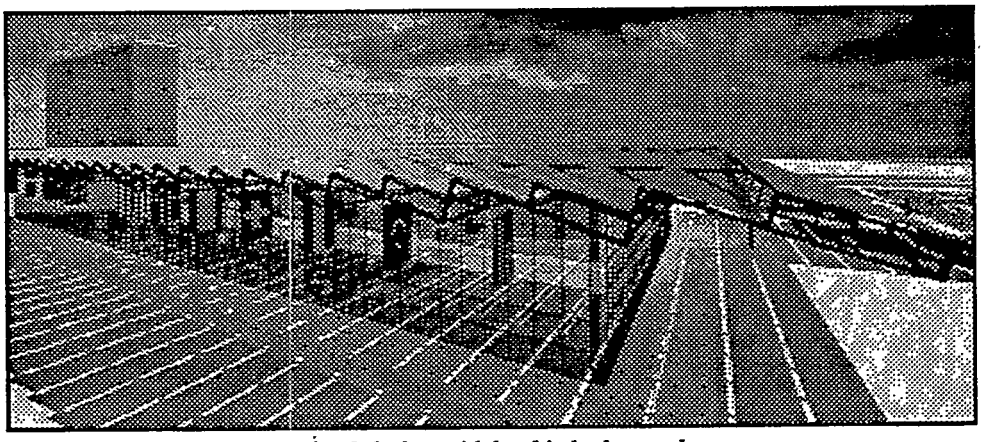


*Fig 30. Conference center roof and shadow with hotel in background.*

# RECOMMENDATIONS FOR FUTURE STUDY

**PRODUCT DEVELOPMENT:**

The construction cost estimates in this study are based on consultation with contractors, manufacturers, and on industry standard cost references. Since many of the BIPV products and applications evaluated have not been released as products, the cost estimates are preliminary. At present some of these products are being studied or developed; a compilation of ongoing development work would yield more reliable cost/performance data. Relevant research might include:

- Insulated PV glazing units
- Flush-glazed PV glazing units.
- Curtain wall extrusions with integral wiring raceways.
- Semitransparent PV window units in custom transparencies.
- Metal-substrate PV products for standing-seam roofing applications.
- Any development of products that will reduce the cost of PV-related construction elements (framing, wiring, etc.)

**RESEARCH:**

Other findings in this study should be investigated more thoroughly:

- The environmental analysis would benefit from detailed thermal evaluation of specific building designs including boundary conditions
- The payback analysis should include life cycle costs including O&M costs, present value calculations, and other parameters.
- More research should be done on utility rate structures and the effects of the inclusion of environmental externalities and T&D costs in electrical rates.

# PRINCIPAL SOURCES

Advanced Photovoltaic Systems, Inc., Princeton, NJ

Arthur D Little, Cambridge, MA

Ascension Technology, Inc., Lincoln Center, MA

Bell Products, Inc., Napa, CA

DeaMor, Inc., Vancouver, WA

Devcon Construction, Inc., Milpitas, CA

Energy Photovoltaics, Inc., Princeton, NJ

Gas Research Institute, Chicago, IL

New York Power Authority, NY, NY

Ove Arup & Partners New York, NY

Ove Arup & Partners San Francisco, CA

Pacific Gas and Electric, San Francisco, CA

Solar Design Associates, Harvard, MA

Viracon Corporation, Owatunna, MN

PV F-Chart Software, ©1992 S.A. Klein and W. Beckman

RS Means Construction Cost Data 1994, RS Means Co., Inc.

# APPENDICES

# A. PAYBACK ANALYSIS

The following charts detail the payback calculations for all the roof options and climates analyzed.

| | | PV1: 140W/ms @ $4.40/W | Oakland | New York 1 | New York 2 | Phoenix | Miami | Chicago | Cincinnati | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Av $/kWh | $0.175 | $0.131 | $0.273 | $0.090 | $0.116 | $0.073 | $0.056 | |
| | | Construction cost location fact | 1.14 | 1.24 | 1.24 | 0.90 | 0.87 | 1.06 | 0.95 | |
| OPTION 1 | 1 | Base system cost, $/m2 | $1,268.14 | $1,377.44 | $1,377.44 | $1,001.57 | $965.88 | $1,183.37 | $1,058.46 | |
| | 2 | Additional HVAC, $/m2 | $77.64 | $113.00 | $113.00 | $142.49 | $99.18 | $103.13 | $95.10 | |
| | 3 | Base system + HVAC | $1,345.78 | $1,490.44 | $1,490.44 | $1,144.06 | $1,065.07 | $1,286.51 | $1,153.56 | |
| | 4 | | | | | | | | | |
| | 5 | PV output | | | | | | | | |
| | 6 | kWh/m2/yr | 202.72 | 145.17 | 145.17 | 236.79 | 182.37 | 161.81 | 152.22 | |
| | 7 | $/m2/yr | $35.54 | $18.96 | $39.59 | $21.24 | $21.12 | $11.77 | $8.53 | |
| | 8 | **PV only payback, years** | **35.68** | **72.65** | **34.79** | **47.15** | **45.74** | **100.54** | **124.02** | **65.80** |
| | 9 | | | | | | | | | |
| | 10 | Lighting savings | | | | | | | | |
| | 11 | kWh/m2/yr | 61.64 | 59.33 | 59.33 | 67.54 | 62.65 | 56.89 | 56.61 | |
| | 12 | $/m2/yr | $10.81 | $7.75 | $16.18 | $6.06 | $7.25 | $4.14 | $3.17 | |
| | 13 | | | | | | | | | |
| | 14 | Thermal savings (loss) | | | | | | | | |
| | 15 | kWh/m2/yr | (118.29) | (165.92) | (165.92) | (334.16) | (246.37) | (185.52) | (200.35) | |
| | 16 | $/m2/yr | ($20.74) | ($21.67) | ($45.25) | ($29.97) | ($28.53) | ($13.49) | ($11.23) | |
| | 17 | | | | | | | | | |
| | 18 | PV+Lighting+Thermal | | | | | | | | |
| | 19 | kWh/m2/yr | 146.07 | 38.58 | 38.58 | (29.83) | (1.35) | 33.18 | 8.48 | |
| | 20 | $/m2/yr | $25.61 | $5.04 | $10.52 | ($2.68) | ($0.16) | $2.41 | $0.48 | |
| | 21 | **Combined payback, years** | **52.55** | **295.81** | **141.65** | **(427.53)** | **(6,788.64)** | **533.09** | **2,426.02** | **(538.15)** |
| OPTION 1a | 1 | System cost, $/m2 | $981.58 | $1,066.18 | $1,066.18 | $775.25 | $747.62 | $915.97 | $819.28 | |
| | 2 | | | | | | | | | |
| | 3 | PV output | | | | | | | | |
| | 4 | kWh/m2/yr | 202.72 | 145.17 | 145.17 | 236.79 | 182.37 | 161.81 | 152.22 | |
| | 5 | $/m2/yr | $35.54 | $18.96 | $39.59 | $21.24 | $21.12 | $11.77 | $8.53 | |
| | 6 | **Simple payback, years** | **27.62** | **56.24** | **26.93** | **36.50** | **35.41** | **77.82** | **96.00** | **50.93** |
| OPTION 2 | 1 | System cost, $/m2 | $1,521.49 | $1,652.63 | $1,652.63 | $1,201.67 | $1,158.85 | $1,419.79 | $1,269.91 | |
| | 2 | Additional HVAC, $/m2 | $12.49 | $22.79 | $113.00 | $35.78 | $22.19 | $20.79 | $20.02 | |
| | 3 | Base system + HVAC | $1,533.98 | $1,675.42 | $1,765.62 | $1,237.45 | $1,181.03 | $1,440.57 | $1,289.94 | |
| | 4 | | | | | | | | | |
| | 5 | PV output | | | | | | | | |
| | 6 | kWh/m2/yr | 200.44 | 143.81 | 143.81 | 233.80 | 180.28 | 160.20 | 150.75 | |
| | 7 | $/m2/yr | $35.14 | $18.78 | $39.22 | $20.97 | $20.87 | $11.65 | $8.45 | |
| | 8 | **PV only payback, years** | **43.30** | **87.99** | **42.14** | **57.30** | **55.52** | **121.84** | **150.26** | **79.76** |
| | 9 | | | | | | | | | |
| | 10 | Lighting savings | | | | | | | | |
| | 11 | kWh/m2/yr | 61.64 | 59.33 | 59.33 | 67.54 | 62.65 | 56.89 | 56.61 | |
| | 12 | $/m2/yr | $10.81 | $7.75 | $16.18 | $6.06 | $7.25 | $4.14 | $3.17 | |
| | 13 | | | | | | | | | |
| | 14 | Thermal savings (loss) | | | | | | | | |
| | 15 | kWh/m2/yr | (14.12) | (30.78) | (30.78) | (78.51) | (51.80) | (37.25) | (40.24) | |
| | 16 | $/m2/yr | ($2.48) | ($4.02) | ($8.39) | ($7.04) | ($6.00) | ($2.71) | ($2.26) | |
| | 17 | | | | | | | | | |
| | 18 | PV+Lighting+Thermal | | | | | | | | |
| | 19 | kWh/m2/yr | 247.96 | 172.36 | 172.36 | 222.83 | 191.13 | 179.84 | 167.12 | |
| | 20 | $/m2/yr | $43.47 | $22.51 | $47.01 | $19.99 | $22.13 | $13.08 | $9.37 | |
| | 21 | **Combined payback, years** | **35.29** | **74.43** | **37.56** | **61.91** | **53.37** | **110.12** | **137.67** | **72.91** |
| OPTION 2a | 1 | System cost, $/m2 | $1,020.99 | $1,108.99 | $1,108.99 | $806.37 | $777.64 | $952.74 | $852.17 | |
| | 2 | | | | | | | | | |
| | 3 | PV output | | | | | | | | |
| | 4 | kWh/m2/yr | 200.44 | 143.81 | 143.81 | 233.80 | 180.28 | 160.20 | 150.75 | |
| | 5 | $/m2/yr | $35.14 | $18.78 | $39.22 | $20.97 | $20.87 | $11.65 | $8.45 | |
| | 6 | **Simple payback, years** | **29.05** | **59.05** | **28.27** | **38.45** | **37.25** | **81.76** | **100.83** | **53.52** |

| | | *PV1: 140W/ms @ $4.40/W* | Oakland | New York 1 | New York 2 | Phoenix | Miami | Chicago | Cincinnati | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Av $/kWh | $0.175 | $0.131 | $0.273 | $0.090 | $0.116 | $0.073 | $0.056 | |
| | | Construction cost location fact | 1.14 | 1.24 | 1.24 | 0.90 | 0.87 | 1.06 | 0.95 | |
| OPTION 3 | 1 | System cost, $/m2 | $1,253.22 | $1,361.24 | $1,361.24 | $989.79 | $954.52 | $1,169.45 | $1,046.00 | |
| | 2 | | | | | | | | | |
| | 3 | | | | | | | | | |
| | 4 | PV output | | | | | | | | |
| | 5 | kWh/m2/yr | 205.74 | 146.97 | 146.97 | 240.76 | 185.13 | 163.94 | 154.18 | |
| | 6 | $/m2/yr | $36.07 | $19.19 | $40.08 | $21.60 | $21.44 | $11.93 | $8.64 | |
| | 7 | **PV only payback, years** | **34.74** | **70.92** | **33.96** | **45.83** | **44.53** | **98.07** | **121.01** | **64.15** |
| | 8 | | | | | | | | | |
| | 9 | | | | | | | | | |
| | 10 | Lighting savings | | | | | | | | |
| | 11 | kWh/m2/yr | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| | 12 | $/m2/yr | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | |
| | 13 | | | | | | | | | |
| | 14 | Thermal savings (loss) | | | | | | | | |
| | 15 | kWh/m2/yr | 0.45 | 0.53 | 0.53 | 1.21 | 0.97 | 0.55 | 0.65 | |
| | 16 | $/m2/yr | $0.08 | $0.07 | $0.14 | $0.11 | $0.11 | $0.04 | $0.04 | |
| | 17 | | | | | | | | | |
| | 18 | PV+Lighting+Thermal | | | | | | | | |
| | 19 | kWh/m2/yr | 206.19 | 147.50 | 147.50 | 241.97 | 186.10 | 164.49 | 154.83 | |
| | 20 | $/m2/yr | $36.15 | $19.26 | $40.23 | $21.70 | $21.55 | $11.97 | $8.68 | |
| | 21 | **Combined payback, years** | **34.67** | **70.67** | **33.84** | **45.60** | **44.30** | **97.74** | **120.50** | **63.90** |
| OPTION 4 | 1 | System cost, $/m2 | $1,307.39 | $1,420.08 | $1,420.08 | $1,032.57 | $995.78 | $1,220.00 | $1,091.22 | |
| | 2 | Additional HVAC, $/m2 | ($17.85) | ($16.14) | ($16.14) | ($7.81) | ($9.79) | ($13.59) | ($12.16) | |
| | 3 | Base system + HVAC | $1,289.54 | $1,403.94 | $1,403.94 | $1,024.77 | $985.99 | $1,206.41 | $1,079.06 | |
| | 4 | | | | | | | | | |
| | 5 | System cost, PV only, $/m2 | $1,151.88 | $1,251.17 | $1,251.17 | $909.75 | $877.34 | $1,074.89 | $961.42 | |
| | 6 | | | | | | | | | |
| | 7 | PV output | | | | | | | | |
| | 8 | kWh/m2/yr | 194.72 | 140.40 | 140.40 | 226.28 | 175.03 | 156.15 | 147.03 | |
| | 9 | $/m2/yr | $34.14 | $18.34 | $38.29 | $20.30 | $20.27 | $11.36 | $8.24 | |
| | 10 | **PV only payback, years** | **33.74** | **68.24** | **32.68** | **44.82** | **43.29** | **94.63** | **116.63** | **62.00** |
| | 11 | | | | | | | | | |
| | 12 | | | | | | | | | |
| | 13 | Lighting savings | | | | | | | | |
| | 14 | kWh/m2/yr | 61.64 | 59.33 | 59.33 | 67.54 | 62.65 | 56.89 | 56.61 | |
| | 15 | $/m2/yr | $10.81 | $7.75 | $16.18 | $6.06 | $7.25 | $4.14 | $3.17 | |
| | 16 | | | | | | | | | |
| | 17 | Thermal savings (loss) | | | | | | | | |
| | 18 | kWh/m2/yr | 33.54 | 25.65 | 25.65 | 27.84 | 30.59 | 24.38 | 26.06 | |
| | 19 | $/m2/yr | $5.88 | $3.35 | $7.00 | $2.50 | $3.54 | $1.77 | $1.46 | |
| | 20 | | | | | | | | | |
| | 21 | PV+Lighting+Thermal | | | | | | | | |
| | 22 | kWh/m2/yr | 289.90 | 225.38 | 225.38 | 321.66 | 268.27 | 237.42 | 229.70 | |
| | 23 | $/m2/yr | $50.83 | $29.43 | $61.47 | $28.85 | $31.06 | $17.27 | $12.88 | |
| | 24 | **Combined payback, years** | **25.37** | **47.70** | **22.84** | **35.52** | **31.74** | **69.86** | **83.79** | **45.26** |
| | 25 | | | | | | | | | |
| | 26 | Lighting+Thermal | $16.69 | $11.10 | $23.18 | $8.56 | $10.80 | $5.91 | $4.63 | |
| | 27 | **Lighitng/thermal payback, yrs** | **8.10** | **13.42** | **6.43** | **13.54** | **10.19** | **22.11** | **25.51** | **14.19** |

| | | PV1: 140W/ms @ $4.40/W | Oakland | New York 1 | New York 2 | Phoenix | Miami | Chicago | Cincinnati | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Av $/kWh | $0.175 | $0.131 | $0.273 | $0.090 | $0.116 | $0.073 | $0.056 | |
| | | Construction cost location fact | 1.14 | 1.24 | 1.24 | 0.90 | 0.87 | 1.06 | 0.95 | |
| OPTION 5 | 1 | System cost, $/m2 | $1,619.85 | $1,759.47 | $1,759.47 | $1,279.36 | $1,233.77 | $1,511.58 | $1,352.01 | |
| | 2 | Additional HVAC, $/m2 | ($17.85) | ($16.14) | ($16.14) | ($7.81) | ($9.79) | ($13.59) | ($12.16) | |
| | 3 | Base system + HVAC | $1,602.00 | $1,743.33 | $1,743.33 | $1,271.55 | $1,223.98 | $1,497.99 | $1,339.86 | |
| | 4 | | | | | | | | | |
| | 5 | System cost, PV only, $/m2 | $1,351.74 | $1,468.25 | $1,468.25 | $1,067.61 | $1,029.56 | $1,261.39 | $1,128.24 | |
| | 6 | | | | | | | | | |
| | 7 | PV output | | | | | | | | |
| | 8 | kWh/m2/yr | 204.96 | 146.51 | 146.51 | 239.74 | 184.42 | 163.39 | 153.68 | |
| | 9 | $/m2/yr | $35.93 | $19.13 | $39.96 | $21.50 | $21.35 | $11.89 | $8.62 | |
| | 10 | **PV only payback, years** | **37.62** | **76.74** | **36.75** | **49.64** | **48.21** | **106.13** | **130.95** | **69.43** |
| | 11 | | | | | | | | | |
| | 12 | Lighting savings | | | | | | | | |
| | 13 | kWh/m2/yr | 61.64 | 59.33 | 59.33 | 67.54 | 62.65 | 56.89 | 56.61 | |
| | 14 | $/m2/yr | $10.81 | $7.75 | $16.18 | $6.06 | $7.25 | $4.14 | $3.17 | |
| | 15 | | | | | | | | | |
| | 16 | Thermal savings (loss) | | | | | | | | |
| | 17 | kWh/m2/yr | 3.34 | 18.25 | 18.25 | 4.79 | 0.00 | 23.33 | 16.49 | |
| | 18 | $/m2/yr | $0.59 | $2.38 | $4.98 | $0.43 | $0.00 | $1.70 | $0.92 | |
| | 19 | | | | | | | | | |
| | 20 | PV+Lighting+Thermal | | | | | | | | |
| | 21 | kWh/m2/yr | 269.94 | 224.09 | 224.09 | 312.07 | 247.07 | 243.61 | 226.78 | |
| | 22 | $/m2/yr | $47.33 | $29.27 | $61.12 | $27.99 | $28.61 | $17.72 | $12.71 | |
| | 23 | **Combined payback, years** | **33.85** | **59.57** | **28.53** | **45.42** | **42.79** | **84.53** | **105.38** | **57.15** |
| | 24 | | | | | | | | | |
| | 25 | Max thermal savings (loss) | | | | | | | | |
| | 26 | kWh/m2/yr | 77.62 | 74.70 | 74.70 | 124.56 | 94.15 | 74.52 | 75.95 | |
| | 27 | $/m2/yr | $13.61 | $9.76 | $20.37 | $11.17 | $10.90 | $5.42 | $4.26 | |
| | 28 | | | | | | | | | |
| | 29 | PV+Lighting+Max thermal | | | | | | | | |
| | 30 | kWh/m2/yr | 344.22 | 280.54 | 280.54 | 431.84 | 341.22 | 294.80 | 286.24 | |
| | 31 | $/m2/yr | $60.35 | $36.64 | $76.51 | $38.74 | $39.51 | $21.44 | $16.05 | |
| | 32 | **Combined (max thermal), yrs** | **26.55** | **47.58** | **22.79** | **32.83** | **30.98** | **69.86** | **83.49** | **44.87** |
| | 33 | | | | | | | | | |
| | 34 | Lighitng+Thermal | $11.39 | $10.13 | $21.16 | $6.49 | $7.25 | $5.84 | $4.10 | |
| | 35 | **Lighitng/thermal payback, yrs** | **21.75** | **26.78** | **12.82** | **31.56** | **26.98** | **40.40** | **51.79** | **30.30** |
| | 36 | Lighitng +Max thermal | $24.42 | $17.50 | $36.55 | $17.23 | $18.16 | $9.56 | $7.43 | |
| | 37 | **Lighitng/max thermal pbk, yrs** | **10.15** | **15.50** | **7.42** | **11.88** | **10.78** | **24.66** | **28.56** | **15.56** |

| | | PV2: 52W/ms @ $3.00/W | Oakland | New York 1 | New York 2 | Phoenix | Miami | Chicago | Cincinnati | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Av $/kWh | $0.175 | $0.131 | $0.273 | $0.090 | $0.116 | $0.073 | $0.056 | |
| | | Construction cost location | 1.14 | 1.24 | 1.24 | 0.90 | 0.87 | 1.06 | 0.95 | |
| OPTION 1 | 1 | Base system cost, $/m2 | $527.24 | $572.69 | $572.69 | $416.41 | $401.58 | $492.00 | $440.06 | |
| | 2 | Additional HVAC, $/m2 | $77.64 | $113.00 | $113.00 | $142.49 | $99.18 | $103.13 | $95.10 | |
| | 3 | Base system + HVAC | $604.88 | $685.68 | $685.68 | $558.90 | $500.76 | $595.13 | $535.17 | |
| | 4 | | | | | | | | | |
| | 5 | PV output | | | | | | | | |
| | 6 | kWh/m2/yr | 81.63 | 58.18 | 58.18 | 97.03 | 74.52 | 64.83 | 61.06 | |
| | 7 | $/m2/yr | $14.31 | $7.60 | $15.87 | $8.70 | $8.63 | $4.72 | $3.42 | |
| | 8 | **PV only payback, years** | **36.84** | **75.38** | **36.10** | **47.84** | **46.54** | **104.32** | **128.55** | **67.94** |
| | 9 | | | | | | | | | |
| | 10 | Lighting savings | | | | | | | | |
| | 11 | kWh/m2/yr | 61.64 | 59.33 | 59.33 | 67.54 | 62.65 | 56.89 | 56.61 | |
| | 12 | $/m2/yr | $10.81 | $7.75 | $16.18 | $6.06 | $7.25 | $4.14 | $3.17 | |
| | 13 | | | | | | | | | |
| | 14 | Thermal savings (loss) | | | | | | | | |
| | 15 | kWh/m2/yr | (118.29) | (165.92) | (165.92) | (334.16) | (246.37) | (185.52) | (200.35) | |
| | 16 | $/m2/yr | ($20.74) | ($21.67) | ($45.25) | ($29.97) | ($28.53) | ($13.49) | ($11.23) | |
| | 17 | | | | | | | | | |
| | 18 | PV+Lighting+Thermal | | | | | | | | |
| | 19 | kWh/m2/yr | 24.98 | (48.42) | (48.42) | (169.59) | (109.20) | (63.80) | (82.68) | |
| | 20 | $/m2/yr | $4.38 | ($6.32) | ($13.20) | ($15.21) | ($12.64) | ($4.64) | ($4.64) | |
| | 21 | **Combined payback, years** | **138.10** | **(108.45)** | **(51.93)** | **(36.74)** | **(39.60)** | **(128.25)** | **(115.45)** | **(48.90)** |
| OPTION 1a | 1 | System cost, $/m2 | $240.68 | $261.42 | $261.42 | $190.09 | $183.31 | $224.59 | $200.88 | |
| | 2 | | | | | | | | | |
| | 3 | PV output | | | | | | | | |
| | 4 | kWh/m2/yr | 81.63 | 58.18 | 58.18 | 97.03 | 74.52 | 64.83 | 61.06 | |
| | 5 | $/m2/yr | $14.31 | $7.60 | $15.87 | $8.70 | $8.63 | $4.72 | $3.42 | |
| | 6 | **Simple payback, years** | **16.82** | **34.41** | **16.48** | **21.84** | **21.25** | **47.62** | **58.68** | **31.01** |
| OPTION 2 | 1 | System cost, $/m2 | $780.59 | $847.87 | $847.87 | $616.51 | $594.54 | $728.41 | $651.52 | |
| | 2 | Additional HVAC, $/m2 | $12.49 | $22.79 | $113.00 | $35.78 | $22.19 | $20.79 | $20.02 | |
| | 3 | Base system + HVAC | $793.08 | $870.66 | $960.87 | $652.29 | $616.72 | $749.20 | $671.54 | |
| | 4 | | | | | | | | | |
| | 5 | PV output | | | | | | | | |
| | 6 | kWh/m2/yr | 81.01 | 57.80 | 57.80 | 96.21 | 73.95 | 64.39 | 60.66 | |
| | 7 | $/m2/yr | $14.20 | $7.55 | $15.76 | $8.63 | $8.56 | $4.68 | $3.40 | |
| | 8 | **PV only payback, years** | **54.96** | **112.31** | **53.78** | **71.43** | **69.44** | **155.51** | **191.59** | **101.29** |
| | 9 | | | | | | | | | |
| | 10 | Lighting savings | | | | | | | | |
| | 11 | kWh/m2/yr | 61.64 | 59.33 | 59.33 | 67.54 | 62.65 | 56.89 | 56.61 | |
| | 12 | $/m2/yr | $10.81 | $7.75 | $16.18 | $6.06 | $7.25 | $4.14 | $3.17 | |
| | 13 | | | | | | | | | |
| | 14 | Thermal savings (loss) | | | | | | | | |
| | 15 | kWh/m2/yr | (14.12) | (30.78) | (30.78) | (78.51) | (51.80) | (37.25) | (40.24) | |
| | 16 | $/m2/yr | ($2.48) | ($4.02) | ($8.39) | ($7.04) | ($6.00) | ($2.71) | ($2.26) | |
| | 17 | | | | | | | | | |
| | 18 | PV+Lighting+Thermal | | | | | | | | |
| | 19 | kWh/m2/yr | 128.53 | 86.35 | 86.35 | 85.24 | 84.80 | 84.03 | 77.03 | |
| | 20 | $/m2/yr | $22.53 | $11.28 | $23.55 | $7.65 | $9.82 | $6.11 | $4.32 | |
| | 21 | **Combined payback, years** | **35.19** | **77.20** | **40.80** | **85.31** | **62.81** | **122.57** | **155.50** | **82.77** |
| OPTION 2a | 1 | System cost, $/m2 | $280.09 | $304.23 | $304.23 | $221.21 | $213.33 | $261.37 | $233.78 | |
| | 2 | | | | | | | | | |
| | 3 | PV output | | | | | | | | |
| | 4 | kWh/m2/yr | 81.01 | 57.80 | 57.80 | 96.21 | 73.95 | 64.39 | 60.66 | |
| | 5 | $/m2/yr | $14.20 | $7.55 | $15.76 | $8.63 | $8.56 | $4.68 | $3.40 | |
| | 6 | **Simple payback, years** | **19.72** | **40.30** | **19.30** | **25.63** | **24.92** | **55.80** | **68.74** | **36.34** |

| | | PV1: 140W/ms @ $4.40/ | Oakland | New York 1 | New York 2 | Phoenix | Miami | Chicago | Cincinnati | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Av $/kWh | $0.175 | $0.131 | $0.273 | $0.090 | $0.116 | $0.073 | $0.056 | |
| | | Construction cost location | 1.14 | 1.24 | 1.24 | 0.90 | 0.87 | 1.06 | 0.95 | |
| OPTION 3 | 1 | System cost, $/m2 | $512.32 | $556.48 | $556.48 | $404.63 | $390.21 | $478.08 | $427.61 | |
| | 2 | | | | | | | | | |
| | 3 | | | | | | | | | |
| | 4 | PV output | | | | | | | | |
| | 5 | kWh/m2/yr | 82.46 | 58.67 | 58.67 | 98.12 | 75.28 | 65.42 | 61.60 | |
| | 6 | $/m2/yr | $14.46 | $7.66 | $16.00 | $8.80 | $8.72 | $4.76 | $3.45 | |
| | 7 | **PV only payback, years** | **35.44** | **72.63** | **34.78** | **45.97** | **44.77** | **100.47** | **123.82** | **65.41** |
| | 8 | | | | | | | | | |
| | 9 | | | | | | | | | |
| | 10 | Lighting savings | | | | | | | | |
| | 11 | kWh/m2/yr | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| | 12 | $/m2/yr | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | |
| | 13 | | | | | | | | | |
| | 14 | Thermal savings (loss) | | | | | | | | |
| | 15 | kWh/m2/yr | 0.45 | 0.53 | 0.53 | 1.21 | 0.97 | 0.55 | 0.65 | |
| | 16 | $/m2/yr | $0.08 | $0.07 | $0.14 | $0.11 | $0.11 | $0.04 | $0.04 | |
| | 17 | | | | | | | | | |
| | 18 | PV+Lighting+Thermal | | | | | | | | |
| | 19 | kWh/m2/yr | 82.91 | 59.20 | 59.20 | 99.33 | 76.25 | 65.97 | 62.25 | |
| | 20 | $/m2/yr | $14.54 | $7.73 | $16.14 | $8.91 | $8.83 | $4.80 | $3.49 | |
| | 21 | **Combined payback, years** | **35.25** | **71.98** | **34.47** | **45.41** | **44.20** | **99.63** | **122.53** | **64.78** |
| OPTION 4 | 1 | System cost, $/m2 | $566.49 | $615.32 | $615.32 | $447.42 | $431.47 | $528.63 | $472.83 | |
| | 2 | Additional HVAC, $/m2 | ($17.85) | ($16.14) | ($16.14) | ($7.81) | ($9.79) | ($13.59) | ($12.16) | |
| | 3 | Base system + HVAC | $548.65 | $599.18 | $599.18 | $439.61 | $421.68 | $515.04 | $460.67 | |
| | 4 | | | | | | | | | |
| | 5 | System cost, PV only, $/m | $410.98 | $446.41 | $446.41 | $324.59 | $313.03 | $383.51 | $343.03 | |
| | 6 | | | | | | | | | |
| | 7 | PV output | | | | | | | | |
| | 8 | kWh/m2/yr | 79.45 | 56.87 | 56.87 | 94.15 | 72.51 | 63.29 | 59.64 | |
| | 9 | $/m2/yr | $13.93 | $7.43 | $15.51 | $8.45 | $8.40 | $4.60 | $3.34 | |
| | 10 | **PV only payback, years** | **29.51** | **60.11** | **28.78** | **38.43** | **37.28** | **83.31** | **102.59** | **54.29** |
| | 11 | | | | | | | | | |
| | 12 | | | | | | | | | |
| | 13 | Lighting savings | | | | | | | | |
| | 14 | kWh/m2/yr | 61.64 | 59.33 | 59.33 | 67.54 | 62.65 | 56.89 | 56.61 | |
| | 15 | $/m2/yr | $10.81 | $7.75 | $16.18 | $6.06 | $7.25 | $4.14 | $3.17 | |
| | 16 | | | | | | | | | |
| | 17 | Thermal savings (loss) | | | | | | | | |
| | 18 | kWh/m2/yr | 33.54 | 25.65 | 25.65 | 27.84 | 30.59 | 24.38 | 26.06 | |
| | 19 | $/m2/yr | $5.88 | $3.35 | $7.00 | $2.50 | $3.54 | $1.77 | $1.46 | |
| | 20 | | | | | | | | | |
| | 21 | PV+Lighting+Thermal | | | | | | | | |
| | 22 | kWh/m2/yr | 174.63 | 141.85 | 141.85 | 189.53 | 165.75 | 144.56 | 142.31 | |
| | 23 | $/m2/yr | $30.62 | $18.53 | $38.69 | $17.00 | $19.19 | $10.52 | $7.98 | |
| | 24 | **Combined payback, years** | **17.92** | **32.34** | **15.49** | **25.86** | **21.97** | **48.98** | **57.74** | **31.47** |

| | | PV1: 140W/ms @ $4.40/ | Oakland | New York 1 | New York 2 | Phoenix | Miami | Chicago | Cincinnati | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Av $/kWh | $0.175 | $0.131 | $0.273 | $0.090 | $0.116 | $0.073 | $0.056 | |
| | | Construction cost location | 1.14 | 1.24 | 1.24 | 0.90 | 0.87 | 1.06 | 0.95 | |
| OPTION 5 | 1 | System cost, $/m2 | $878.95 | $954.71 | $954.71 | $694.20 | $669.46 | $820.20 | $733.62 | |
| | 2 | Additional HVAC, $/m2 | ($17.85) | ($16.14) | ($16.14) | ($7.81) | ($9.79) | ($13.59) | ($12.16) | |
| | 3 | Base system + HVAC | $861.11 | $938.57 | $938.57 | $686.39 | $659.67 | $806.61 | $721.47 | |
| | 4 | | | | | | | | | |
| | 5 | System cost, PV only, $/m | $610.85 | $663.50 | $663.50 | $482.45 | $465.25 | $570.02 | $509.84 | |
| | 6 | | | | | | | | | |
| | 7 | PV output | | | | | | | | |
| | 8 | kWh/m2/yr | 82.25 | 58.54 | 58.54 | 97.84 | 75.08 | 65.27 | 61.46 | |
| | 9 | $/m2/yr | $14.42 | $7.65 | $15.97 | $8.78 | $8.69 | $4.75 | $3.45 | |
| | 10 | **PVonlypayback,years** | **42.36** | **86.78** | **41.56** | **54.97** | **53.52** | **120.06** | **147.97** | **78.17** |
| | 11 | | | | | | | | | |
| | 12 | Lighting savings | | | | | | | | |
| | 13 | kWh/m2/yr | 61.64 | 59.33 | 59.33 | 67.54 | 62.65 | 56.89 | 56.61 | |
| | 14 | $/m2/yr | $10.81 | $7.75 | $16.18 | $6.06 | $7.25 | $4.14 | $3.17 | |
| | 15 | | | | | | | | | |
| | 16 | Thermal savings (loss) | | | | | | | | |
| | 17 | kWh/m2/yr | 3.34 | 18.25 | 18.25 | 4.79 | 0.00 | 23.33 | 16.49 | |
| | 18 | $/m2/yr | $0.59 | $2.38 | $4.98 | $0.43 | $0.00 | $1.70 | $0.92 | |
| | 19 | | | | | | | | | |
| | 20 | PV+Lighting+Thermal | | | | | | | | |
| | 21 | kWh/m2/yr | 147.23 | 136.12 | 136.12 | 170.17 | 137.73 | 145.49 | 134.56 | |
| | 22 | $/m2/yr | $25.81 | $17.78 | $37.12 | $15.26 | $15.95 | $10.58 | $7.54 | |
| | 23 | **Combinedpayback,years** | **33.36** | **52.80** | **25.28** | **44.97** | **41.37** | **76.22** | **95.63** | **52.80** |
| | 24 | | | | | | | | | |
| | 25 | Max thermal savings (loss) | | | | | | | | |
| | 26 | kWh/m2/yr | 77.62 | 74.70 | 74.70 | 124.56 | 94.15 | 74.52 | 75.95 | |
| | 27 | $/m2/yr | $13.61 | $9.76 | $20.37 | $11.17 | $10.90 | $5.42 | $4.26 | |
| | 28 | | | | | | | | | |
| | 29 | PV+Lighting+Max thermal | | | | | | | | |
| | 30 | kWh/m2/yr | 221.51 | 192.57 | 192.57 | 289.94 | 231.88 | 196.68 | 194.02 | |
| | 31 | $/m2/yr | $38.84 | $25.15 | $52.52 | $26.01 | $26.85 | $14.31 | $10.88 | |
| | 32 | **Combined(maxthermal),y** | **22.17** | **37.32** | **17.87** | **26.39** | **24.57** | **56.38** | **66.32** | **35.86** |

| | | PV3: 108W/ms @ $2.00/ | Oakland | New York 1 | New York 2 | Phoenix | Miami | Chicago | Cincinnati | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Av $/kWh | $0.175 | $0.131 | $0.273 | $0.090 | $0.116 | $0.073 | $0.056 | |
| | | Construction cost location | 1.14 | 1.24 | 1.24 | 0.90 | 0.87 | 1.06 | 0.95 | |
| OPTION 1 | 1 | Base system cost, $/m2 | $693.89 | $753.70 | $753.70 | $548.03 | $528.50 | $647.51 | $579.16 | |
| | 2 | Additional HVAC, $/m2 | $77.64 | $113.00 | $113.00 | $142.49 | $99.18 | $103.13 | $95.10 | |
| | 3 | Base system + HVAC | $771.53 | $866.69 | $866.69 | $690.52 | $627.69 | $750.64 | $674.26 | |
| | 4 | | | | | | | | | |
| | 5 | PV output | | | | | | | | |
| | 6 | kWh/m2/yr | 156.46 | 111.77 | 111.77 | 184.37 | 141.79 | 124.58 | 117.26 | |
| | 7 | $/m2/yr | $27.43 | $14.60 | $30.48 | $16.54 | $16.42 | $9.06 | $6.57 | |
| | 8 | **PV only payback, years** | **25.30** | **51.63** | **24.72** | **33.14** | **32.19** | **71.46** | **88.10** | **46.65** |
| | 9 | | | | | | | | | |
| | 10 | Lighting savings | | | | | | | | |
| | 11 | kWh/m2/yr | 61.64 | 59.33 | 59.33 | 67.54 | 62.65 | 56.89 | 56.61 | |
| | 12 | $/m2/yr | $10.81 | $7.75 | $16.18 | $6.06 | $7.25 | $4.14 | $3.17 | |
| | 13 | | | | | | | | | |
| | 14 | Thermal savings (loss) | | | | | | | | |
| | 15 | kWh/m2/yr | (118.29) | (165.92) | (165.92) | (334.16) | (246.37) | (185.52) | (200.35) | |
| | 16 | $/m2/yr | ($20.74) | ($21.67) | ($45.25) | ($29.97) | ($28.53) | ($13.49) | ($11.23) | |
| | 17 | | | | | | | | | |
| | 18 | PV+Lighting+Thermal | | | | | | | | |
| | 19 | kWh/m2/yr | 99.81 | 5.18 | 5.18 | (82.25) | (41.93) | (4.05) | (26.48) | |
| | 20 | $/m2/yr | $17.50 | $0.68 | $1.41 | ($7.38) | ($4.85) | ($0.29) | ($1.48) | |
| | 21 | **Combined payback, years** | **44.09** | **1,280.41** | **613.14** | **(93.59)** | **(129.30)** | **(2,544.86)** | **(454.13)** | **(183.46)** |
| OPTION 1a | 1 | System cost, $/m2 | $407.33 | $442.43 | $442.43 | $321.70 | $310.24 | $380.10 | $339.97 | |
| | 2 | | | | | | | | | |
| | 3 | PV output | | | | | | | | |
| | 4 | kWh/m2/yr | 156.46 | 111.77 | 111.77 | 184.37 | 141.79 | 124.58 | 117.26 | |
| | 5 | $/m2/yr | $27.43 | $14.60 | $30.48 | $16.54 | $16.42 | $9.06 | $6.57 | |
| | 6 | **Simple payback, years** | **14.85** | **30.31** | **14.51** | **19.45** | **18.90** | **41.95** | **51.71** | **27.38** |
| OPTION 2 | 1 | System cost, $/m2 | $947.23 | $1,028.88 | $1,028.88 | $748.12 | $721.46 | $883.92 | $790.61 | |
| | 2 | Additional HVAC, $/m2 | $12.49 | $22.79 | $113.00 | $35.78 | $22.19 | $20.79 | $20.02 | |
| | 3 | Base system + HVAC | $959.73 | $1,051.67 | $1,141.88 | $783.91 | $743.65 | $904.71 | $810.63 | |
| | 4 | | | | | | | | | |
| | 5 | PV output | | | | | | | | |
| | 6 | kWh/m2/yr | 154.99 | 110.89 | 110.89 | 182.43 | 140.44 | 123.53 | 116.30 | |
| | 7 | $/m2/yr | $27.17 | $14.48 | $30.24 | $16.36 | $16.26 | $8.99 | $6.52 | |
| | 8 | **PV only payback, years** | **34.86** | **71.04** | **34.02** | **45.72** | **44.37** | **98.37** | **121.25** | **64.23** |
| | 9 | | | | | | | | | |
| | 10 | Lighting savings | | | | | | | | |
| | 11 | kWh/m2/yr | 61.64 | 59.33 | 59.33 | 67.54 | 62.65 | 56.89 | 56.61 | |
| | 12 | $/m2/yr | $10.81 | $7.75 | $16.18 | $6.06 | $7.25 | $4.14 | $3.17 | |
| | 13 | | | | | | | | | |
| | 14 | Thermal savings (loss) | | | | | | | | |
| | 15 | kWh/m2/yr | (14.12) | (30.78) | (30.78) | (78.51) | (51.80) | (37.25) | (40.24) | |
| | 16 | $/m2/yr | ($2.48) | ($4.02) | ($8.39) | ($7.04) | ($6.00) | ($2.71) | ($2.26) | |
| | 17 | | | | | | | | | |
| | 18 | PV+Lighting+Thermal | | | | | | | | |
| | 19 | kWh/m2/yr | 202.51 | 139.44 | 139.44 | 171.46 | 151.29 | 143.17 | 132.67 | |
| | 20 | $/m2/yr | $35.50 | $18.21 | $38.03 | $15.38 | $17.52 | $10.41 | $7.44 | |
| | 21 | **Combined payback, years** | **27.03** | **57.75** | **30.03** | **50.97** | **42.45** | **86.87** | **108.98** | **57.73** |
| OPTION 2a | 1 | System cost, $/m2 | $446.73 | $485.24 | $485.24 | $352.83 | $340.26 | $416.87 | $372.87 | |
| | 2 | | | | | | | | | |
| | 3 | PV output | | | | | | | | |
| | 4 | kWh/m2/yr | 154.99 | 110.89 | 110.89 | 182.43 | 140.44 | 123.53 | 116.30 | |
| | 5 | $/m2/yr | $27.17 | $14.48 | $30.24 | $16.36 | $16.26 | $8.99 | $6.52 | |
| | 6 | **Simple payback, years** | **16.44** | **33.51** | **16.04** | **21.56** | **20.92** | **46.39** | **57.18** | **30.29** |

| | | PV1: 140W/ms @ $4.40/ | Oakland | New York 1 | New York 2 | Phoenix | Miami | Chicago | Cincinnati. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Av $/kWh | $0.175 | $0.131 | $0.273 | $0.090 | $0.116 | $0.073 | $0.056 | |
| | | Construction cost location | 1.14 | 1.24 | 1.24 | 0.90 | 0.87 | 1.06 | 0.95 | |
| OPTION 3 | 1 | System cost, $/m2 | $678.97 | $737.49 | $737.49 | $536.25 | $517.14 | $633.58 | $566.70 | |
| | 2 | | | | | | | | | |
| | 3 | | | | | | | | | |
| | 4 | PV output | | | | | | | | |
| | 5 | kWh/m2/yr | 158.42 | 112.94 | 112.94 | 186.94 | 143.59 | 125.96 | 118.53 | |
| | 6 | $/m2/yr | $27.77 | $14.75 | $30.80 | $16.77 | $16.63 | $9.16 | $6.65 | |
| | 7 | **PVonlypayback,years** | **24.45** | **50.00** | **23.94** | **31.98** | **31.11** | **69.15** | **85.28** | **45.13** |
| | 8 | | | | | | | | | |
| | 9 | | | | | | | | | |
| | 10 | Lighting savings | | | | | | | | |
| | 11 | kWh/m2/yr | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| | 12 | $/m2/yr | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | |
| | 13 | | | | | | | | | |
| | 14 | Thermal savings (loss) | | | | | | | | |
| | 15 | kWh/m2/yr | 0.45 | 0.53 | 0.53 | 1.21 | 0.97 | 0.55 | 0.65 | |
| | 16 | $/m2/yr | $0.08 | $0.07 | $0.14 | $0.11 | $0.11 | $0.04 | $0.04 | |
| | 17 | | | | | | | | | |
| | 18 | PV+Lighting+Thermal | | | | | | | | |
| | 19 | kWh/m2/yr | 158.87 | 113.47 | 113.47 | 188.15 | 144.56 | 126.51 | 119.18 | |
| | 20 | $/m2/yr | $27.85 | $14.82 | $30.95 | $16.88 | $16.74 | $9.20 | $6.68 | |
| | 21 | **Combinedpayback,years** | **24.38** | **49.77** | **23.83** | **31.77** | **30.90** | **68.85** | **84.81** | **44.90** |
| OPTION 4 | 1 | System cost, $/m2 | $733.14 | $796.33 | $796.33 | $579.03 | $558.40 | $684.13 | $611.92 | |
| | 2 | Additional HVAC, $/m2 | ($17.85) | ($16.14) | ($16.14) | ($7.81) | ($9.79) | ($13.59) | ($12.16) | |
| | 3 | Base system + HVAC | $715.29 | $780.19 | $780.19 | $571.22 | $548.61 | $670.54 | $599.76 | |
| | 4 | | | | | | | | | |
| | 5 | System cost, PV only, $/m | $577.63 | $627.42 | $627.42 | $456.21 | $439.95 | $539.02 | $482.12 | |
| | 6 | | | | | | | | | |
| | 7 | PV output | | | | | | | | |
| | 8 | kWh/m2/yr | 151.29 | 108.68 | 108.68 | 177.56 | 137.04 | 120.91 | 113.90 | |
| | 9 | $/m2/yr | $26.52 | $14.19 | $29.64 | $15.93 | $15.87 | $8.80 | $6.39 | |
| | 10 | **PVonlypayback,years** | **21.78** | **44.20** | **21.17** | **28.64** | **27.73** | **61.29** | **75.50** | **40.04** |
| | 11 | | | | | | | | | |
| | 12 | | | | | | | | | |
| | 13 | Lighting savings | | | | | | | | |
| | 14 | kWh/m2/yr | 61.64 | 59.33 | 59.33 | 67.54 | 62.65 | 56.89 | 56.61 | |
| | 15 | $/m2/yr | $10.81 | $7.75 | $16.18 | $6.06 | $7.25 | $4.14 | $3.17 | |
| | 16 | | | | | | | | | |
| | 17 | Thermal savings (loss) | | | | | | | | |
| | 18 | kWh/m2/yr | 33.54 | 25.65 | 25.65 | 27.84 | 30.59 | 24.38 | 26.06 | |
| | 19 | $/m2/yr | $5.88 | $3.35 | $7.00 | $2.50 | $3.54 | $1.77 | $1.46 | |
| | 20 | | | | | | | | | |
| | 21 | PV+Lighting+Thermal | | | | | | | | |
| | 22 | kWh/m2/yr | 246.47 | 193.66 | 193.66 | 272.94 | 230.28 | 202.18 | 196.57 | |
| | 23 | $/m2/yr | $43.21 | $25.29 | $52.82 | $24.48 | $26.66 | $14.71 | $11.02 | |
| | 24 | **Combinedpayback,years** | **16.55** | **30.85** | **14.77** | **23.33** | **20.58** | **45.59** | **54.42** | **29.44** |

| | | PV1: 140W/ms @ $4.40/ | Oakland | New York 1 | New York 2 | Phoenix | Miami | Chicago | Cincinnati | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Av $/kWh | $0.175 | $0.131 | $0.273 | $0.090 | $0.116 | $0.073 | $0.056 | |
| | | Construction cost location | 1.14 | 1.24 | 1.24 | 0.90 | 0.87 | 1.06 | 0.95 | |
| OPTION 5 | 1 | System cost, $/m2 | $1,045.60 | $1,135.72 | $1,135.72 | $825.81 | $796.38 | $975.71 | $872.71 | |
| | 2 | Additional HVAC, $/m2 | ($17.85) | ($16.14) | ($16.14) | ($7.81) | ($9.79) | ($13.59) | ($12.16) | |
| | 3 | Base system + HVAC | $1,027.75 | $1,119.58 | $1,119.58 | $818.01 | $786.60 | $962.12 | $860.56 | |
| | 4 | | | | | | | | | |
| | 5 | System cost, PV only, $/m | $777.49 | $844.51 | $844.51 | $614.06 | $592.18 | $725.52 | $648.94 | |
| | 6 | | | | | | | | | |
| | 7 | PV output | | | | | | | | |
| | 8 | kWh/m2/yr | 157.92 | 112.64 | 112.64 | 186.28 | 143.13 | 125.60 | 118.20 | |
| | 9 | $/m2/yr | $27.69 | $14.71 | $30.72 | $16.71 | $16.57 | $9.14 | $6.63 | |
| | 10 | **PVonlypayback,years** | **28.08** | **57.41** | **27.49** | **36.75** | **35.73** | **79.41** | **97.92** | **51.83** |
| | 11 | | | | | | | | | |
| | 12 | Lighting savings | | | | | | | | |
| | 13 | kWh/m2/yr | 61.64 | 59.33 | 59.33 | 67.54 | 62.65 | 56.89 | 56.61 | |
| | 14 | $/m2/yr | $10.81 | $7.75 | $16.18 | $6.06 | $7.25 | $4.14 | $3.17 | |
| | 15 | | | | | | | | | |
| | 16 | Thermal savings (loss) | | | | | | | | |
| | 17 | kWh/m2/yr | 3.34 | 18.25 | 18.25 | 4.79 | 0.00 | 23.33 | 16.49 | |
| | 18 | $/m2/yr | $0.59 | $2.38 | $4.98 | $0.43 | $0.00 | $1.70 | $0.92 | |
| | 19 | | | | | | | | | |
| | 20 | PV+Lighting+Thermal | | | | | | | | |
| | 21 | kWh/m2/yr | 222.90 | 190.22 | 190.22 | 258.61 | 205.78 | 205.82 | 191.30 | |
| | 22 | $/m2/yr | $39.08 | $24.84 | $51.88 | $23.20 | $23.83 | $14.97 | $10.73 | |
| | 23 | **Combinedpayback,years** | **26.30** | **45.07** | **21.58** | **35.26** | **33.01** | **64.26** | **80.24** | **43.67** |
| | 24 | | | | | | | | | |
| | 25 | Max thermal savings (loss) | | | | | | | | |
| | 26 | kWh/m2/yr | 77.62 | 74.70 | 74.70 | 124.56 | 94.15 | 74.52 | 75.95 | |
| | 27 | $/m2/yr | $13.61 | $9.76 | $20.37 | $11.17 | $10.90 | $5.42 | $4.26 | |
| | 28 | | | | | | | | | |
| | 29 | PV+Lighting+Max thermal | | | | | | | | |
| | 30 | kWh/m2/yr | 297.18 | 246.67 | 246.67 | 378.38 | 299.93 | 257.01 | 250.76 | |
| | 31 | $/m2/yr | $52.10 | $32.21 | $67.27 | $33.94 | $34.73 | $18.70 | $14.06 | |
| | 32 | **Combined(maxthermal),y** | **19.73** | **34.75** | **16.64** | **24.10** | **22.65** | **51.46** | **61.21** | **32.94** |

# B BUILDING ENERGY BALANCE MODEL: PARAMETERS AND EQUATIONS

The building load data provided in this study was calculated from a building energy balance computer model developed by Mahadev Raman at Ove Arup & Partners, Engineers. The following is a brief discussion of the parameters assumed and equations used in calculating the energy loads for each of the five roof options in six cities. Detailed energy balance calculation spreadsheets for each option are provided in the appendix following this discussion.

## 1.0 BUILDING DATA

The configuration assumed for analysis is a single story space with a PV array integrated into the roof. The PV array therefore exchanges heat directly with the occupied space.

A single square meter of roof and corresponding floor space is used for analysis. It is assumed that the only direct heat exchange with the external environment is through the roof. Floor gains and losses are ignored as are perimeter conditions. The effective error this introduces to the analysis depends on multiple factors: overall building size and shape (i.e. floor-to-roof ratio), facade materials, the amount of perimeter windows, building use, climatic variations, etc. Since the perimeter of the case study building is small relative to roof area, it is assumed that the primary energy gains and losses are determined by roof conditions. Detailed design of supplemental building conditions is not considered in the scope of this study.

The temperature within the space is assumed to be at a constant 21° C during occupied hours but is allowed to drift by up to ±5° C when the building is unoccupied.

The following heat gains are assumed:

| | |
|---|---|
| People | 20 W/m2 (~ 500 lux) |
| Lights | 20 W/m2 (~ 500 lux) |
| Equipment | 10 W/m2 (~ 250 lux) |

These heat gains are assumed to be constant during occupied hours. When the building is unoccupied, gains of 4.5 W/m2 are assumed to take account of security lighting and equipment.

A fresh air provision of 2 liters/s per m2 is taken into account and corresponds to 10 liters/s per person.

As the model for this analysis is a convention center, a seven-days-per-week and ten-hours-per-day occupancy profile is assumed.

On the whole, these assumptions are conservative and can be expected to over estimate energy consumption.

## 2.0 WEATHER & CLIMATIC DATA

Climatic data have been obtained for the following cities:

- Oakland
- New York City

- Phoenix
- Miami
- Chicago
- Cincinnati

Together, these cities cover the majority of climate types found in the continental USA.

The following items of weather data are used in the analysis:

- Average daily maximum and minimum temperatures for each month (TMX, TMN).
- Corresponding relative humidities (RMX, RMN).
- Monthly hours of bright sunshine (HS).
- Theoretical 24 hour average solar radiation figures for each month based on latitude and climate type (IAV).

These are manipulated to create four analysis conditions for each month:

1. Sunny day occupied period
2. Sunny day unoccupied period
3. Cloudy day occupied period
4. Cloudy day unoccupied period

Each month is divided into equivalent sunny and cloudy days as follows:

NS = HS /HD and NC = N - NS

where
NS = number of sunny days in the month
HS = hours of bright sunshine in the month
HD = hours of daylight per day in the month
NC = number of cloudy days in the month
N = total days in the month

The 24 hour average direct and diffuse solar radiation figures were obtained from tables in the CIBSE (Chartered Institution Building Services Engineers, United Kingdom) guide. All solar radiation is assumed to occur evenly over the daylight hours. The occupied period is assumed to occur during daylight hours. Radiation occurring in daylight hours outside the occupied period is spread evenly over the unoccupied hours.

IO = (IAV x 24) /HD

where
IO = occupied hours solar intensity W/m2
IAV = 24 hour average solar intensity W/m2
HD = hours of daylight per day

$IU = IO \times (HD - HO) / HU$

where
IU = unoccupied hours solar intensity W/m2
HO = occupied hours per day
HU = unoccupied hours per day

IAV for sunny days is calculated from the sum of the theoretical direct and diffuse radiation components taking into account factors related to the climate type:

$IAV = (ID \times RD) + (Id \times Rd)$

where
ID = 24 hour average direct radiation W/m2
Id = 24 hour average diffuse radiation W/m2
RD = direct radiation factor
Rd = diffuse radiation factor

On cloudy days:

$IAV = Id$

The external temperature during occupied and unoccupied periods are approximated as follows:

$TO = (TMX + TAV) / 2$

$TU = [(TAV \times 24) - (TO \times HO)] / HU$

where
TAV = the average of TMX and TMN ° C
TO = temperature during occupied hours ° C
TU = temperature during unoccupied hours ° C

## 3.0 ANALYSIS MODEL

The analysis model carries out steady state thermal balance calculation for the four analysis conditions defined above for each month.

At the roof, the equations governing energy transfers are as follows:

$QL = U (Ti - To) - a R3 U I$

where
QL = conduction loss W/m2
U = thermal transmittance W/m2 K
Ti = inside temperature ° C
To = outside temperature ° C
a = absorbtivity
R3 = external surface resistance m2 K /W
I = solar intensity W/m2

$QT = t I - QL$

where
QT = total heat gain W/m2
t = transmittivity

For each month the resulting energy transfer is summed with the appropriate level of internal heat gains to determine the net heat gain or loss in each of the four analysis condition (sunny/cloudy, occupied/unoccupied). Gains due to lighting are reduced when appropriate to account for the use of natural light.

The overall heating and cooling requirements in kWh are then calculated by multiplying the instantaneous gains and losses by the number of hours in each period.

The electrical energy consumption for heating and cooling is calculated by using a coefficient of performance of 3.5 for cooling and 4.5 for heating. This assumes a reverse cycle heat pump based system. Full credit is given for free outside air cooling when this is available.

Fan energy consumption is calculated assuming a constant volume system sized to match the peak heat gain. Electricity consumed by equipment and artificial lighting is also taken into account.

Fresh air heating and cooling requirements (needed during occupied hours only) are determined using an enthalpy difference calculation where the outdoor enthalpy is determined from the outdoor temperature and humidity. The indoor enthalpy is based on the internal temperature and humidity. This humidity is allowed to vary between upper and lower limits to minimize energy consumption. Again, the heating and cooling of the outside air is by means of a reverse cycle heat pump system using the coefficients of performance defined above.

# C. BUILDING ENERGY BALANCE CALCULATIONS

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 1: SEMI-TRANSPARENT SINGLE-GLAZED PV ROOF

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | San Francisco | Longitude | 37.62 N | | | | |
| | | Latitude | 122.38 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate costal warm | Altitude | 2.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 13.00 | 5.40 | 85.00 | 40.00 | 154.00 | 10.00 | 15.40 | 15.60 | 75 | 85 |
| February | 14.70 | 6.30 | 130.00 | 55.00 | 191.00 | 11.56 | 16.52 | 11.48 | 71 | 85 |
| March | 16.40 | 7.20 | 190.00 | 75.00 | 262.00 | 12.43 | 21.08 | 9.92 | 66 | 83 |
| April | 17.90 | 8.40 | 250.00 | 100.00 | 297.00 | 13.94 | 21.30 | 8.70 | 66 | 85 |
| May | 19.40 | 9.80 | 290.00 | 120.00 | 328.00 | 14.90 | 22.01 | 8.99 | 66 | 85 |
| June | 21.20 | 11.30 | 305.00 | 125.00 | 341.00 | 15.36 | 22.20 | 7.80 | 65 | 87 |
| July | 22.20 | 11.90 | 290.00 | 120.00 | 295.00 | 14.20 | 20.77 | 10.23 | 69 | 90 |
| August | 22.10 | 12.10 | 250.00 | 100.00 | 275.00 | 13.65 | 20.15 | 10.85 | 69 | 90 |
| September | 23.20 | 12.20 | 190.00 | 75.00 | 275.00 | 12.73 | 21.60 | 8.40 | 66 | 88 |
| October | 21.40 | 10.30 | 130.00 | 55.00 | 242.00 | 11.31 | 21.39 | 9.61 | 65 | 86 |
| November | 17.80 | 7.70 | 85.00 | 40.00 | 198.00 | 10.00 | 19.80 | 10.20 | 68 | 84 |
| December | 14.00 | 6.10 | 70.00 | 35.00 | 179.00 | 10.31 | 17.36 | 13.64 | 74 | 86 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.05 |
| Thermal Transmittance | W/m2oC | 6.00 |
| PV slope | (°) | 0.00 |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### INTERNAL TEMPERATURES

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 11.10 | 7.84 | 207.60 | 0.00 | 96.00 | 0.00 | 15.40 | 15.60 | 28.01 | 22.52 |
| February | 12.60 | 9.00 | 260.51 | 29.06 | 114.17 | 12.74 | 16.52 | 11.48 | 30.55 | 25.19 |
| March | 14.10 | 10.16 | 342.75 | 59.46 | 144.82 | 25.13 | 21.08 | 9.92 | 32.71 | 27.53 |
| April | 15.53 | 11.45 | 404.48 | 113.94 | 172.12 | 48.48 | 21.30 | 8.70 | 36.08 | 31.15 |
| May | 17.00 | 12.89 | 446.11 | 156.21 | 193.26 | 67.67 | 22.01 | 8.99 | 39.69 | 34.84 |
| June | 18.73 | 14.48 | 453.11 | 173.49 | 185.31 | 74.78 | 22.20 | 7.80 | 43.67 | 39.69 |
| July | 19.63 | 15.21 | 468.06 | 140.53 | 202.77 | 60.88 | 20.77 | 10.23 | 47.62 | 42.64 |
| August | 19.60 | 15.31 | 413.26 | 107.67 | 175.85 | 45.82 | 20.15 | 10.85 | 47.55 | 42.94 |
| September | 20.45 | 15.74 | 334.60 | 65.28 | 141.38 | 27.58 | 21.60 | 8.40 | 48.59 | 43.54 |
| October | 18.63 | 13.87 | 266.23 | 24.98 | 116.67 | 10.95 | 21.39 | 9.61 | 43.42 | 37.72 |
| November | 15.28 | 10.95 | 207.60 | 0.00 | 96.00 | 0.00 | 19.80 | 10.20 | 36.10 | 29.66 |
| December | 12.03 | 8.64 | 171.08 | 3.80 | 81.47 | 1.81 | 17.36 | 13.64 | 29.94 | 24.53 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -6.98 | 25.00 | 18.02 | -48.94 | 4.50 | -44.44 | -9.58 | 2.77 | -2.48 | 0.00 |
| February | 15.38 | 25.00 | 40.38 | -34.66 | 4.50 | -30.16 | -6.98 | 6.67 | -1.86 | 0.00 |
| March | 45.14 | 25.00 | 70.14 | -20.04 | 4.50 | -15.54 | -4.59 | 14.79 | -1.50 | 0.00 |
| April | 69.28 | 25.00 | 94.28 | 1.49 | 4.50 | 5.99 | 0.00 | 21.87 | -0.14 | 0.00 |
| May | 88.64 | 25.00 | 113.64 | 10.76 | 4.50 | 15.26 | 0.00 | 29.71 | 0.00 | 0.00 |
| June | 100.76 | 25.00 | 125.76 | 19.70 | 4.50 | 24.20 | 0.00 | 35.44 | 0.00 | 0.00 |
| July | 109.94 | 25.00 | 134.94 | 15.75 | 4.50 | 20.25 | 0.00 | 33.91 | 0.00 | 0.08 |
| August | 95.95 | 25.00 | 120.95 | 8.07 | 4.50 | 12.57 | 0.00 | 27.92 | 0.00 | 0.05 |
| September | 81.19 | 25.00 | 106.19 | -0.10 | 4.50 | 4.40 | 0.00 | 24.27 | 0.00 | 0.48 |
| October | 52.97 | 25.00 | 77.97 | -6.49 | 4.50 | -1.99 | -0.59 | 16.68 | 0.00 | 0.00 |
| November | 18.07 | 25.00 | 43.07 | -30.32 | 4.50 | -25.82 | -7.16 | 8.53 | -0.12 | 0.00 |
| December | -10.65 | 25.00 | 14.35 | -43.20 | 4.50 | -38.70 | -9.41 | 2.49 | -2.16 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -35.16 | 45.00 | 9.84 | -48.94 | 4.50 | -44.44 | -9.71 | 1.54 | -2.52 | 0.00 |
| February | -21.57 | 40.00 | 18.43 | -38.78 | 4.50 | -34.28 | -6.51 | 2.12 | -1.29 | 0.00 |
| March | -4.83 | 35.00 | 30.17 | -28.71 | 4.50 | -24.21 | -3.36 | 2.99 | -0.71 | 0.00 |
| April | 10.61 | 30.00 | 40.61 | -15.04 | 4.50 | -10.54 | -1.28 | 3.53 | -0.06 | 0.00 |
| May | 24.80 | 25.00 | 49.80 | -1.60 | 4.50 | 2.90 | 0.00 | 4.84 | 0.00 | 0.00 |
| June | 35.67 | 25.00 | 60.67 | 9.77 | 4.50 | 14.27 | 0.00 | 6.29 | 0.00 | 0.00 |
| July | 42.95 | 25.00 | 67.95 | 10.64 | 4.50 | 15.14 | 0.00 | 9.12 | 0.00 | 0.04 |
| August | 36.00 | 25.00 | 61.00 | 7.45 | 4.50 | 11.95 | 0.00 | 8.43 | 0.00 | 0.03 |
| September | 32.40 | 30.00 | 62.40 | 5.38 | 4.50 | 9.88 | 0.00 | 6.40 | 0.00 | 0.19 |
| October | 15.21 | 35.00 | 50.21 | -10.03 | 4.50 | -5.53 | -0.74 | 4.83 | 0.00 | 0.00 |
| November | -10.11 | 40.00 | 29.89 | -30.32 | 4.50 | -25.82 | -3.69 | 3.05 | -0.06 | 0.00 |
| December | -33.28 | 45.00 | 11.72 | -43.71 | 4.50 | -39.21 | -7.49 | 1.60 | -1.69 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 5.40 | 9.58 | 5.76 | 20.73 |
| February | 0.00 | 0.00 | 0.22 | 3.48 | 8.65 | 4.10 | 16.23 |
| March | 0.00 | 0.00 | 0.22 | 2.26 | 9.58 | 3.63 | 15.46 |
| April | 0.29 | 7.26 | 0.22 | 0.33 | 9.27 | 2.99 | 19.84 |
| May | 0.29 | 9.87 | 0.22 | 0.00 | 9.58 | 2.64 | 22.09 |
| June | 0.29 | 11.92 | 0.22 | 0.00 | 9.27 | 2.55 | 23.74 |
| July | 0.29 | 12.33 | 0.22 | 0.00 | 9.58 | 2.64 | 24.54 |
| August | 0.29 | 10.41 | 0.22 | 0.00 | 9.58 | 2.64 | 22.62 |
| September | 0.29 | 8.95 | 0.22 | 0.00 | 9.27 | 2.97 | 21.19 |
| October | 0.29 | 6.14 | 0.22 | 0.30 | 9.58 | 3.60 | 19.62 |
| November | 0.29 | 3.31 | 0.22 | 2.45 | 9.27 | 4.08 | 19.11 |
| December | 0.00 | 0.00 | 0.22 | 4.61 | 9.58 | 5.36 | 19.55 |
| TOTAL/m2 | | 70.19 | | 18.82 | 112.78 | 42.93 | 244.73 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 1: SEMI-TRANSPARENT SINGLE-GLAZED PV ROOF

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | New York | Longitude | 40.70 N | | | | |
| | | Latitude | 74.02 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate costal cold | Altitude | 3.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 4.30 | -2.80 | 85.00 | 40.00 | 151.00 | 10.00 | 15.10 | 15.90 | 61 | 69 |
| February | 4.10 | -2.40 | 130.00 | 55.00 | 164.00 | 10.28 | 15.96 | 12.04 | 58 | 67 |
| March | 8.90 | 0.50 | 190.00 | 75.00 | 209.00 | 11.83 | 17.67 | 13.33 | 56 | 67 |
| April | 14.90 | 6.10 | 250.00 | 100.00 | 214.00 | 12.09 | 17.70 | 12.30 | 55 | 68 |
| May | 20.90 | 11.80 | 290.00 | 120.00 | 250.00 | 13.44 | 18.60 | 12.40 | 56 | 69 |
| June | 25.60 | 16.90 | 305.00 | 125.00 | 301.00 | 16.18 | 18.60 | 11.40 | 58 | 72 |
| July | 28.30 | 19.90 | 290.00 | 120.00 | 307.00 | 15.00 | 20.46 | 10.54 | 57 | 74 |
| August | 27.40 | 19.30 | 250.00 | 100.00 | 275.00 | 13.86 | 19.84 | 11.16 | 60 | 76 |
| September | 23.80 | 15.80 | 190.00 | 75.00 | 237.00 | 12.54 | 18.90 | 11.10 | 60 | 76 |
| October | 18.40 | 10.30 | 130.00 | 55.00 | 218.00 | 11.34 | 19.22 | 11.78 | 59 | 74 |
| November | 11.90 | 4.40 | 85.00 | 40.00 | 172.00 | 10.06 | 17.10 | 12.90 | 60 | 71 |
| December | 5.70 | -1.20 | 70.00 | 35.00 | 158.00 | 10.00 | 15.80 | 15.20 | 60 | 67 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | | |
|---|---|---|---|
| Conversion Efficiency | % | 10.00 | |
| Direct Transmittance | % | 0.05 | |
| Thermal Transmittance | W/m2oC | 6.00 | |
| PV slope | (°) | 0.00 | |

### INTERNAL TEMPERATURES

| | | | |
|---|---|---|---|
| Occupied Period Set Point | oC | 21.00 | |
| Unoccupied Period Offset | oC | 5.00 | |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 2.53 | -0.52 | 207.50 | 0.00 | 96.00 | 0.00 | 15.10 | 15.90 | 8.95 | 4.83 |
| February | 2.48 | -0.31 | 293.12 | 5.77 | 128.46 | 2.53 | 15.96 | 12.04 | 8.56 | 4.99 |
| March | 6.83 | 3.27 | 360.16 | 47.03 | 152.18 | 19.87 | 17.67 | 13.33 | 15.67 | 10.86 |
| April | 12.70 | 8.93 | 466.49 | 69.65 | 198.50 | 29.64 | 17.70 | 12.30 | 26.71 | 21.80 |
| May | 18.63 | 14.73 | 494.61 | 121.56 | 214.27 | 52.66 | 18.60 | 12.40 | 39.98 | 35.06 |
| June | 23.43 | 19.70 | 430.09 | 169.84 | 185.38 | 81.87 | 18.60 | 11.40 | 52.74 | 49.03 |
| July | 26.20 | 22.60 | 443.06 | 158.39 | 191.94 | 68.62 | 20.46 | 10.54 | 59.60 | 58.33 |
| August | 25.38 | 21.90 | 406.90 | 112.21 | 173.15 | 47.75 | 19.84 | 11.16 | 59.06 | 57.18 |
| September | 21.80 | 18.37 | 339.72 | 61.63 | 143.54 | 26.04 | 18.90 | 11.10 | 49.48 | 46.90 |
| October | 16.38 | 12.90 | 265.55 | 25.46 | 116.38 | 11.16 | 19.22 | 11.78 | 35.84 | 32.04 |
| November | 10.03 | 6.81 | 206.39 | 0.86 | 85.44 | 0.40 | 17.10 | 12.90 | 22.45 | 18.01 |
| December | 3.98 | 1.02 | 176.40 | 0.00 | 84.00 | 0.00 | 15.80 | 15.20 | 11.26 | 7.09 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -58.43 | 25.00 | -33.43 | -99.11 | 4.50 | -94.61 | -20.00 | -5.05 | -7.96 | 0.00 |
| February | -37.14 | 25.00 | -12.14 | -96.41 | 4.50 | -91.91 | -20.54 | -1.94 | -8.54 | 0.00 |
| March | 5.89 | 25.00 | 30.89 | -64.52 | 4.50 | -60.02 | -14.85 | 5.46 | -7.04 | 0.00 |
| April | 67.99 | 25.00 | 92.99 | -24.84 | 4.50 | -20.34 | -5.04 | 16.46 | -3.30 | 0.00 |
| May | 110.64 | 25.00 | 135.64 | -6.96 | 4.50 | -2.46 | -0.64 | 25.23 | 0.00 | 0.00 |
| June | 123.15 | 25.00 | 148.15 | 20.14 | 4.50 | 24.64 | 0.00 | 33.97 | 0.00 | 1.90 |
| July | 143.07 | 25.00 | 168.07 | 19.59 | 4.50 | 24.09 | 0.00 | 41.29 | 0.00 | 4.78 |
| August | 128.99 | 25.00 | 153.99 | 13.76 | 4.50 | 18.26 | 0.00 | 35.62 | 0.00 | 4.43 |
| September | 90.58 | 25.00 | 115.58 | -0.21 | 4.50 | 4.29 | 0.00 | 22.98 | 0.00 | -0.75 |
| October | 39.30 | 25.00 | 64.30 | -12.15 | 4.50 | -7.65 | -2.06 | 12.36 | -0.21 | 0.00 |
| November | -13.74 | 25.00 | 11.26 | -54.92 | 4.50 | -50.42 | -12.07 | 1.93 | -4.58 | 0.00 |
| December | -57.61 | 25.00 | -32.61 | -89.89 | 4.50 | -85.39 | -18.89 | -5.15 | -7.63 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -86.61 | 45.00 | -41.61 | -99.11 | 4.50 | -94.61 | -21.06 | -6.62 | -8.38 | 0.00 |
| February | -78.71 | 40.00 | -38.71 | -97.23 | 4.50 | -92.73 | -15.63 | -4.66 | -6.44 | 0.00 |
| March | -46.62 | 35.00 | -11.62 | -71.38 | 4.50 | -66.88 | -12.48 | -1.55 | -5.31 | 0.00 |
| April | 0.32 | 30.00 | 30.32 | -34.94 | 4.50 | -30.44 | -5.24 | 3.73 | -2.29 | 0.00 |
| May | 39.85 | 25.00 | 64.85 | 5.65 | 4.50 | 10.15 | 0.00 | 9.80 | 0.00 | 0.00 |
| June | 61.36 | 25.00 | 86.36 | 9.85 | 4.50 | 14.35 | 0.00 | 12.14 | 0.00 | 1.16 |
| July | 79.66 | 25.00 | 104.66 | 11.93 | 4.50 | 16.43 | 0.00 | 13.46 | 0.00 | 2.46 |
| August | 69.97 | 25.00 | 94.97 | 7.48 | 4.50 | 11.98 | 0.00 | 12.47 | 0.00 | 2.49 |
| September | 41.04 | 30.00 | 71.04 | -6.20 | 4.50 | -1.70 | -0.26 | 7.89 | 0.00 | 0.44 |
| October | 1.64 | 35.00 | 36.64 | -15.76 | 4.50 | -11.26 | -1.86 | 4.32 | -0.13 | 0.00 |
| November | -41.75 | 40.00 | -1.75 | -55.04 | 4.50 | -50.54 | -9.13 | -0.23 | -3.46 | 0.00 |
| December | -80.94 | 45.00 | -35.94 | -89.89 | 4.50 | -85.39 | -18.17 | -5.46 | -7.34 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 12.76 | 11.28 | 5.82 | 29.86 |
| February | 0.00 | 0.00 | 0.22 | 11.36 | 10.19 | 4.19 | 25.74 |
| March | 0.00 | 0.00 | 0.22 | 8.82 | 11.28 | 3.97 | 24.07 |
| April | 0.00 | 0.00 | 0.22 | 3.53 | 10.92 | 3.17 | 17.61 |
| May | 0.29 | 10.01 | 0.22 | 0.14 | 11.28 | 2.64 | 24.07 |
| June | 0.29 | 14.05 | 0.22 | 0.00 | 10.92 | 2.55 | 27.52 |
| July | 0.29 | 17.71 | 0.22 | 0.00 | 11.28 | 2.64 | 31.63 |
| August | 0.29 | 15.72 | 0.22 | 0.00 | 11.28 | 2.64 | 29.64 |
| September | 0.29 | 9.16 | 0.22 | 0.06 | 10.92 | 3.11 | 23.24 |
| October | 0.29 | 4.76 | 0.22 | 0.95 | 11.28 | 3.81 | 20.81 |
| November | 0.00 | 0.00 | 0.22 | 6.50 | 10.92 | 4.49 | 21.90 |
| December | 0.00 | 0.00 | 0.22 | 11.56 | 11.28 | 5.68 | 28.52 |
| TOTAL/m2 | | 71.41 | | 55.67 | 132.86 | 44.67 | 304.61 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 1: SEMI-TRANSPARENT SINGLE-GLAZED PV ROOF

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Phoenix | Longitude | 33.43 N | | | | |
| | | Latitude | 112.02 W | Direct Radiation Factor | 1.10 | | |
| Climate | Temperate arid | Altitude | 340.00 m | Diffuse Radiation Factor | 0.90 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 17.80 | 1.80 | 105.00 | 25.00 | 262.00 | 10.84 | 24.18 | 6.82 | 44 | 72 |
| February | 20.10 | 3.80 | 150.00 | 30.00 | 271.00 | 12.41 | 21.84 | 6.16 | 42 | 71 |
| March | 23.90 | 6.10 | 205.00 | 35.00 | 331.00 | 12.56 | 26.35 | 4.65 | 31 | 60 |
| April | 28.80 | 10.20 | 260.00 | 45.00 | 360.00 | 13.48 | 26.70 | 3.30 | 26 | 50 |
| May | 33.80 | 13.90 | 295.00 | 45.00 | 408.00 | 14.00 | 29.14 | 1.86 | 19 | 41 |
| June | 38.70 | 18.60 | 305.00 | 50.00 | 411.00 | 14.57 | 28.20 | 1.80 | 17 | 37 |
| July | 40.30 | 23.90 | 295.00 | 45.00 | 390.00 | 14.30 | 27.28 | 3.72 | 29 | 51 |
| August | 38.70 | 23.00 | 260.00 | 45.00 | 379.00 | 14.22 | 26.66 | 4.34 | 35 | 60 |
| September | 36.80 | 19.60 | 205.00 | 35.00 | 354.00 | 13.11 | 27.00 | 3.00 | 29 | 66 |
| October | 30.40 | 12.60 | 150.00 | 30.00 | 323.00 | 11.98 | 26.97 | 4.03 | 30 | 58 |
| November | 23.20 | 5.80 | 105.00 | 25.00 | 282.00 | 10.93 | 25.80 | 4.20 | 33 | 83 |
| December | 18.90 | 2.80 | 90.00 | 25.00 | 260.00 | 10.75 | 24.18 | 6.82 | 42 | 70 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.05 |
| Thermal Transmittance | W/m2oC | 6.00 |
| PV slope (°) | | 0.00 |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### INTERNAL TEMPERATURES

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 13.80 | 6.94 | 305.66 | 18.24 | 110.75 | 6.61 | 24.18 | 6.82 | 25.84 | 18.43 |
| February | 16.03 | 9.04 | 371.36 | 63.89 | 116.05 | 18.96 | 21.84 | 6.16 | 29.56 | 22.60 |
| March | 19.45 | 11.82 | 491.02 | 89.84 | 133.74 | 24.47 | 26.35 | 4.65 | 31.89 | 26.13 |
| April | 24.15 | 16.18 | 581.17 | 144.59 | 160.20 | 39.86 | 26.70 | 3.30 | 37.82 | 32.46 |
| May | 28.83 | 20.30 | 625.65 | 178.82 | 154.27 | 44.09 | 29.14 | 1.86 | 41.52 | 37.52 |
| June | 33.68 | 25.06 | 626.58 | 204.73 | 164.67 | 53.81 | 28.20 | 1.80 | 47.87 | 45.49 |
| July | 36.20 | 29.17 | 612.75 | 188.04 | 151.09 | 46.36 | 27.28 | 3.72 | 63.15 | 63.82 |
| August | 34.78 | 28.05 | 551.21 | 165.99 | 151.94 | 45.76 | 26.66 | 4.34 | 65.41 | 66.63 |
| September | 32.50 | 25.13 | 470.44 | 104.54 | 128.14 | 28.47 | 27.00 | 3.00 | 55.49 | 61.70 |
| October | 25.95 | 18.32 | 384.76 | 54.31 | 120.24 | 16.97 | 26.97 | 4.03 | 43.31 | 40.03 |
| November | 18.85 | 11.39 | 303.01 | 20.13 | 109.79 | 7.29 | 25.80 | 4.20 | 31.61 | 30.54 |
| December | 14.88 | 7.98 | 271.19 | 14.58 | 111.60 | 6.00 | 24.18 | 6.82 | 27.38 | 20.20 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | 33.98 | 25.00 | 58.98 | -49.74 | 4.50 | -45.24 | -15.31 | 14.26 | -4.86 | 0.00 |
| February | 63.92 | 25.00 | 88.92 | -25.63 | 4.50 | -21.13 | -6.46 | 19.42 | -2.88 | 0.00 |
| March | 114.68 | 25.00 | 139.68 | -2.39 | 4.50 | 2.11 | 0.00 | 37.59 | -2.29 | 0.00 |
| April | 165.65 | 25.00 | 190.65 | 7.58 | 4.50 | 12.08 | 0.00 | 55.42 | 0.00 | 0.00 |
| May | 204.93 | 25.00 | 229.93 | 40.93 | 4.50 | 45.43 | 0.00 | 85.53 | 0.00 | 0.00 |
| June | 234.26 | 25.00 | 259.26 | 46.06 | 4.50 | 50.56 | 0.00 | 93.07 | 0.00 | 0.24 |
| July | 245.92 | 25.00 | 270.92 | 66.51 | 4.50 | 71.01 | 0.00 | 101.03 | 0.00 | 8.24 |
| August | 221.83 | 25.00 | 246.83 | 54.19 | 4.50 | 58.69 | 0.00 | 87.71 | 0.00 | 9.21 |
| September | 187.79 | 25.00 | 212.79 | 21.17 | 4.50 | 25.67 | 0.00 | 67.15 | 0.00 | 4.18 |
| October | 126.85 | 25.00 | 151.85 | -2.36 | 4.50 | 2.14 | 0.00 | 41.76 | 0.00 | 0.00 |
| November | 63.61 | 25.00 | 88.61 | -22.56 | 4.50 | -18.06 | -6.52 | 22.86 | -2.38 | 0.00 |
| December | 31.72 | 25.00 | 56.72 | -44.47 | 4.50 | -39.97 | -13.53 | 13.72 | -4.19 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -15.24 | 45.00 | 29.76 | -52.67 | 4.50 | -48.17 | -4.60 | 2.03 | -1.37 | 0.00 |
| February | -0.55 | 40.00 | 39.45 | -36.72 | 4.50 | -32.22 | -2.78 | 2.43 | -0.81 | 0.00 |
| March | 24.47 | 35.00 | 59.47 | -18.89 | 4.50 | -14.39 | -0.94 | 2.77 | -0.40 | 0.00 |
| April | 59.35 | 30.00 | 89.35 | -3.86 | 4.50 | 0.64 | 0.00 | 2.58 | 0.00 | 0.00 |
| May | 85.90 | 25.00 | 110.90 | 6.91 | 4.50 | 11.41 | 0.00 | 2.36 | 0.00 | 0.00 |
| June | 117.63 | 25.00 | 142.63 | 22.95 | 4.50 | 27.45 | 0.00 | 3.26 | 0.00 | 0.02 |
| July | 129.35 | 25.00 | 154.35 | 30.74 | 4.50 | 35.24 | 0.00 | 7.58 | 0.00 | 1.12 |
| August | 121.02 | 25.00 | 146.02 | 23.83 | 4.50 | 28.33 | 0.00 | 8.06 | 0.00 | 1.50 |
| September | 101.35 | 30.00 | 131.35 | 1.96 | 4.50 | 6.46 | 0.00 | 4.21 | 0.00 | 0.46 |
| October | 60.06 | 35.00 | 95.06 | -11.79 | 4.50 | -7.29 | -0.41 | 3.83 | 0.00 | 0.00 |
| November | 14.82 | 40.00 | 54.82 | -25.60 | 4.50 | -21.30 | -1.25 | 2.30 | -0.39 | 0.00 |
| December | -8.57 | 45.00 | 36.43 | -46.64 | 4.50 | -42.14 | -4.02 | 2.48 | -1.18 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 5.81 | 19.75 | 4.00 | 29.56 |
| February | 0.29 | 6.24 | 0.22 | 2.87 | 17.84 | 3.30 | 30.26 |
| March | 0.29 | 11.53 | 0.22 | 0.81 | 19.75 | 3.10 | 35.18 |
| April | 0.29 | 16.68 | 0.22 | 0.00 | 19.11 | 2.72 | 38.51 |
| May | 0.29 | 25.11 | 0.22 | 0.00 | 19.75 | 2.64 | 47.49 |
| June | 0.29 | 27.60 | 0.22 | 0.00 | 19.11 | 2.55 | 49.26 |
| July | 0.29 | 33.70 | 0.22 | 0.00 | 19.75 | 2.64 | 56.09 |
| August | 0.29 | 30.42 | 0.22 | 0.00 | 19.75 | 2.64 | 52.80 |
| September | 0.29 | 21.72 | 0.22 | 0.00 | 19.11 | 2.70 | 43.53 |
| October | 0.29 | 13.03 | 0.22 | 0.03 | 19.75 | 3.04 | 35.90 |
| November | 0.29 | 7.19 | 0.22 | 2.34 | 19.11 | 3.18 | 31.82 |
| December | 0.00 | 0.00 | 0.22 | 5.10 | 19.75 | 4.00 | 28.84 |
| TOTAL/m2 | | 193.22 | | 17.02 | 232.51 | 36.49 | 479.24 |

## OPTION 1: SEMI-TRANSPARENT SINGLE-GLAZED PV ROOF

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Miami | Longitude | 25.80 N | | | | |
| | | Latitude | 80.27 W | Direct Radiation Factor | 0.50 | | |
| Climate | Sub-tropical | Altitude | 2.00 m | Diffuse Radiation Factor | 1.10 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 24.30 | 14.40 | 150.00 | 65.00 | 239.00 | 11.51 | 20.77 | 10.23 | 59 | 84 |
| February | 25.00 | 14.90 | 195.00 | 80.00 | 233.00 | 11.72 | 19.88 | 8.12 | 56 | 84 |
| March | 26.60 | 16.20 | 235.00 | 95.00 | 269.00 | 12.22 | 22.01 | 8.99 | 56 | 82 |
| April | 28.10 | 18.80 | 275.00 | 115.00 | 283.00 | 13.10 | 21.60 | 8.40 | 56 | 79 |
| May | 29.70 | 20.90 | 295.00 | 125.00 | 276.00 | 13.49 | 20.46 | 10.54 | 59 | 78 |
| June | 31.10 | 23.10 | 295.00 | 125.00 | 255.00 | 13.93 | 18.30 | 11.70 | 64 | 81 |
| July | 31.60 | 23.70 | 295.00 | 125.00 | 270.00 | 13.82 | 19.53 | 11.47 | 64 | 81 |
| August | 32.10 | 23.80 | 275.00 | 115.00 | 261.00 | 13.16 | 19.84 | 11.16 | 63 | 83 |
| September | 31.10 | 23.70 | 235.00 | 95.00 | 212.00 | 11.98 | 17.70 | 12.30 | 66 | 85 |
| October | 29.30 | 21.60 | 195.00 | 80.00 | 200.00 | 11.73 | 17.05 | 13.95 | 64 | 85 |
| November | 26.80 | 18.10 | 150.00 | 65.00 | 224.00 | 11.31 | 19.80 | 10.20 | 60 | 84 |
| December | 26.10 | 15.10 | 135.00 | 55.00 | 221.00 | 11.14 | 19.84 | 11.16 | 60 | 85 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

**PV PANEL DATA**

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.05 |
| Thermal Transmittance W/m2oC | | 6.00 |
| PV slope (°) | | 0.00 |

**INTERNAL TEMPERATURES**

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

**HUMIDITY-WINTER**

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

**HUMIDITY-SUMMER**

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 21.83 | 17.58 | 305.55 | 32.89 | 135.57 | 14.59 | 20.77 | 10.23 | 49.06 | 47.57 |
| February | 22.48 | 18.15 | 379.85 | 46.68 | 163.82 | 20.13 | 19.88 | 8.12 | 49.32 | 49.23 |
| March | 24.00 | 19.54 | 435.95 | 69.18 | 186.55 | 29.60 | 22.01 | 8.99 | 53.21 | 52.64 |
| April | 25.78 | 21.79 | 483.60 | 107.15 | 210.66 | 46.67 | 21.60 | 8.40 | 57.88 | 58.21 |
| May | 27.50 | 23.73 | 507.05 | 126.39 | 222.39 | 55.43 | 20.46 | 10.54 | 64.43 | 63.82 |
| June | 29.10 | 25.67 | 490.87 | 137.95 | 215.29 | 60.50 | 18.30 | 11.70 | 72.43 | 71.86 |
| July | 29.63 | 26.24 | 494.76 | 135.17 | 217.00 | 59.28 | 19.53 | 11.47 | 74.06 | 73.80 |
| August | 30.03 | 26.47 | 481.63 | 108.55 | 209.80 | 47.28 | 19.84 | 11.16 | 74.60 | 75.78 |
| September | 29.25 | 26.08 | 444.84 | 62.83 | 190.36 | 26.88 | 17.70 | 12.30 | 74.26 | 75.58 |
| October | 27.38 | 24.08 | 379.53 | 46.91 | 163.68 | 20.23 | 17.05 | 13.95 | 67.19 | 68.60 |
| November | 24.63 | 20.90 | 310.79 | 29.15 | 137.89 | 12.93 | 19.80 | 10.20 | 57.00 | 57.67 |
| December | 23.35 | 18.64 | 275.78 | 22.44 | 118.50 | 9.64 | 19.84 | 11.16 | 53.56 | 51.08 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | 82.10 | 25.00 | 107.10 | -6.20 | 4.50 | -1.70 | -0.50 | 22.25 | 0.00 | 0.66 |
| February | 104.76 | 25.00 | 129.76 | 0.66 | 4.50 | 5.16 | 0.00 | 27.23 | 0.00 | 0.72 |
| March | 128.08 | 25.00 | 153.08 | 5.73 | 4.50 | 10.23 | 0.00 | 36.84 | 0.00 | 2.45 |
| April | 150.76 | 25.00 | 175.76 | 16.79 | 4.50 | 21.29 | 0.00 | 44.40 | 0.00 | 4.34 |
| May | 167.03 | 25.00 | 192.03 | 28.29 | 4.50 | 32.79 | 0.00 | 48.68 | 0.00 | 6.68 |
| June | 172.54 | 25.00 | 197.54 | 32.86 | 4.50 | 37.36 | 0.00 | 45.72 | 0.00 | 8.78 |
| July | 176.68 | 25.00 | 201.68 | 35.57 | 4.50 | 40.07 | 0.00 | 50.34 | 0.00 | 9.99 |
| August | 175.76 | 25.00 | 200.76 | 30.22 | 4.50 | 34.72 | 0.00 | 49.47 | 0.00 | 10.35 |
| September | 161.82 | 25.00 | 186.82 | 16.34 | 4.50 | 20.84 | 0.00 | 38.23 | 0.00 | 9.12 |
| October | 134.08 | 25.00 | 159.08 | 10.29 | 4.50 | 14.79 | 0.00 | 30.65 | 0.00 | 6.47 |
| November | 100.22 | 25.00 | 125.22 | 0.74 | 4.50 | 5.24 | 0.00 | 26.25 | 0.00 | 3.64 |
| December | 83.74 | 25.00 | 108.74 | -2.52 | 4.50 | 1.98 | 0.00 | 22.12 | 0.00 | 2.34 |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | 39.18 | 45.00 | 84.18 | -1.82 | 4.50 | 2.68 | 0.00 | 9.00 | 0.00 | 0.33 |
| February | 50.21 | 40.00 | 90.21 | -2.04 | 4.50 | 2.46 | 0.00 | 7.61 | 0.00 | 0.30 |
| March | 65.10 | 35.00 | 100.10 | 1.73 | 4.50 | 6.23 | 0.00 | 9.78 | 0.00 | 1.00 |
| April | 81.84 | 30.00 | 111.84 | 6.52 | 4.50 | 11.02 | 0.00 | 10.69 | 0.00 | 1.69 |
| May | 95.15 | 25.00 | 120.15 | 10.37 | 4.50 | 14.87 | 0.00 | 14.86 | 0.00 | 3.44 |
| June | 102.96 | 25.00 | 127.96 | 13.31 | 4.50 | 17.81 | 0.00 | 17.89 | 0.00 | 5.62 |
| July | 106.54 | 25.00 | 131.54 | 16.41 | 4.50 | 20.91 | 0.00 | 18.44 | 0.00 | 5.86 |
| August | 107.13 | 25.00 | 132.13 | 14.75 | 4.50 | 19.25 | 0.00 | 17.75 | 0.00 | 5.82 |
| September | 97.57 | 30.00 | 127.57 | 7.26 | 4.50 | 11.76 | 0.00 | 17.72 | 0.00 | 6.34 |
| October | 79.58 | 35.00 | 114.58 | 3.56 | 4.50 | 8.06 | 0.00 | 17.56 | 0.00 | 5.29 |
| November | 56.57 | 40.00 | 96.57 | -0.36 | 4.50 | 4.14 | 0.00 | 10.44 | 0.00 | 1.87 |
| December | 44.02 | 45.00 | 89.02 | -1.75 | 4.50 | 2.75 | 0.00 | 10.36 | 0.00 | 1.31 |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and Power kWh | Total kWh Consumed |
|---|---|---|---|---|---|---|---|
| | l/cop | kWh Electric | l/cop | kWh Electric | kWh | | |
| January | 0.29 | 9.21 | 0.22 | 0.11 | 15.05 | 4.68 | 29.05 |
| February | 0.29 | 10.25 | 0.22 | 0.00 | 13.59 | 3.60 | 27.43 |
| March | 0.29 | 14.31 | 0.22 | 0.00 | 15.05 | 3.53 | 32.89 |
| April | 0.29 | 17.46 | 0.22 | 0.00 | 14.56 | 2.97 | 34.99 |
| May | 0.29 | 21.05 | 0.22 | 0.00 | 15.05 | 2.64 | 38.73 |
| June | 0.29 | 22.29 | 0.22 | 0.00 | 14.56 | 2.55 | 39.40 |
| July | 0.29 | 24.18 | 0.22 | 0.00 | 15.05 | 2.64 | 41.86 |
| August | 0.29 | 23.83 | 0.22 | 0.00 | 15.05 | 2.64 | 41.51 |
| September | 0.29 | 20.40 | 0.22 | 0.00 | 14.56 | 3.17 | 38.13 |
| October | 0.29 | 17.14 | 0.22 | 0.00 | 15.05 | 4.03 | 36.21 |
| November | 0.29 | 12.06 | 0.22 | 0.00 | 14.56 | 4.08 | 30.70 |
| December | 0.29 | 10.32 | 0.22 | 0.00 | 15.05 | 4.87 | 30.24 |
| TOTAL/m2 | | 202.48 | | 0.11 | 177.16 | 41.38 | 421.13 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 1: SEMI-TRANSPARENT SINGLE-GLAZED PV ROOF

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Chicago | Longitude | 41.78 N | | | | |
| | | Latitude | 87.75 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate continental | Altitude | 186.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 0.60 | -7.20 | 85.00 | 40.00 | 125.00 | 10.00 | 12.50 | 18.50 | 70 | 80 |
| February | 1.50 | -6.30 | 130.00 | 55.00 | 141.00 | 10.49 | 13.44 | 14.56 | 67 | 79 |
| March | 6.40 | -1.70 | 190.00 | 75.00 | 206.00 | 12.78 | 16.12 | 14.88 | 61 | 77 |
| April | 14.10 | 4.70 | 250.00 | 100.00 | 206.00 | 12.48 | 16.50 | 13.50 | 56 | 74 |
| May | 20.60 | 10.50 | 290.00 | 120.00 | 275.00 | 14.54 | 18.91 | 12.09 | 55 | 75 |
| June | 26.40 | 15.40 | 305.00 | 125.00 | 307.00 | 15.51 | 19.80 | 10.20 | 56 | 77 |
| July | 28.90 | 19.50 | 290.00 | 120.00 | 310.00 | 13.89 | 22.32 | 8.68 | 53 | 77 |
| August | 28.00 | 18.80 | 250.00 | 100.00 | 285.00 | 13.13 | 21.70 | 9.30 | 56 | 81 |
| September | 23.80 | 14.10 | 190.00 | 75.00 | 246.00 | 12.42 | 19.80 | 10.20 | 53 | 81 |
| October | 17.40 | 8.20 | 130.00 | 55.00 | 214.00 | 11.13 | 19.22 | 11.78 | 54 | 79 |
| November | 8.40 | 0.30 | 85.00 | 40.00 | 135.00 | 10.00 | 13.50 | 16.50 | 62 | 78 |
| December | 2.10 | -5.30 | 70.00 | 35.00 | 115.00 | 10.00 | 11.50 | 19.50 | 69 | 80 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.05 |
| Thermal Transmittance | W/m2oC | 6.00 |
| PV slope (°) | | 0.00 |

### INTERNAL TEMPERATURES

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | -1.35 | -4.69 | 207.60 | 0.00 | 96.00 | 0.00 | 12.50 | 18.50 | 3.63 | -0.55 |
| February | -0.45 | -3.79 | 287.10 | 10.07 | 125.82 | 4.41 | 13.44 | 14.56 | 4.78 | 0.64 |
| March | 4.38 | 0.90 | 333.36 | 66.17 | 140.85 | 27.96 | 16.12 | 14.88 | 12.07 | 7.80 |
| April | 11.75 | 7.72 | 451.75 | 80.18 | 192.23 | 34.12 | 16.50 | 13.50 | 25.03 | 20.36 |
| May | 18.08 | 13.75 | 457.14 | 148.33 | 198.04 | 64.26 | 18.91 | 12.09 | 38.34 | 34.37 |
| June | 23.65 | 18.94 | 448.89 | 176.51 | 193.49 | 76.08 | 19.80 | 10.20 | 52.31 | 48.88 |
| July | 26.55 | 22.52 | 478.66 | 132.96 | 207.36 | 57.60 | 22.32 | 8.68 | 58.17 | 59.53 |
| August | 25.70 | 21.76 | 429.43 | 96.12 | 182.74 | 40.90 | 21.70 | 9.30 | 57.68 | 59.03 |
| September | 21.38 | 17.22 | 342.88 | 59.37 | 144.88 | 25.09 | 19.80 | 10.20 | 45.23 | 45.46 |
| October | 15.10 | 11.16 | 270.52 | 21.92 | 118.55 | 9.60 | 19.22 | 11.78 | 31.44 | 29.05 |
| November | 6.38 | 2.90 | 207.60 | 0.00 | 96.00 | 0.00 | 13.50 | 16.50 | 15.78 | 11.43 |
| December | 0.25 | -2.92 | 176.40 | 0.00 | 84.00 | 0.00 | 11.50 | 19.50 | 6.03 | 1.95 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -81.68 | 25.00 | -56.68 | -124.16 | 4.50 | -119.66 | -20.94 | -7.09 | -7.87 | 0.00 |
| February | -56.21 | 25.00 | -31.21 | -116.21 | 4.50 | -111.71 | -21.02 | -4.19 | -8.16 | 0.00 |
| March | -15.58 | 25.00 | 9.42 | -73.87 | 4.50 | -69.37 | -15.66 | 1.52 | -7.54 | 0.00 |
| April | 58.57 | 25.00 | 83.57 | -29.43 | 4.50 | -24.93 | -5.76 | 13.79 | -3.61 | 0.00 |
| May | 97.88 | 25.00 | 122.88 | 8.93 | 4.50 | 13.43 | 0.00 | 26.79 | 0.00 | 0.00 |
| June | 129.24 | 25.00 | 154.24 | 22.18 | 4.50 | 26.68 | 0.00 | 37.94 | 0.00 | 1.86 |
| July | 154.16 | 25.00 | 179.16 | 22.70 | 4.50 | 27.20 | 0.00 | 48.49 | 0.00 | 4.61 |
| August | 136.63 | 25.00 | 161.63 | 13.81 | 4.50 | 18.31 | 0.00 | 40.64 | 0.00 | 4.27 |
| September | 88.83 | 25.00 | 113.83 | 7.30 | 4.50 | 11.80 | 0.00 | 25.81 | 0.00 | 0.00 |
| October | 32.91 | 25.00 | 57.91 | -23.52 | 4.50 | -19.02 | -5.12 | 11.13 | -1.84 | 0.00 |
| November | -35.33 | 25.00 | -10.33 | -78.58 | 4.50 | -74.08 | -14.00 | -1.39 | -5.35 | 0.00 |
| December | -79.96 | 25.00 | -54.96 | -113.53 | 4.50 | -109.03 | -17.55 | -6.32 | -6.71 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -109.86 | 45.00 | -64.86 | -124.16 | 4.50 | -119.66 | -30.99 | -12.00 | -11.64 | 0.00 |
| February | -96.93 | 40.00 | -56.93 | -117.64 | 4.50 | -113.14 | -23.06 | -8.29 | -8.84 | 0.00 |
| March | -64.18 | 35.00 | -29.18 | -83.52 | 4.50 | -79.02 | -16.46 | -4.34 | -6.96 | 0.00 |
| April | -6.96 | 30.00 | 23.04 | -41.06 | 4.50 | -36.56 | -6.91 | 3.11 | -2.95 | 0.00 |
| May | 32.45 | 25.00 | 57.45 | 2.70 | 4.50 | 7.20 | 0.00 | 8.17 | 0.00 | 0.00 |
| June | 64.76 | 25.00 | 89.76 | 9.82 | 4.50 | 14.32 | 0.00 | 11.20 | 0.00 | 0.96 |
| July | 85.66 | 25.00 | 110.66 | 8.67 | 4.50 | 13.17 | 0.00 | 11.21 | 0.00 | 1.79 |
| August | 74.34 | 25.00 | 99.34 | 4.87 | 4.50 | 9.37 | 0.00 | 10.46 | 0.00 | 1.83 |
| September | 38.83 | 30.00 | 68.83 | -1.36 | 4.50 | 3.14 | 0.00 | 7.47 | 0.00 | 0.00 |
| October | -5.47 | 35.00 | 29.53 | -26.63 | 4.50 | -22.13 | -3.65 | 3.48 | -1.13 | 0.00 |
| November | -63.51 | 40.00 | -23.51 | -78.58 | 4.50 | -74.08 | -17.11 | -3.88 | -6.54 | 0.00 |
| December | -103.29 | 45.00 | -58.29 | -113.53 | 4.50 | -109.03 | -29.76 | -11.37 | -11.38 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 15.88 | 11.75 | 6.34 | 33.96 |
| February | 0.00 | 0.00 | 0.22 | 13.58 | 10.61 | 4.56 | 28.75 |
| March | 0.00 | 0.00 | 0.22 | 10.36 | 11.75 | 4.12 | 26.23 |
| April | 0.00 | 0.00 | 0.22 | 4.27 | 11.37 | 3.23 | 18.87 |
| May | 0.29 | 9.99 | 0.22 | 0.00 | 11.75 | 2.64 | 24.37 |
| June | 0.29 | 14.84 | 0.22 | 0.00 | 11.37 | 2.55 | 28.76 |
| July | 0.29 | 18.88 | 0.22 | 0.00 | 11.75 | 2.64 | 33.27 |
| August | 0.29 | 16.34 | 0.22 | 0.00 | 11.75 | 2.64 | 30.73 |
| September | 0.29 | 9.51 | 0.22 | 0.00 | 11.37 | 3.06 | 23.94 |
| October | 0.29 | 4.17 | 0.22 | 2.61 | 11.75 | 3.81 | 22.34 |
| November | 0.00 | 0.00 | 0.22 | 9.55 | 11.37 | 5.03 | 25.95 |
| December | 0.00 | 0.00 | 0.22 | 14.53 | 11.75 | 6.54 | 32.82 |
| TOTAL/m2 | | 73.74 | | 70.78 | 138.33 | 47.14 | 329.98 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 1: SEMI-TRANSPARENT SINGLE-GLAZED PV ROOF

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Cincinnati | Longitude | 39.15 N | | | | |
| | | Latitude | 84.52 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate continental | Altitude | 232.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 6.20 | -3.30 | 85.00 | 40.00 | 108.00 | 10.00 | 10.80 | 20.20 | 68 | 83 |
| February | 6.30 | -2.90 | 130.00 | 55.00 | 129.00 | 10.24 | 12.60 | 15.40 | 64 | 81 |
| March | 11.10 | 0.70 | 190.00 | 75.00 | 173.00 | 11.16 | 15.50 | 15.50 | 57 | 79 |
| April | 18.00 | 6.60 | 250.00 | 100.00 | 201.00 | 11.96 | 16.80 | 13.20 | 53 | 76 |
| May | 23.80 | 11.90 | 290.00 | 120.00 | 241.00 | 12.74 | 18.91 | 12.09 | 53 | 78 |
| June | 28.80 | 17.20 | 305.00 | 125.00 | 305.00 | 14.73 | 20.70 | 9.30 | 55 | 80 |
| July | 30.80 | 19.10 | 290.00 | 120.00 | 322.00 | 14.43 | 22.32 | 8.68 | 52 | 82 |
| August | 30.20 | 18.30 | 250.00 | 100.00 | 291.00 | 13.41 | 21.70 | 9.30 | 52 | 86 |
| September | 26.80 | 14.20 | 190.00 | 75.00 | 254.00 | 12.45 | 20.40 | 9.60 | 50 | 86 |
| October | 20.50 | 8.20 | 130.00 | 55.00 | 213.00 | 11.26 | 18.91 | 12.09 | 61 | 85 |
| November | 11.80 | 2.20 | 85.00 | 40.00 | 145.00 | 10.51 | 13.80 | 16.20 | 60 | 81 |
| December | 5.90 | -2.30 | 70.00 | 35.00 | 126.00 | 10.16 | 12.40 | 18.60 | 68 | 82 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 18.00 |

### PV PANEL DATA

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.05 |
| Thermal Transmittance | W/m2oC | 6.00 |
| PV slope | (°) | 0.00 |

### INTERNAL TEMPERATURES

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 3.83 | -0.25 | 207.60 | 0.00 | 96.00 | 0.00 | 10.80 | 20.20 | 11.96 | 6.36 |
| February | 4.00 | 0.06 | 284.20 | 5.00 | 128.93 | 2.19 | 12.60 | 15.40 | 11.79 | 6.71 |
| March | 8.50 | 4.04 | 381.68 | 31.66 | 161.27 | 13.38 | 15.50 | 15.50 | 18.91 | 13.69 |
| April | 15.15 | 10.26 | 471.40 | 66.14 | 200.60 | 28.14 | 16.80 | 13.20 | 31.24 | 26.31 |
| May | 20.83 | 15.73 | 521.63 | 102.26 | 225.98 | 44.30 | 18.91 | 12.09 | 43.93 | 40.35 |
| June | 25.90 | 20.93 | 472.37 | 159.74 | 203.61 | 68.85 | 20.70 | 9.30 | 57.64 | 56.01 |
| July | 27.88 | 22.86 | 460.82 | 145.70 | 199.53 | 63.12 | 22.32 | 8.68 | 61.04 | 63.03 |
| August | 27.23 | 22.13 | 420.58 | 102.44 | 178.97 | 43.59 | 21.70 | 9.30 | 59.33 | 62.55 |
| September | 23.65 | 18.25 | 342.14 | 59.90 | 144.57 | 25.31 | 20.40 | 9.60 | 49.24 | 50.29 |
| October | 17.43 | 12.15 | 267.40 | 24.14 | 117.19 | 10.58 | 18.91 | 12.09 | 38.98 | 32.94 |
| November | 9.40 | 5.29 | 197.58 | 7.16 | 91.37 | 3.31 | 13.80 | 16.20 | 21.21 | 16.41 |
| December | 3.85 | 0.34 | 173.60 | 2.00 | 82.67 | 0.95 | 12.40 | 18.60 | 12.00 | 7.27 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -50.63 | 25.00 | -25.63 | -97.48 | 4.50 | -92.98 | -14.06 | -2.77 | -5.07 | 0.00 |
| February | -27.72 | 25.00 | -2.72 | -94.39 | 4.50 | -89.89 | -15.86 | -0.34 | -5.96 | 0.00 |
| March | 21.37 | 25.00 | 46.37 | -63.75 | 4.50 | -59.25 | -12.86 | 7.19 | -5.21 | 0.00 |
| April | 83.93 | 25.00 | 108.93 | -17.71 | 4.50 | -13.21 | -3.11 | 18.30 | -1.57 | 0.00 |
| May | 130.66 | 25.00 | 155.66 | 9.17 | 4.50 | 13.67 | 0.00 | 33.06 | 0.00 | 0.00 |
| June | 148.67 | 25.00 | 173.67 | 19.91 | 4.50 | 24.41 | 0.00 | 43.02 | 0.00 | 4.06 |
| July | 157.61 | 25.00 | 182.61 | 17.95 | 4.50 | 22.45 | 0.00 | 47.77 | 0.00 | 5.83 |
| August | 143.55 | 25.00 | 168.55 | 12.62 | 4.50 | 17.12 | 0.00 | 41.77 | 0.00 | 4.96 |
| September | 102.29 | 25.00 | 127.29 | 4.62 | 4.50 | 9.12 | 0.00 | 28.57 | 0.00 | 0.71 |
| October | 46.07 | 25.00 | 71.07 | -16.98 | 4.50 | -12.48 | -3.30 | 13.44 | 0.00 | 0.00 |
| November | -19.71 | 25.00 | 5.29 | -62.48 | 4.50 | -57.98 | -11.20 | 0.73 | -4.03 | 0.00 |
| December | -59.07 | 25.00 | -34.07 | -93.48 | 4.50 | -88.98 | -15.45 | -4.22 | -5.81 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -78.81 | 45.00 | -33.81 | -97.48 | 4.50 | -92.98 | -26.29 | -6.83 | -9.48 | 0.00 |
| February | -69.45 | 40.00 | -29.45 | -85.10 | 4.50 | -80.60 | -19.53 | -4.53 | -7.28 | 0.00 |
| March | -34.28 | 35.00 | 0.72 | -68.37 | 4.50 | -63.87 | -13.86 | 0.11 | -5.21 | 0.00 |
| April | 15.55 | 30.00 | 45.55 | -27.31 | 4.50 | -22.81 | -4.21 | 6.01 | -1.31 | 0.00 |
| May | 56.01 | 25.00 | 81.01 | -5.46 | 4.50 | -0.96 | -0.16 | 9.79 | 0.00 | 0.00 |
| June | 80.81 | 25.00 | 105.81 | 10.96 | 4.50 | 15.46 | 0.00 | 11.85 | 0.00 | 1.82 |
| July | 91.66 | 25.00 | 116.66 | 12.10 | 4.50 | 16.60 | 0.00 | 12.14 | 0.00 | 2.27 |
| August | 82.54 | 25.00 | 107.54 | 7.76 | 4.50 | 12.26 | 0.00 | 11.50 | 0.00 | 2.13 |
| September | 52.40 | 30.00 | 82.40 | -4.11 | 4.50 | 0.39 | 0.00 | 7.96 | 0.00 | 0.33 |
| October | 8.14 | 35.00 | 43.14 | -20.41 | 4.50 | -15.91 | -2.69 | 5.22 | 0.00 | 0.00 |
| November | -46.53 | 40.00 | -6.53 | -63.45 | 4.50 | -58.95 | -13.37 | -1.06 | -4.73 | 0.00 |
| December | -82.03 | 45.00 | -37.03 | -93.75 | 4.50 | -89.25 | -23.24 | -6.89 | -8.72 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 12.20 | 13.23 | 6.68 | 32.10 |
| February | 0.00 | 0.00 | 0.22 | 10.81 | 11.95 | 4.69 | 27.44 |
| March | 0.00 | 0.00 | 0.22 | 8.25 | 13.23 | 4.19 | 25.67 |
| April | 0.29 | 6.95 | 0.22 | 2.29 | 12.80 | 3.21 | 25.25 |
| May | 0.29 | 12.24 | 0.22 | 0.04 | 13.23 | 2.64 | 28.14 |
| June | 0.29 | 17.36 | 0.22 | 0.00 | 12.80 | 2.55 | 32.71 |
| July | 0.29 | 19.43 | 0.22 | 0.00 | 13.23 | 2.64 | 35.30 |
| August | 0.29 | 17.27 | 0.22 | 0.00 | 13.23 | 2.64 | 33.14 |
| September | 0.29 | 10.74 | 0.22 | 0.00 | 12.80 | 3.03 | 26.57 |
| October | 0.29 | 5.33 | 0.22 | 1.33 | 13.23 | 3.84 | 23.73 |
| November | 0.00 | 0.00 | 0.22 | 7.41 | 12.80 | 4.98 | 25.19 |
| December | 0.00 | 0.00 | 0.22 | 11.83 | 13.23 | 6.36 | 31.41 |
| TOTAL/m2 | | 89.32 | | 54.15 | 155.75 | 47.42 | 346.65 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 2: SEMI-TRANSPARENT DOUBLE GLAZED PV ROOF

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | San Francisco | Longitude | 37.62 N | | | | |
| | | Latitude | 122.38 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate costal warm | Altitude | 2.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 13.00 | 5.40 | 85.00 | 40.00 | 154.00 | 10.00 | 15.40 | 15.60 | 75 | 85 |
| February | 14.70 | 6.30 | 130.00 | 55.00 | 191.00 | 11.56 | 16.52 | 11.48 | 71 | 85 |
| March | 16.40 | 7.20 | 190.00 | 75.00 | 262.00 | 12.43 | 21.08 | 9.92 | 66 | 83 |
| April | 17.90 | 8.40 | 250.00 | 100.00 | 297.00 | 13.94 | 21.30 | 8.70 | 66 | 85 |
| May | 19.40 | 9.80 | 290.00 | 120.00 | 328.00 | 14.90 | 22.01 | 8.99 | 66 | 85 |
| June | 21.20 | 11.30 | 305.00 | 125.00 | 341.00 | 15.36 | 22.20 | 7.80 | 65 | 87 |
| July | 22.20 | 11.90 | 290.00 | 120.00 | 295.00 | 14.20 | 20.77 | 10.23 | 69 | 90 |
| August | 22.10 | 12.10 | 250.00 | 100.00 | 275.00 | 13.65 | 20.15 | 10.85 | 69 | 90 |
| September | 23.20 | 12.20 | 190.00 | 75.00 | 275.00 | 12.73 | 21.60 | 8.40 | 66 | 88 |
| October | 21.40 | 10.30 | 130.00 | 55.00 | 242.00 | 11.31 | 21.39 | 9.61 | 65 | 86 |
| November | 17.80 | 7.70 | 85.00 | 40.00 | 198.00 | 10.00 | 19.80 | 10.20 | 68 | 84 |
| December | 14.00 | 6.10 | 70.00 | 35.00 | 179.00 | 10.31 | 17.36 | 13.64 | 74 | 86 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | | |
|---|---|---|---|
| Conversion Efficiency | % | 10.00 | |
| Direct Transmittance | % | 0.03 | |
| Thermal Transmittance | W/m2oC | 2.00 | |
| PV slope | (°) | 0.00 | |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### INTERNAL TEMPERATURES

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 11.10 | 7.84 | 207.60 | 0.00 | 96.00 | 0.00 | 15.40 | 15.60 | 28.01 | 22.52 |
| February | 12.60 | 9.00 | 260.51 | 29.06 | 114.17 | 12.74 | 16.52 | 11.48 | 30.55 | 25.18 |
| March | 14.10 | 10.16 | 342.75 | 59.46 | 144.82 | 25.13 | 21.08 | 9.92 | 32.71 | 27.53 |
| April | 15.53 | 11.45 | 404.48 | 113.94 | 172.12 | 48.48 | 21.30 | 8.70 | 36.08 | 31.15 |
| May | 17.00 | 12.89 | 446.11 | 156.21 | 193.26 | 67.67 | 22.01 | 8.99 | 39.69 | 34.84 |
| June | 18.73 | 14.48 | 453.11 | 173.49 | 195.31 | 74.78 | 22.20 | 7.80 | 43.67 | 39.69 |
| July | 19.63 | 15.21 | 468.06 | 140.53 | 202.77 | 60.88 | 20.77 | 10.23 | 47.62 | 42.64 |
| August | 19.60 | 15.31 | 413.26 | 107.67 | 175.85 | 45.82 | 20.15 | 10.85 | 47.55 | 42.94 |
| September | 20.45 | 15.74 | 334.60 | 65.28 | 141.38 | 27.58 | 21.60 | 8.40 | 48.59 | 43.54 |
| October | 18.63 | 13.87 | 266.23 | 24.98 | 116.67 | 10.95 | 21.39 | 9.61 | 43.42 | 37.72 |
| November | 15.28 | 10.95 | 207.60 | 0.00 | 96.00 | 0.00 | 19.80 | 10.20 | 36.10 | 29.66 |
| December | 12.03 | 8.64 | 171.08 | 3.80 | 81.47 | 1.81 | 17.36 | 13.64 | 29.94 | 24.53 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -2.30 | 25.00 | 22.70 | -16.31 | 4.50 | -11.81 | -2.55 | 3.50 | -2.48 | 0.00 |
| February | 5.16 | 25.00 | 30.16 | -11.55 | 4.50 | -7.05 | -1.63 | 4.98 | -1.86 | 0.00 |
| March | 15.09 | 25.00 | 40.09 | -6.67 | 4.50 | -2.17 | -0.64 | 8.45 | -1.50 | 0.00 |
| April | 23.15 | 25.00 | 48.15 | 0.51 | 4.50 | 5.01 | 0.00 | 11.75 | -0.14 | 0.00 |
| May | 29.61 | 25.00 | 54.61 | 3.61 | 4.50 | 8.11 | 0.00 | 14.52 | 0.00 | 0.00 |
| June | 33.65 | 25.00 | 58.65 | 6.59 | 4.50 | 11.09 | 0.00 | 16.47 | 0.00 | 0.00 |
| July | 36.71 | 25.00 | 61.71 | 5.27 | 4.50 | 9.77 | 0.00 | 15.66 | 0.00 | 0.08 |
| August | 32.04 | 25.00 | 57.04 | 2.71 | 4.50 | 7.21 | 0.00 | 13.53 | 0.00 | 0.05 |
| September | 27.11 | 25.00 | 52.11 | -0.03 | 4.50 | 4.47 | 0.00 | 12.61 | 0.00 | 0.48 |
| October | 17.69 | 25.00 | 42.69 | -2.16 | 4.50 | 2.34 | 0.00 | 9.83 | 0.00 | 0.00 |
| November | 6.05 | 25.00 | 31.05 | -10.11 | 4.50 | -5.61 | -1.55 | 6.15 | -0.12 | 0.00 |
| December | -3.53 | 25.00 | 21.47 | -14.40 | 4.50 | -9.90 | -2.41 | 3.73 | -2.16 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -11.71 | 45.00 | 33.29 | -16.31 | 4.50 | -11.81 | -2.58 | 5.19 | -2.52 | 0.00 |
| February | -7.18 | 40.00 | 32.82 | -12.93 | 4.50 | -8.43 | -1.35 | 3.77 | -1.29 | 0.00 |
| March | -1.59 | 35.00 | 33.41 | -9.57 | 4.50 | -5.07 | -0.70 | 3.31 | -0.71 | 0.00 |
| April | 3.56 | 30.00 | 33.56 | -5.01 | 4.50 | -0.51 | -0.06 | 2.92 | -0.06 | 0.00 |
| May | 8.29 | 25.00 | 33.29 | -0.52 | 4.50 | 3.98 | 0.00 | 3.49 | 0.00 | 0.00 |
| June | 11.91 | 25.00 | 36.91 | 3.27 | 4.50 | 7.77 | 0.00 | 3.73 | 0.00 | 0.00 |
| July | 14.34 | 25.00 | 39.34 | 3.55 | 4.50 | 8.05 | 0.00 | 5.18 | 0.00 | 0.04 |
| August | 12.02 | 25.00 | 37.02 | 2.49 | 4.50 | 6.99 | 0.00 | 5.08 | 0.00 | 0.03 |
| September | 10.82 | 30.00 | 40.82 | 1.80 | 4.50 | 6.30 | 0.00 | 4.17 | 0.00 | 0.19 |
| October | 5.09 | 35.00 | 40.09 | -3.34 | 4.50 | 1.16 | 0.00 | 4.01 | 0.00 | 0.00 |
| November | -3.36 | 40.00 | 36.64 | -10.11 | 4.50 | -5.61 | -0.80 | 3.74 | -0.06 | 0.00 |
| December | -11.08 | 45.00 | 33.92 | -14.57 | 4.50 | -10.07 | -1.92 | 4.63 | -1.69 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 2.25 | 4.47 | 5.76 | 12.47 |
| February | 0.00 | 0.00 | 0.22 | 1.36 | 4.03 | 4.10 | 9.50 |
| March | 0.00 | 0.00 | 0.22 | 0.79 | 4.47 | 3.63 | 8.88 |
| April | 0.29 | 4.19 | 0.22 | 0.06 | 4.32 | 2.99 | 11.56 |
| May | 0.29 | 5.15 | 0.22 | 0.00 | 4.47 | 2.64 | 12.25 |
| June | 0.29 | 5.77 | 0.22 | 0.00 | 4.32 | 2.55 | 12.64 |
| July | 0.29 | 5.99 | 0.22 | 0.00 | 4.47 | 2.64 | 13.09 |
| August | 0.29 | 5.34 | 0.22 | 0.00 | 4.47 | 2.64 | 12.44 |
| September | 0.29 | 4.98 | 0.22 | 0.00 | 4.32 | 2.97 | 12.28 |
| October | 0.29 | 3.95 | 0.22 | 0.00 | 4.47 | 3.60 | 12.02 |
| November | 0.29 | 2.82 | 0.22 | 0.56 | 4.32 | 4.08 | 11.79 |
| December | 0.00 | 0.00 | 0.22 | 1.82 | 4.47 | 5.36 | 11.65 |
| TOTAL/m2 | | 38.19 | | 6.84 | 52.60 | 42.93 | 140.56 |

## OPTION 2: SEMI-TRANSPARENT DOUBLE GLAZED PV ROOF

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | New York | Longitude | 40.70 N | | | | |
| | | Latitude | 74.02 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate costal cold | Altitude | 3.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 4.30 | -2.80 | 85.00 | 40.00 | 151.00 | 10.00 | 15.10 | 15.90 | 61 | 69 |
| February | 4.10 | -2.40 | 130.00 | 55.00 | 164.00 | 10.28 | 15.96 | 12.04 | 58 | 67 |
| March | 8.90 | 0.60 | 190.00 | 75.00 | 209.00 | 11.83 | 17.67 | 13.33 | 56 | 67 |
| April | 14.90 | 6.10 | 250.00 | 100.00 | 214.00 | 12.09 | 17.70 | 12.30 | 55 | 68 |
| May | 20.90 | 11.80 | 290.00 | 120.00 | 250.00 | 13.44 | 18.60 | 12.40 | 56 | 69 |
| June | 25.60 | 16.90 | 305.00 | 125.00 | 301.00 | 16.18 | 18.60 | 11.40 | 58 | 72 |
| July | 28.30 | 19.90 | 290.00 | 120.00 | 307.00 | 15.00 | 20.46 | 10.54 | 57 | 74 |
| August | 27.40 | 19.30 | 250.00 | 100.00 | 275.00 | 13.86 | 19.84 | 11.16 | 60 | 76 |
| September | 23.80 | 15.80 | 190.00 | 75.00 | 237.00 | 12.54 | 18.90 | 11.10 | 60 | 76 |
| October | 18.40 | 10.30 | 130.00 | 55.00 | 218.00 | 11.34 | 19.22 | 11.78 | 59 | 74 |
| November | 11.90 | 4.40 | 85.00 | 40.00 | 172.00 | 10.06 | 17.10 | 12.90 | 60 | 71 |
| December | 5.70 | -1.20 | 70.00 | 35.00 | 158.00 | 10.00 | 15.80 | 15.20 | 60 | 67 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.03 |
| Thermal Transmittance | W/m2oC | 2.00 |
| PV slope | (°) | 0.00 |

### INTERNAL TEMPERATURES

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 2.53 | -0.52 | 207.60 | 0.00 | 96.00 | 0.00 | 15.10 | 15.90 | 8.95 | 4.83 |
| February | 2.48 | -0.31 | 293.12 | 5.77 | 128.46 | 2.53 | 15.96 | 12.04 | 8.56 | 4.99 |
| March | 6.83 | 3.27 | 360.16 | 47.03 | 152.18 | 19.87 | 17.67 | 13.33 | 15.67 | 10.86 |
| April | 12.70 | 8.93 | 466.49 | 69.65 | 198.50 | 29.64 | 17.70 | 12.30 | 26.71 | 21.80 |
| May | 18.63 | 14.73 | 494.61 | 121.56 | 214.27 | 52.66 | 18.60 | 12.40 | 39.98 | 35.06 |
| June | 23.43 | 19.70 | 430.09 | 189.94 | 185.38 | 81.87 | 18.60 | 11.40 | 52.74 | 49.03 |
| July | 26.20 | 22.60 | 443.06 | 158.39 | 191.94 | 68.62 | 20.46 | 10.54 | 59.60 | 58.33 |
| August | 25.38 | 21.90 | 406.90 | 112.21 | 173.15 | 47.75 | 19.84 | 11.16 | 59.06 | 57.18 |
| September | 21.80 | 18.37 | 339.72 | 61.63 | 143.54 | 26.04 | 18.90 | 11.10 | 49.48 | 46.90 |
| October | 16.38 | 12.90 | 265.55 | 25.46 | 116.38 | 11.16 | 19.22 | 11.78 | 35.84 | 32.04 |
| November | 10.03 | 6.81 | 206.39 | 0.86 | 95.44 | 0.40 | 17.10 | 12.90 | 22.45 | 18.01 |
| December | 3.98 | 1.02 | 176.40 | 0.00 | 84.00 | 0.00 | 15.80 | 15.20 | 11.26 | 7.09 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -19.45 | 25.00 | 5.55 | -33.04 | 4.50 | -28.54 | -6.03 | 0.84 | -7.96 | 0.00 |
| February | -12.34 | 25.00 | 12.66 | -32.13 | 4.50 | -27.63 | -6.17 | 2.02 | -8.54 | 0.00 |
| March | 2.01 | 25.00 | 27.01 | -21.50 | 4.50 | -17.00 | -4.21 | 4.77 | -7.04 | 0.00 |
| April | 22.72 | 25.00 | 47.72 | -8.27 | 4.50 | -3.77 | -0.93 | 8.45 | -3.30 | 0.00 |
| May | 36.95 | 25.00 | 61.95 | -2.30 | 4.50 | 2.20 | 0.00 | 12.09 | 0.00 | 0.00 |
| June | 41.11 | 25.00 | 66.11 | 6.74 | 4.50 | 11.24 | 0.00 | 15.22 | 0.00 | 1.90 |
| July | 47.75 | 25.00 | 72.75 | 6.55 | 4.50 | 11.05 | 0.00 | 18.05 | 0.00 | 4.78 |
| August | 43.05 | 25.00 | 68.05 | 4.60 | 4.50 | 9.10 | 0.00 | 16.03 | 0.00 | 4.43 |
| September | 30.24 | 25.00 | 55.24 | -0.06 | 4.50 | 4.44 | 0.00 | 11.61 | 0.00 | 0.75 |
| October | 13.14 | 25.00 | 38.14 | -4.05 | 4.50 | 0.45 | 0.00 | 7.45 | -0.21 | 0.00 |
| November | -4.55 | 25.00 | 20.45 | -18.31 | 4.50 | -13.81 | -3.31 | 3.50 | -4.58 | 0.00 |
| December | -19.18 | 25.00 | 5.82 | -29.96 | 4.50 | -25.46 | -5.63 | 0.92 | -7.63 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -28.86 | 45.00 | 16.14 | -33.04 | 4.50 | -28.54 | -6.35 | 2.57 | -8.38 | 0.00 |
| February | -26.22 | 40.00 | 13.78 | -32.41 | 4.50 | -27.91 | -4.70 | 1.66 | -6.44 | 0.00 |
| March | -15.52 | 35.00 | 19.48 | -23.79 | 4.50 | -19.29 | -3.60 | 2.60 | -5.31 | 0.00 |
| April | 0.13 | 30.00 | 30.13 | -11.64 | 4.50 | -7.14 | -1.23 | 3.71 | -2.29 | 0.00 |
| May | 13.31 | 25.00 | 38.31 | 1.89 | 4.50 | 6.39 | 0.00 | 5.86 | 0.00 | 0.00 |
| June | 20.48 | 25.00 | 45.48 | 3.29 | 4.50 | 7.79 | 0.00 | 6.43 | 0.00 | 1.16 |
| July | 26.58 | 25.00 | 51.58 | 3.98 | 4.50 | 8.48 | 0.00 | 6.69 | 0.00 | 2.46 |
| August | 23.35 | 25.00 | 48.35 | 2.50 | 4.50 | 7.00 | 0.00 | 6.49 | 0.00 | 2.49 |
| September | 13.70 | 30.00 | 43.70 | -2.06 | 4.50 | 2.44 | 0.00 | 5.23 | 0.00 | 0.44 |
| October | 0.56 | 35.00 | 35.56 | -5.25 | 4.50 | -0.75 | -0.12 | 4.19 | -0.13 | 0.00 |
| November | -13.90 | 40.00 | 26.10 | -18.34 | 4.50 | -13.84 | -2.50 | 3.37 | -3.46 | 0.00 |
| December | -26.97 | 45.00 | 18.03 | -29.96 | 4.50 | -25.46 | -5.42 | 2.74 | -7.34 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 6.38 | 5.04 | 5.82 | 17.23 |
| February | 0.00 | 0.00 | 0.22 | 5.75 | 4.55 | 4.19 | 14.48 |
| March | 0.00 | 0.00 | 0.22 | 4.48 | 5.04 | 3.97 | 13.48 |
| April | 0.00 | 0.00 | 0.22 | 1.72 | 4.87 | 3.17 | 9.76 |
| May | 0.29 | 5.13 | 0.22 | 0.00 | 5.04 | 2.64 | 12.80 |
| June | 0.29 | 7.06 | 0.22 | 0.00 | 4.87 | 2.55 | 14.48 |
| July | 0.29 | 9.14 | 0.22 | 0.00 | 5.04 | 2.64 | 16.81 |
| August | 0.29 | 8.41 | 0.22 | 0.00 | 5.04 | 2.64 | 16.08 |
| September | 0.29 | 5.15 | 0.22 | 0.00 | 4.87 | 3.11 | 13.13 |
| October | 0.29 | 3.33 | 0.22 | 0.10 | 5.04 | 3.81 | 12.28 |
| November | 0.00 | 0.00 | 0.22 | 3.08 | 4.87 | 4.49 | 12.44 |
| December | 0.00 | 0.00 | 0.22 | 5.78 | 5.04 | 5.68 | 16.49 |
| TOTAL/m2 | | 38.22 | | 27.30 | 59.28 | 44.67 | 169.47 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 2: SEMI-TRANSPARENT DOUBLE GLAZED PV ROOF

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Phoenix | Longitude | 33.43 N | | | | |
| | | Latitude | 112.02 W | Direct Radiation Factor | 1.10 | | |
| Climate | Temperate arid | Altitude | 340.00 m | Diffuse Radiation Factor | 0.90 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 17.80 | 1.80 | 105.00 | 25.00 | 262.00 | 10.84 | 24.18 | 6.82 | 44 | 72 |
| February | 20.10 | 3.80 | 150.00 | 30.00 | 271.00 | 12.41 | 21.84 | 6.16 | 42 | 71 |
| March | 23.90 | 6.10 | 205.00 | 35.00 | 331.00 | 12.56 | 26.35 | 4.65 | 31 | 60 |
| April | 28.80 | 10.20 | 260.00 | 45.00 | 360.00 | 13.48 | 26.70 | 3.30 | 26 | 50 |
| May | 33.80 | 13.90 | 295.00 | 45.00 | 408.00 | 14.00 | 29.14 | 1.86 | 19 | 41 |
| June | 38.70 | 18.60 | 305.00 | 50.00 | 411.00 | 14.57 | 28.20 | 1.80 | 17 | 37 |
| July | 40.30 | 23.90 | 295.00 | 45.00 | 390.00 | 14.30 | 27.28 | 3.72 | 29 | 51 |
| August | 38.70 | 23.00 | 260.00 | 45.00 | 379.00 | 14.22 | 26.66 | 4.34 | 35 | 60 |
| September | 36.80 | 19.60 | 205.00 | 35.00 | 354.00 | 13.11 | 27.00 | 3.00 | 29 | 66 |
| October | 30.40 | 12.60 | 150.00 | 30.00 | 323.00 | 11.98 | 26.97 | 4.03 | 30 | 58 |
| November | 23.20 | 5.80 | 105.00 | 25.00 | 282.00 | 10.93 | 25.80 | 4.20 | 33 | 83 |
| December | 18.90 | 2.80 | 90.00 | 25.00 | 260.00 | 10.75 | 24.18 | 6.82 | 42 | 70 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

**PV PANEL DATA**

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.03 |
| Thermal Transmittance | W/m2oC | 2.00 |
| PV slope (°) | | 0.00 |

**INTERNAL TEMPERATURES**

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

**HUMIDITY-WINTER**

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

**HUMIDITY-SUMMER**

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 13.80 | 6.94 | 305.66 | 18.24 | 110.75 | 6.51 | 24.18 | 6.82 | 25.94 | 18.43 |
| February | 16.03 | 9.04 | 371.36 | 63.89 | 116.05 | 19.96 | 21.84 | 6.16 | 29.56 | 22.60 |
| March | 19.45 | 11.82 | 491.02 | 89.84 | 133.74 | 24.47 | 26.35 | 4.65 | 31.89 | 26.13 |
| April | 24.15 | 16.18 | 581.17 | 144.59 | 160.20 | 39.86 | 26.70 | 3.30 | 37.82 | 32.46 |
| May | 28.83 | 20.30 | 625.65 | 178.82 | 154.27 | 44.09 | 29.14 | 1.86 | 41.52 | 37.62 |
| June | 33.68 | 25.06 | 626.58 | 204.73 | 164.67 | 53.81 | 28.20 | 1.80 | 47.87 | 45.49 |
| July | 36.20 | 29.17 | 612.75 | 188.04 | 151.09 | 46.36 | 27.28 | 3.72 | 63.15 | 63.82 |
| August | 34.78 | 28.05 | 551.21 | 165.99 | 151.94 | 45.76 | 26.66 | 4.34 | 65.41 | 66.63 |
| September | 32.50 | 25.13 | 470.44 | 104.54 | 128.14 | 28.47 | 27.00 | 3.00 | 55.49 | 61.70 |
| October | 25.95 | 18.32 | 384.76 | 54.31 | 120.24 | 16.97 | 26.97 | 4.03 | 43.31 | 40.03 |
| November | 18.85 | 11.39 | 303.01 | 20.13 | 109.79 | 7.29 | 25.80 | 4.20 | 31.61 | 30.54 |
| December | 14.88 | 7.98 | 271.19 | 14.58 | 111.60 | 6.00 | 24.18 | 6.82 | 27.38 | 20.20 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | 11.37 | 25.00 | 36.37 | -16.58 | 4.50 | -12.08 | -4.09 | 8.79 | -4.86 | 0.00 |
| February | 21.36 | 25.00 | 46.36 | -8.54 | 4.50 | -4.04 | -1.23 | 10.12 | -2.88 | 0.00 |
| March | 38.29 | 25.00 | 63.29 | -0.78 | 4.50 | 3.72 | 0.00 | 18.05 | -2.29 | 0.00 |
| April | 55.29 | 25.00 | 80.29 | 2.55 | 4.50 | 7.05 | 0.00 | 24.07 | 0.00 | 0.00 |
| May | 68.39 | 25.00 | 93.39 | 13.67 | 4.50 | 18.17 | 0.00 | 34.63 | 0.00 | 0.00 |
| June | 78.17 | 25.00 | 103.17 | 15.38 | 4.50 | 19.88 | 0.00 | 36.94 | 0.00 | 0.24 |
| July | 82.05 | 25.00 | 107.05 | 22.19 | 4.50 | 26.69 | 0.00 | 39.40 | 0.00 | 8.24 |
| August | 74.02 | 25.00 | 99.02 | 18.09 | 4.50 | 22.59 | 0.00 | 34.83 | 0.00 | 9.21 |
| September | 62.66 | 25.00 | 87.66 | 7.07 | 4.50 | 11.57 | 0.00 | 28.04 | 0.00 | 4.18 |
| October | 42.34 | 25.00 | 67.34 | -0.78 | 4.50 | 3.72 | 0.00 | 19.57 | 0.00 | 0.00 |
| November | 21.24 | 25.00 | 46.24 | -7.52 | 4.50 | -3.02 | -1.09 | 11.93 | -2.38 | 0.00 |
| December | 10.61 | 25.00 | 35.61 | -14.82 | 4.50 | -10.32 | -3.49 | 8.61 | -4.19 | 0.00 |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -5.06 | 45.00 | 39.94 | -17.56 | 4.50 | -13.06 | -1.25 | 2.72 | -1.37 | 0.00 |
| February | -0.17 | 40.00 | 39.83 | -12.24 | 4.50 | -7.74 | -0.67 | 2.45 | -0.81 | 0.00 |
| March | 8.17 | 35.00 | 43.17 | -6.29 | 4.50 | -1.79 | -0.12 | 2.01 | -0.40 | 0.00 |
| April | 19.80 | 30.00 | 49.80 | -1.28 | 4.50 | 3.22 | 0.00 | 1.79 | 0.00 | 0.00 |
| May | 28.66 | 25.00 | 53.66 | 2.31 | 4.50 | 6.81 | 0.00 | 1.18 | 0.00 | 0.00 |
| June | 39.23 | 25.00 | 64.23 | 7.66 | 4.50 | 12.16 | 0.00 | 1.46 | 0.00 | 0.02 |
| July | 43.14 | 25.00 | 68.14 | 10.25 | 4.50 | 14.75 | 0.00 | 3.30 | 0.00 | 1.12 |
| August | 40.36 | 25.00 | 65.36 | 7.95 | 4.50 | 12.45 | 0.00 | 3.59 | 0.00 | 1.50 |
| September | 33.80 | 30.00 | 63.80 | 0.66 | 4.50 | 5.16 | 0.00 | 2.13 | 0.00 | 0.46 |
| October | 20.04 | 35.00 | 55.04 | -3.93 | 4.50 | 0.57 | 0.00 | 2.25 | 0.00 | 0.00 |
| November | 4.96 | 40.00 | 44.96 | -8.60 | 4.50 | -4.10 | -0.24 | 1.89 | -0.39 | 0.00 |
| December | -2.84 | 45.00 | 42.16 | -15.54 | 4.50 | -11.04 | -1.05 | 2.88 | -1.18 | 0.00 |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and Power kWh | Total kWh Consumed |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | | |
| January | 0.00 | 0.00 | 0.22 | 2.57 | 7.86 | 4.00 | 14.43 |
| February | 0.29 | 3.59 | 0.22 | 1.24 | 7.10 | 3.30 | 15.24 |
| March | 0.29 | 5.73 | 0.22 | 0.62 | 7.86 | 3.10 | 17.31 |
| April | 0.29 | 7.39 | 0.22 | 0.00 | 7.60 | 2.72 | 17.71 |
| May | 0.29 | 10.23 | 0.22 | 0.00 | 7.86 | 2.64 | 20.72 |
| June | 0.29 | 11.05 | 0.22 | 0.00 | 7.60 | 2.55 | 21.20 |
| July | 0.29 | 14.87 | 0.22 | 0.00 | 7.86 | 2.64 | 25.37 |
| August | 0.29 | 14.04 | 0.22 | 0.00 | 7.86 | 2.64 | 24.53 |
| September | 0.29 | 9.95 | 0.22 | 0.00 | 7.60 | 2.70 | 20.25 |
| October | 0.29 | 6.23 | 0.22 | 0.00 | 7.86 | 3.04 | 17.13 |
| November | 0.29 | 3.95 | 0.22 | 0.91 | 7.60 | 3.18 | 15.64 |
| December | 0.00 | 0.00 | 0.22 | 2.21 | 7.86 | 4.00 | 14.06 |
| TOTAL/m2 | | 87.03 | | 7.55 | 92.52 | 36.49 | 223.59 |

## OPTION 2: SEMI-TRANSPARENT DOUBLE GLAZED PV ROOF

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Miami | Longitude | 25.80 N | | | | |
| | | Latitude | 80.27 W | Direct Radiation Factor | 0.50 | | |
| Climate | Sub-tropical | Altitude | 2.00 m | Diffuse Radiation Factor | 1.10 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 24.30 | 14.40 | 150.00 | 65.00 | 239.00 | 11.51 | 20.77 | 10.23 | 59 | 84 |
| February | 25.00 | 14.80 | 195.00 | 80.00 | 233.00 | 11.72 | 19.88 | 8.12 | 56 | 84 |
| March | 26.60 | 16.20 | 235.00 | 95.00 | 269.00 | 12.22 | 22.01 | 8.99 | 56 | 82 |
| April | 28.10 | 18.80 | 275.00 | 115.00 | 283.00 | 13.10 | 21.60 | 8.40 | 56 | 79 |
| May | 29.70 | 20.90 | 295.00 | 125.00 | 276.00 | 13.49 | 20.46 | 10.54 | 59 | 78 |
| June | 31.10 | 23.10 | 295.00 | 125.00 | 255.00 | 13.93 | 18.30 | 11.70 | 64 | 81 |
| July | 31.60 | 23.70 | 295.00 | 125.00 | 270.00 | 13.82 | 19.53 | 11.47 | 64 | 81 |
| August | 32.10 | 23.80 | 275.00 | 115.00 | 261.00 | 13.16 | 19.84 | 11.16 | 63 | 83 |
| September | 31.10 | 23.70 | 235.00 | 95.00 | 212.00 | 11.98 | 17.70 | 12.30 | 66 | 85 |
| October | 29.30 | 21.60 | 195.00 | 80.00 | 200.00 | 11.73 | 17.05 | 13.95 | 64 | 85 |
| November | 26.80 | 18.10 | 150.00 | 65.00 | 224.00 | 11.31 | 19.80 | 10.20 | 60 | 84 |
| December | 26.10 | 15.10 | 135.00 | 55.00 | 221.00 | 11.14 | 19.84 | 11.16 | 60 | 85 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

**PV PANEL DATA**

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.03 |
| Thermal Transmittance W/m2oC | | 2.00 |
| PV slope (°) | | 0.00 |

**INTERNAL TEMPERATURES**

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

**HUMIDITY-WINTER**

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

**HUMIDITY-SUMMER**

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 21.83 | 17.58 | 305.55 | 32.89 | 135.57 | 14.59 | 20.77 | 10.23 | 49.08 | 47.57 |
| February | 22.48 | 18.15 | 379.85 | 46.68 | 163.82 | 20.13 | 19.88 | 8.12 | 49.32 | 49.23 |
| March | 24.00 | 19.54 | 435.95 | 69.18 | 186.55 | 29.60 | 22.01 | 8.99 | 53.21 | 52.64 |
| April | 25.78 | 21.78 | 483.60 | 107.15 | 210.66 | 46.67 | 21.60 | 8.40 | 57.88 | 58.21 |
| May | 27.50 | 23.73 | 507.05 | 126.39 | 222.38 | 55.43 | 20.46 | 10.54 | 64.43 | 63.82 |
| June | 29.10 | 25.67 | 490.87 | 137.95 | 215.29 | 60.50 | 18.30 | 11.70 | 72.43 | 71.86 |
| July | 29.63 | 26.24 | 494.76 | 135.17 | 217.00 | 59.29 | 19.53 | 11.47 | 74.06 | 73.80 |
| August | 30.03 | 26.47 | 481.63 | 108.55 | 209.80 | 47.28 | 19.84 | 11.16 | 74.60 | 75.78 |
| September | 29.25 | 26.08 | 444.84 | 62.83 | 190.36 | 26.89 | 17.70 | 12.30 | 74.26 | 75.58 |
| October | 27.38 | 24.08 | 379.53 | 46.91 | 163.68 | 20.23 | 17.05 | 13.95 | 67.19 | 68.60 |
| November | 24.63 | 20.90 | 310.78 | 29.15 | 137.89 | 12.93 | 19.80 | 10.20 | 57.00 | 57.67 |
| December | 23.35 | 18.64 | 275.78 | 22.44 | 118.50 | 9.64 | 19.84 | 11.16 | 53.56 | 51.08 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | 27.41 | 25.00 | 52.41 | -2.06 | 4.50 | 2.44 | 0.00 | 11.59 | 0.00 | 0.66 |
| February | 34.97 | 25.00 | 59.97 | 0.23 | 4.50 | 4.73 | 0.00 | 13.24 | 0.00 | 0.72 |
| March | 42.75 | 25.00 | 67.75 | 1.92 | 4.50 | 6.42 | 0.00 | 16.89 | 0.00 | 2.45 |
| April | 50.32 | 25.00 | 75.32 | 5.61 | 4.50 | 10.11 | 0.00 | 19.33 | 0.00 | 4.34 |
| May | 55.74 | 25.00 | 80.74 | 9.45 | 4.50 | 13.95 | 0.00 | 20.51 | 0.00 | 6.68 |
| June | 57.58 | 25.00 | 82.58 | 10.97 | 4.50 | 15.47 | 0.00 | 19.08 | 0.00 | 8.78 |
| July | 58.96 | 25.00 | 83.96 | 11.87 | 4.50 | 16.37 | 0.00 | 20.87 | 0.00 | 9.99 |
| August | 58.65 | 25.00 | 83.65 | 10.09 | 4.50 | 14.59 | 0.00 | 20.65 | 0.00 | 10.35 |
| September | 54.00 | 25.00 | 79.00 | 5.45 | 4.50 | 9.95 | 0.00 | 16.45 | 0.00 | 9.12 |
| October | 44.74 | 25.00 | 69.74 | 3.44 | 4.50 | 7.94 | 0.00 | 13.79 | 0.00 | 6.47 |
| November | 33.45 | 25.00 | 58.45 | 0.25 | 4.50 | 4.75 | 0.00 | 12.89 | 0.00 | 3.64 |
| December | 27.95 | 25.00 | 52.95 | -0.84 | 4.50 | 3.66 | 0.00 | 11.52 | 0.00 | 2.34 |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | 13.08 | 45.00 | 58.08 | -0.61 | 4.50 | 3.89 | 0.00 | 6.50 | 0.00 | 0.33 |
| February | 16.76 | 40.00 | 56.76 | -0.68 | 4.50 | 3.82 | 0.00 | 5.04 | 0.00 | 0.30 |
| March | 21.73 | 35.00 | 56.73 | 0.58 | 4.50 | 5.08 | 0.00 | 5.74 | 0.00 | 1.00 |
| April | 27.31 | 30.00 | 57.31 | 2.18 | 4.50 | 6.68 | 0.00 | 5.60 | 0.00 | 1.69 |
| May | 31.75 | 25.00 | 56.75 | 3.46 | 4.50 | 7.96 | 0.00 | 7.16 | 0.00 | 3.44 |
| June | 34.35 | 25.00 | 59.35 | 4.44 | 4.50 | 8.94 | 0.00 | 8.41 | 0.00 | 5.62 |
| July | 35.54 | 25.00 | 60.54 | 5.48 | 4.50 | 9.98 | 0.00 | 8.55 | 0.00 | 5.96 |
| August | 35.74 | 25.00 | 60.74 | 4.92 | 4.50 | 9.42 | 0.00 | 8.25 | 0.00 | 5.82 |
| September | 32.55 | 30.00 | 62.55 | 2.42 | 4.50 | 6.92 | 0.00 | 8.89 | 0.00 | 6.34 |
| October | 26.55 | 35.00 | 61.55 | 1.19 | 4.50 | 5.69 | 0.00 | 9.70 | 0.00 | 5.29 |
| November | 18.87 | 40.00 | 58.87 | -0.12 | 4.50 | 4.38 | 0.00 | 6.63 | 0.00 | 1.87 |
| December | 14.69 | 45.00 | 59.69 | -0.58 | 4.50 | 3.92 | 0.00 | 7.27 | 0.00 | 1.31 |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.29 | 5.45 | 0.22 | 0.00 | 6.29 | 4.68 | 16.42 |
| February | 0.29 | 5.51 | 0.22 | 0.00 | 5.68 | 3.60 | 14.79 |
| March | 0.29 | 7.45 | 0.22 | 0.00 | 6.29 | 3.53 | 17.27 |
| April | 0.29 | 8.84 | 0.22 | 0.00 | 6.09 | 2.97 | 17.90 |
| May | 0.29 | 10.80 | 0.22 | 0.00 | 6.29 | 2.64 | 19.72 |
| June | 0.29 | 11.97 | 0.22 | 0.00 | 6.09 | 2.55 | 20.60 |
| July | 0.29 | 12.93 | 0.22 | 0.00 | 6.29 | 2.64 | 21.86 |
| August | 0.29 | 12.88 | 0.22 | 0.00 | 6.29 | 2.64 | 21.80 |
| September | 0.29 | 11.65 | 0.22 | 0.00 | 6.09 | 3.17 | 20.91 |
| October | 0.29 | 10.07 | 0.22 | 0.00 | 6.29 | 4.03 | 20.39 |
| November | 0.29 | 7.15 | 0.22 | 0.00 | 6.09 | 4.08 | 17.32 |
| December | 0.29 | 6.41 | 0.22 | 0.00 | 6.29 | 4.87 | 17.57 |
| TOTAL/m2 | | 111.12 | | 0.00 | 74.06 | 41.38 | 226.56 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 2: SEMI-TRANSPARENT DOUBLE GLAZED PV ROOF

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Chicago | Longitude | 41.78 N | | | | |
| | | Latitude | 87.75 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate continental | Altitude | 186.00 m | Diffuse Radiation Factor | 1.10 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 0.60 | -7.20 | 85.00 | 40.00 | 125.00 | 10.00 | 12.50 | 18.50 | 70 | 80 |
| February | 1.50 | -6.30 | 130.00 | 55.00 | 141.00 | 10.49 | 13.44 | 14.56 | 67 | 79 |
| March | 6.40 | -1.70 | 190.00 | 75.00 | 206.00 | 12.78 | 16.12 | 14.88 | 61 | 77 |
| April | 14.10 | 4.70 | 250.00 | 100.00 | 206.00 | 12.48 | 16.50 | 13.50 | 56 | 74 |
| May | 20.60 | 10.50 | 290.00 | 120.00 | 275.00 | 14.54 | 18.91 | 12.09 | 55 | 75 |
| June | 26.40 | 15.40 | 305.00 | 125.00 | 307.00 | 15.51 | 19.80 | 10.20 | 56 | 77 |
| July | 28.90 | 19.50 | 290.00 | 120.00 | 310.00 | 13.69 | 22.32 | 8.68 | 53 | 77 |
| August | 28.00 | 18.80 | 250.00 | 100.00 | 285.00 | 13.13 | 21.70 | 9.30 | 56 | 81 |
| September | 23.80 | 14.10 | 190.00 | 75.00 | 246.00 | 12.42 | 19.80 | 10.20 | 53 | 81 |
| October | 17.40 | 8.20 | 130.00 | 55.00 | 214.00 | 11.13 | 19.22 | 11.78 | 54 | 79 |
| November | 8.40 | 0.30 | 85.00 | 40.00 | 135.00 | 10.00 | 13.50 | 16.50 | 62 | 78 |
| December | 2.10 | -5.30 | 70.00 | 35.00 | 115.00 | 10.00 | 11.50 | 19.50 | 69 | 80 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

**PV PANEL DATA**

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.03 |
| Thermal Transmittance | W/m2oC | 2.00 |
| PV slope (°) | | 0.00 |

**INTERNAL TEMPERATURES**

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

**HUMIDITY-WINTER**

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

**HUMIDITY-SUMMER**

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | -1.35 | -4.69 | 207.60 | 0.00 | 96.00 | 0.00 | 12.50 | 18.50 | 3.63 | -0.55 |
| February | -0.45 | -3.79 | 287.10 | 10.07 | 125.82 | 4.41 | 13.44 | 14.56 | 4.78 | 0.64 |
| March | 4.38 | 0.90 | 333.36 | 66.17 | 140.85 | 27.96 | 16.12 | 14.88 | 12.07 | 7.80 |
| April | 11.75 | 7.72 | 451.75 | 80.18 | 182.23 | 34.12 | 16.50 | 13.50 | 25.03 | 20.36 |
| May | 18.08 | 13.75 | 457.14 | 148.33 | 198.04 | 64.26 | 18.91 | 12.09 | 38.34 | 34.37 |
| June | 23.65 | 18.94 | 448.89 | 176.51 | 193.48 | 76.08 | 19.80 | 10.20 | 52.31 | 48.88 |
| July | 26.55 | 22.52 | 478.66 | 132.96 | 207.36 | 57.60 | 22.32 | 8.68 | 58.17 | 59.53 |
| August | 25.70 | 21.76 | 429.43 | 96.12 | 182.74 | 40.90 | 21.70 | 9.30 | 57.68 | 59.03 |
| September | 21.38 | 17.22 | 342.88 | 59.37 | 144.88 | 25.09 | 19.80 | 10.20 | 45.23 | 45.46 |
| October | 15.10 | 11.16 | 270.52 | 21.82 | 118.55 | 9.60 | 19.22 | 11.78 | 31.44 | 29.05 |
| November | 6.38 | 2.90 | 207.60 | 0.00 | 96.00 | 0.00 | 13.50 | 16.50 | 15.78 | 11.43 |
| December | 0.25 | -2.92 | 176.40 | 0.00 | 84.00 | 0.00 | 11.50 | 19.50 | 6.03 | 1.95 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -27.20 | 25.00 | -2.20 | -41.39 | 4.50 | -36.89 | -6.46 | -0.27 | -7.87 | 0.00 |
| February | -18.70 | 25.00 | 6.30 | -38.74 | 4.50 | -34.24 | -6.44 | 0.85 | -8.16 | 0.00 |
| March | -5.15 | 25.00 | 19.85 | -24.61 | 4.50 | -20.11 | -4.54 | 3.20 | -7.54 | 0.00 |
| April | 19.58 | 25.00 | 44.58 | -9.80 | 4.50 | -5.30 | -1.22 | 7.36 | -3.61 | 0.00 |
| May | 32.69 | 25.00 | 57.69 | 3.00 | 4.50 | 7.50 | 0.00 | 12.89 | 0.00 | 0.00 |
| June | 43.14 | 25.00 | 68.14 | 7.42 | 4.50 | 11.92 | 0.00 | 16.80 | 0.00 | 1.86 |
| July | 51.45 | 25.00 | 76.45 | 7.58 | 4.50 | 12.08 | 0.00 | 20.84 | 0.00 | 4.61 |
| August | 45.60 | 25.00 | 70.60 | 4.62 | 4.50 | 9.12 | 0.00 | 18.09 | 0.00 | 4.27 |
| September | 29.65 | 25.00 | 54.65 | 2.44 | 4.50 | 6.94 | 0.00 | 12.75 | 0.00 | 0.00 |
| October | 11.00 | 25.00 | 36.00 | -7.84 | 4.50 | -3.34 | -0.90 | 6.92 | -1.84 | 0.00 |
| November | -11.75 | 25.00 | 13.25 | -26.19 | 4.50 | -21.69 | -4.10 | 1.79 | -5.35 | 0.00 |
| December | -26.63 | 25.00 | -1.63 | -37.84 | 4.50 | -33.34 | -5.37 | -0.19 | -6.71 | 0.00 |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -36.61 | 45.00 | 8.39 | -41.39 | 4.50 | -36.89 | -9.55 | 1.55 | -11.64 | 0.00 |
| February | -32.29 | 40.00 | 7.71 | -39.21 | 4.50 | -34.71 | -7.08 | 1.12 | -8.84 | 0.00 |
| March | -21.38 | 35.00 | 13.62 | -27.84 | 4.50 | -23.34 | -4.86 | 2.03 | -6.96 | 0.00 |
| April | -2.29 | 30.00 | 27.71 | -13.68 | 4.50 | -9.18 | -1.74 | 3.74 | -2.95 | 0.00 |
| May | 10.84 | 25.00 | 35.84 | 0.91 | 4.50 | 5.41 | 0.00 | 5.25 | 0.00 | 0.00 |
| June | 21.61 | 25.00 | 46.61 | 3.29 | 4.50 | 7.79 | 0.00 | 5.87 | 0.00 | 0.96 |
| July | 28.58 | 25.00 | 53.58 | 2.90 | 4.50 | 7.40 | 0.00 | 5.55 | 0.00 | 1.79 |
| August | 24.80 | 25.00 | 49.80 | 1.63 | 4.50 | 6.13 | 0.00 | 5.43 | 0.00 | 1.83 |
| September | 12.96 | 30.00 | 42.96 | -0.45 | 4.50 | 4.05 | 0.00 | 4.96 | 0.00 | 0.00 |
| October | -1.81 | 35.00 | 33.19 | -8.88 | 4.50 | -4.38 | -0.72 | 3.91 | -1.13 | 0.00 |
| November | -21.16 | 40.00 | 18.84 | -26.19 | 4.50 | -21.69 | -5.01 | 3.11 | -6.54 | 0.00 |
| December | -34.42 | 45.00 | 10.58 | -37.84 | 4.50 | -33.34 | -9.10 | 2.06 | -11.38 | 0.00 |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and Power kWh | Total kWh Consumed |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | | |
| January | 0.00 | 0.00 | 0.22 | 7.89 | 5.19 | 6.34 | 19.42 |
| February | 0.00 | 0.00 | 0.22 | 6.78 | 4.69 | 4.56 | 16.04 |
| March | 0.00 | 0.00 | 0.22 | 5.31 | 5.19 | 4.12 | 14.62 |
| April | 0.00 | 0.00 | 0.22 | 2.11 | 5.02 | 3.23 | 10.36 |
| May | 0.29 | 5.18 | 0.22 | 0.00 | 5.19 | 2.64 | 13.01 |
| June | 0.29 | 7.28 | 0.22 | 0.00 | 5.02 | 2.55 | 14.85 |
| July | 0.29 | 9.37 | 0.22 | 0.00 | 5.19 | 2.64 | 17.19 |
| August | 0.29 | 8.46 | 0.22 | 0.00 | 5.19 | 2.64 | 16.29 |
| September | 0.29 | 5.06 | 0.22 | 0.00 | 5.02 | 3.06 | 13.14 |
| October | 0.29 | 3.09 | 0.22 | 1.02 | 5.19 | 3.81 | 13.12 |
| November | 0.00 | 0.00 | 0.22 | 4.57 | 5.02 | 5.03 | 14.71 |
| December | 0.00 | 0.00 | 0.22 | 7.23 | 5.19 | 6.54 | 18.96 |
| TOTAL/m2 | | 38.45 | | 35.02 | 61.11 | 47.14 | 181.71 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 2: SEMI-TRANSPARENT DOUBLE GLAZED PV ROOF .

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Cincinnati | Longitude | 39.15 N | | | | |
| | | Latitude | 84.52 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate continental | Altitude | 232.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 6.20 | -3.30 | 85.00 | 40.00 | 108.00 | 10.00 | 10.80 | 20.20 | 68 | 83 |
| February | 6.30 | -2.90 | 130.00 | 55.00 | 129.00 | 10.24 | 12.60 | 15.40 | 64 | 81 |
| March | 11.10 | 0.70 | 190.00 | 75.00 | 173.00 | 11.16 | 15.50 | 15.50 | 57 | 79 |
| April | 18.00 | 6.60 | 250.00 | 100.00 | 201.00 | 11.96 | 16.80 | 13.20 | 53 | 76 |
| May | 23.80 | 11.90 | 290.00 | 120.00 | 241.00 | 12.74 | 18.91 | 12.09 | 53 | 78 |
| June | 28.80 | 17.20 | 305.00 | 125.00 | 305.00 | 14.73 | 20.70 | 9.30 | 55 | 80 |
| July | 30.80 | 19.10 | 290.00 | 120.00 | 322.00 | 14.43 | 22.32 | 8.68 | 52 | 82 |
| August | 30.20 | 18.30 | 250.00 | 100.00 | 291.00 | 13.41 | 21.70 | 9.30 | 52 | 86 |
| September | 26.80 | 14.20 | 190.00 | 75.00 | 254.00 | 12.45 | 20.40 | 9.60 | 50 | 86 |
| October | 20.50 | 8.20 | 130.00 | 55.00 | 213.00 | 11.26 | 18.91 | 12.09 | 61 | 85 |
| November | 11.80 | 2.20 | 85.00 | 40.00 | 145.00 | 10.51 | 13.80 | 16.20 | 60 | 81 |
| December | 5.90 | -2.30 | 70.00 | 35.00 | 126.00 | 10.16 | 12.40 | 18.60 | 68 | 82 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | | | |
|---|---|---|---|---|
| Conversion Efficiency | % | 10.00 | %RH | 35 |
| Direct Transmittance | % | 0.03 | Enthalpy | 36.41 |
| Thermal Transmittance W/m2oC | | 2.00 | | |
| PV slope (°) | | 0.00 | | |

### INTERNAL TEMPERATURES

| | | | | |
|---|---|---|---|---|
| | | | HUMIDITY-WINTER | |
| Occupied Period Set Point | oC | 21.00 | %RH | 60 |
| Unoccupied Period Offset | oC | 5.00 | Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 3.83 | -0.25 | 207.60 | 0.00 | 96.00 | 0.00 | 10.80 | 20.20 | 11.96 | 6.36 |
| February | 4.00 | 0.06 | 294.20 | 5.00 | 128.93 | 2.19 | 12.60 | 15.40 | 11.79 | 6.71 |
| March | 8.50 | 4.04 | 381.68 | 31.66 | 161.27 | 13.38 | 15.50 | 15.50 | 18.91 | 13.69 |
| April | 15.15 | 10.26 | 471.40 | 66.14 | 200.60 | 28.14 | 16.80 | 13.20 | 31.24 | 26.31 |
| May | 20.83 | 15.73 | 521.63 | 102.26 | 225.98 | 44.30 | 18.91 | 12.09 | 43.93 | 40.35 |
| June | 25.90 | 20.93 | 472.37 | 159.74 | 203.61 | 68.85 | 20.70 | 9.30 | 57.64 | 56.01 |
| July | 27.88 | 22.86 | 460.82 | 145.70 | 199.63 | 63.12 | 22.32 | 8.68 | 61.04 | 63.03 |
| August | 27.23 | 22.13 | 420.58 | 102.44 | 178.97 | 43.59 | 21.70 | 9.30 | 59.33 | 62.55 |
| September | 23.65 | 18.25 | 342.14 | 59.90 | 144.57 | 25.31 | 20.40 | 9.60 | 49.24 | 50.29 |
| October | 17.43 | 12.15 | 267.40 | 24.14 | 117.19 | 10.58 | 18.91 | 12.09 | 38.98 | 32.94 |
| November | 9.40 | 5.29 | 197.58 | 7.16 | 91.37 | 3.31 | 13.80 | 16.20 | 21.21 | 16.41 |
| December | 3.85 | 0.34 | 173.60 | 2.00 | 82.67 | 0.95 | 12.40 | 18.60 | 12.00 | 7.27 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -16.85 | 25.00 | 8.15 | -32.49 | 4.50 | -27.99 | -4.23 | 0.88 | -5.07 | 0.00 |
| February | -9.20 | 25.00 | 15.80 | -31.46 | 4.50 | -25.96 | -4.76 | 1.99 | -5.96 | 0.00 |
| March | 7.18 | 25.00 | 32.18 | -21.25 | 4.50 | -16.75 | -3.63 | 4.99 | -5.21 | 0.00 |
| April | 28.04 | 25.00 | 53.04 | -5.90 | 4.50 | -1.40 | -0.33 | 8.91 | -1.67 | 0.00 |
| May | 43.62 | 25.00 | 68.62 | 3.07 | 4.50 | 7.57 | 0.00 | 14.98 | 0.00 | 0.00 |
| June | 49.62 | 25.00 | 74.62 | 6.66 | 4.50 | 11.16 | 0.00 | 18.68 | 0.00 | 4.06 |
| July | 52.60 | 25.00 | 77.60 | 6.00 | 4.50 | 10.50 | 0.00 | 20.60 | 0.00 | 5.83 |
| August | 47.90 | 25.00 | 72.90 | 4.22 | 4.50 | 8.72 | 0.00 | 18.47 | 0.00 | 4.96 |
| September | 34.14 | 25.00 | 59.14 | 1.55 | 4.50 | 6.05 | 0.00 | 13.79 | 0.00 | 0.71 |
| October | 15.39 | 25.00 | 40.39 | -5.66 | 4.50 | -1.16 | -0.31 | 7.64 | 0.00 | 0.00 |
| November | -6.54 | 25.00 | 18.46 | -20.83 | 4.50 | -16.33 | -3.15 | 2.55 | -4.03 | 0.00 |
| December | -19.67 | 25.00 | 5.33 | -31.16 | 4.50 | -26.66 | -4.63 | 0.66 | -5.81 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -26.26 | 45.00 | 18.74 | -32.49 | 4.50 | -27.99 | -7.92 | 3.79 | -9.48 | 0.00 |
| February | -23.13 | 40.00 | 16.87 | -31.70 | 4.50 | -27.20 | -5.86 | 2.60 | -7.28 | 0.00 |
| March | -11.40 | 35.00 | 23.60 | -22.79 | 4.50 | -18.29 | -3.97 | 3.66 | -5.21 | 0.00 |
| April | 5.21 | 30.00 | 35.21 | -9.10 | 4.50 | -4.60 | -0.85 | 4.65 | -1.31 | 0.00 |
| May | 18.70 | 25.00 | 43.70 | -1.82 | 4.50 | 2.68 | 0.00 | 5.74 | 0.00 | 0.00 |
| June | 26.96 | 25.00 | 51.96 | 3.66 | 4.50 | 8.16 | 0.00 | 5.90 | 0.00 | 1.82 |
| July | 30.58 | 25.00 | 55.58 | 4.04 | 4.50 | 8.54 | 0.00 | 5.86 | 0.00 | 2.27 |
| August | 27.54 | 25.00 | 52.54 | 2.59 | 4.50 | 7.09 | 0.00 | 5.81 | 0.00 | 2.13 |
| September | 17.49 | 30.00 | 47.49 | -1.37 | 4.50 | 3.13 | 0.00 | 4.98 | 0.00 | 0.33 |
| October | 2.73 | 35.00 | 37.73 | -6.80 | 4.50 | -2.30 | -0.39 | 4.56 | 0.00 | 0.00 |
| November | -15.50 | 40.00 | 24.50 | -21.15 | 4.50 | -16.65 | -3.78 | 3.97 | -4.73 | 0.00 |
| December | -27.33 | 45.00 | 17.67 | -31.25 | 4.50 | -26.75 | -6.97 | 3.29 | -8.72 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 5.93 | 5.68 | 6.68 | 18.29 |
| February | 0.00 | 0.00 | 0.22 | 5.30 | 5.13 | 4.69 | 15.13 |
| March | 0.00 | 0.00 | 0.22 | 4.00 | 5.68 | 4.19 | 13.87 |
| April | 0.29 | 3.87 | 0.22 | 0.92 | 5.50 | 3.21 | 13.51 |
| May | 0.29 | 5.92 | 0.22 | 0.00 | 5.68 | 2.64 | 14.24 |
| June | 0.29 | 8.70 | 0.22 | 0.00 | 5.50 | 2.55 | 16.75 |
| July | 0.29 | 9.88 | 0.22 | 0.00 | 5.68 | 2.64 | 18.19 |
| August | 0.29 | 8.96 | 0.22 | 0.00 | 5.68 | 2.64 | 17.28 |
| September | 0.29 | 5.66 | 0.22 | 0.00 | 5.50 | 3.03 | 14.19 |
| October | 0.29 | 3.49 | 0.22 | 0.15 | 5.68 | 3.84 | 13.17 |
| November | 0.00 | 0.00 | 0.22 | 3.49 | 5.50 | 4.98 | 13.97 |
| December | 0.00 | 0.00 | 0.22 | 5.80 | 5.68 | 6.36 | 17.84 |
| TOTAL/m2 | | 46.48 | | 25.61 | 66.92 | 47.42 | 186.44 |

BUILDING ENERGY BALANCE CALCULATIONS

**OPTION 3: FLAT INSULATED PV ROOF**

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | San Francisco | Longitude | 37.62 N | | | | |
| | | Latitude | 122.38 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate costal warm | Altitude | 2.00 m | Diffuse Radiation Factor | 1.10 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 13.00 | 5.40 | 85.00 | 40.00 | 154.00 | 10.00 | 15.40 | 15.60 | 75 | 85 |
| February | 14.70 | 6.30 | 130.00 | 55.00 | 191.00 | 11.56 | 16.52 | 11.48 | 71 | 85 |
| March | 16.40 | 7.20 | 190.00 | 75.00 | 262.00 | 12.43 | 21.08 | 9.92 | 66 | 83 |
| April | 17.90 | 8.40 | 250.00 | 100.00 | 297.00 | 13.94 | 21.30 | 8.70 | 66 | 85 |
| May | 19.40 | 9.80 | 290.00 | 120.00 | 328.00 | 14.90 | 22.01 | 8.99 | 66 | 85 |
| June | 21.20 | 11.30 | 305.00 | 125.00 | 341.00 | 15.36 | 22.20 | 7.80 | 65 | 87 |
| July | 22.20 | 11.90 | 290.00 | 120.00 | 295.00 | 14.20 | 20.77 | 10.23 | 69 | 90 |
| August | 22.10 | 12.10 | 250.00 | 100.00 | 275.00 | 13.65 | 20.15 | 10.85 | 69 | 90 |
| September | 23.20 | 12.20 | 190.00 | 75.00 | 275.00 | 12.73 | 21.60 | 8.40 | 66 | 88 |
| October | 21.40 | 10.30 | 130.00 | 55.00 | 242.00 | 11.31 | 21.39 | 9.61 | 65 | 86 |
| November | 17.80 | 7.70 | 85.00 | 40.00 | 198.00 | 10.00 | 19.80 | 10.20 | 68 | 84 |
| December | 14.00 | 6.10 | 70.00 | 35.00 | 179.00 | 10.31 | 17.36 | 13.64 | 74 | 86 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 18.00 |

**PV PANEL DATA**

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.00 |
| Thermal Transmittance | W/m2oC | 0.18 |
| PV slope (°) | | 0.00 |

**INTERNAL TEMPERATURES**

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

**HUMIDITY-WINTER**

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

**HUMIDITY-SUMMER**

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 11.10 | 7.84 | 207.60 | 0.00 | 96.00 | 0.00 | 15.40 | 15.60 | 28.01 | 22.52 |
| February | 12.60 | 9.00 | 260.51 | 29.06 | 114.17 | 12.74 | 16.52 | 11.48 | 30.55 | 25.19 |
| March | 14.10 | 10.16 | 342.75 | 59.46 | 144.82 | 25.13 | 21.08 | 9.92 | 32.71 | 27.53 |
| April | 15.53 | 11.45 | 404.48 | 113.94 | 172.12 | 48.48 | 21.30 | 8.70 | 36.08 | 31.15 |
| May | 17.00 | 12.89 | 446.11 | 156.21 | 193.26 | 67.67 | 22.01 | 8.99 | 39.69 | 34.84 |
| June | 18.73 | 14.48 | 453.11 | 173.49 | 195.31 | 74.78 | 22.20 | 7.80 | 43.67 | 39.59 |
| July | 19.63 | 15.21 | 468.06 | 140.53 | 202.77 | 60.88 | 20.77 | 10.23 | 47.62 | 42.64 |
| August | 19.60 | 15.31 | 413.26 | 107.67 | 175.85 | 45.82 | 20.15 | 10.85 | 47.55 | 42.94 |
| September | 20.45 | 15.74 | 334.60 | 65.28 | 141.38 | 27.58 | 21.60 | 8.40 | 48.59 | 43.54 |
| October | 18.63 | 13.87 | 266.23 | 24.98 | 116.67 | 10.95 | 21.39 | 9.61 | 43.42 | 37.72 |
| November | 15.28 | 10.95 | 207.60 | 0.00 | 96.00 | 0.00 | 19.80 | 10.20 | 36.10 | 29.66 |
| December | 12.03 | 8.64 | 171.08 | 3.80 | 81.47 | 1.81 | 17.36 | 13.64 | 29.84 | 24.53 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -0.21 | 45.00 | 44.79 | -1.47 | 4.50 | 3.03 | 0.00 | 7.55 | -2.48 | 0.00 |
| February | 0.46 | 45.00 | 45.46 | -1.04 | 4.50 | 3.46 | 0.00 | 8.31 | -1.86 | 0.00 |
| March | 1.35 | 45.00 | 46.35 | -0.60 | 4.50 | 3.90 | 0.00 | 10.92 | -1.50 | 0.00 |
| April | 2.07 | 45.00 | 47.07 | 0.04 | 4.50 | 4.54 | 0.00 | 11.38 | -0.14 | 0.00 |
| May | 2.65 | 45.00 | 47.65 | 0.32 | 4.50 | 4.82 | 0.00 | 11.97 | 0.00 | 0.00 |
| June | 3.02 | 45.00 | 48.02 | 0.59 | 4.50 | 5.09 | 0.00 | 12.24 | 0.00 | 0.00 |
| July | 3.29 | 45.00 | 48.29 | 0.47 | 4.50 | 4.97 | 0.00 | 11.48 | 0.00 | 0.08 |
| August | 2.87 | 45.00 | 47.87 | 0.24 | 4.50 | 4.74 | 0.00 | 10.98 | 0.00 | 0.05 |
| September | 2.43 | 45.00 | 47.43 | 0.00 | 4.50 | 4.50 | 0.00 | 11.60 | 0.00 | 0.48 |
| October | 1.59 | 45.00 | 46.59 | -0.19 | 4.50 | 4.31 | 0.00 | 11.25 | 0.00 | 0.00 |
| November | 0.54 | 45.00 | 45.54 | -0.91 | 4.50 | 3.59 | 0.00 | 10.01 | -0.12 | 0.00 |
| December | -0.32 | 45.00 | 44.68 | -1.30 | 4.50 | 3.20 | 0.00 | 8.53 | -2.16 | 0.00 |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -1.06 | 45.00 | 43.94 | -1.47 | 4.50 | 3.03 | 0.00 | 7.52 | -2.52 | 0.00 |
| February | -0.65 | 45.00 | 44.35 | -1.16 | 4.50 | 3.34 | 0.00 | 5.63 | -1.29 | 0.00 |
| March | -0.15 | 45.00 | 44.85 | -0.86 | 4.50 | 3.64 | 0.00 | 4.95 | -0.71 | 0.00 |
| April | 0.32 | 45.00 | 45.32 | -0.45 | 4.50 | 4.05 | 0.00 | 4.44 | -0.06 | 0.00 |
| May | 0.74 | 45.00 | 45.74 | -0.05 | 4.50 | 4.45 | 0.00 | 4.67 | 0.00 | 0.00 |
| June | 1.07 | 45.00 | 46.07 | 0.29 | 4.50 | 4.79 | 0.00 | 4.12 | 0.00 | 0.00 |
| July | 1.29 | 45.00 | 46.29 | 0.32 | 4.50 | 4.82 | 0.00 | 5.43 | 0.00 | 0.04 |
| August | 1.08 | 45.00 | 46.08 | 0.22 | 4.50 | 4.72 | 0.00 | 5.72 | 0.00 | 0.03 |
| September | 0.97 | 45.00 | 45.97 | 0.16 | 4.50 | 4.66 | 0.00 | 4.41 | 0.00 | 0.19 |
| October | 0.45 | 45.00 | 45.45 | -0.30 | 4.50 | 4.20 | 0.00 | 4.93 | 0.00 | 0.00 |
| November | -0.30 | 45.00 | 44.70 | -0.91 | 4.50 | 3.59 | 0.00 | 5.07 | -0.06 | 0.00 |
| December | -1.00 | 45.00 | 44.00 | -1.31 | 4.50 | 3.19 | 0.00 | 6.61 | -1.69 | 0.00 |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 1.11 | 3.66 | 8.84 | 13.60 |
| February | 0.00 | 0.00 | 0.22 | 0.70 | 3.30 | 7.98 | 11.98 |
| March | 0.00 | 0.00 | 0.22 | 0.49 | 3.66 | 8.84 | 12.98 |
| April | 0.29 | 4.52 | 0.22 | 0.04 | 3.54 | 8.55 | 16.65 |
| May | 0.29 | 4.76 | 0.22 | 0.00 | 3.66 | 8.84 | 17.25 |
| June | 0.29 | 4.67 | 0.22 | 0.00 | 3.54 | 8.55 | 16.76 |
| July | 0.29 | 4.86 | 0.22 | 0.00 | 3.66 | 8.84 | 17.35 |
| August | 0.29 | 4.79 | 0.22 | 0.00 | 3.66 | 8.84 | 17.28 |
| September | 0.29 | 4.77 | 0.22 | 0.00 | 3.54 | 8.55 | 16.86 |
| October | 0.29 | 4.62 | 0.22 | 0.00 | 3.66 | 8.84 | 17.12 |
| November | 0.29 | 4.31 | 0.22 | 0.04 | 3.54 | 8.55 | 16.44 |
| December | 0.00 | 0.00 | 0.22 | 0.86 | 3.66 | 8.84 | 13.35 |
| TOTAL/m2 | | 37.30 | | 3.24 | 43.06 | 104.03 | 187.63 |

## OPTION 3: FLAT INSULATED PV ROOF

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | New York | Longitude | 40.70 N | | | | |
| | | Latitude | 74.02 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate costal cold | Altitude | 3.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 4.30 | -2.80 | 85.00 | 40.00 | 151.00 | 10.00 | 15.10 | 15.90 | 61 | 69 |
| February | 4.10 | -2.40 | 130.00 | 55.00 | 164.00 | 10.28 | 15.96 | 12.04 | 58 | 67 |
| March | 8.90 | 0.60 | 190.00 | 75.00 | 209.00 | 11.83 | 17.67 | 13.33 | 56 | 67 |
| April | 14.90 | 6.10 | 250.00 | 100.00 | 214.00 | 12.09 | 17.70 | 12.30 | 55 | 68 |
| May | 20.90 | 11.80 | 290.00 | 120.00 | 250.00 | 13.44 | 18.60 | 12.40 | 56 | 69 |
| June | 25.60 | 16.90 | 305.00 | 125.00 | 301.00 | 16.18 | 18.60 | 11.40 | 58 | 72 |
| July | 28.30 | 19.90 | 290.00 | 120.00 | 307.00 | 15.00 | 20.46 | 10.54 | 57 | 74 |
| August | 27.40 | 19.30 | 250.00 | 100.00 | 275.00 | 13.86 | 19.84 | 11.16 | 60 | 76 |
| September | 23.80 | 15.80 | 190.00 | 75.00 | 237.00 | 12.54 | 18.90 | 11.10 | 60 | 76 |
| October | 18.40 | 10.30 | 130.00 | 55.00 | 218.00 | 11.34 | 19.22 | 11.78 | 59 | 74 |
| November | 11.90 | 4.40 | 85.00 | 40.00 | 172.00 | 10.06 | 17.10 | 12.90 | 60 | 71 |
| December | 5.70 | -1.20 | 70.00 | 35.00 | 158.00 | 10.00 | 15.80 | 15.20 | 60 | 67 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.00 |
| Thermal Transmittance W/m2oC | | 0.18 |
| PV slope (°) | | 0.00 |

### INTERNAL TEMPERATURES

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 2.53 | -0.52 | 207.60 | 0.00 | 96.00 | 0.00 | 15.10 | 15.90 | 8.95 | 4.83 |
| February | 2.48 | -0.31 | 293.12 | 5.77 | 128.46 | 2.53 | 15.96 | 12.04 | 8.56 | 4.99 |
| March | 6.83 | 3.27 | 360.16 | 47.03 | 152.18 | 19.87 | 17.67 | 13.33 | 15.67 | 10.86 |
| April | 12.70 | 8.93 | 466.49 | 69.65 | 198.50 | 29.64 | 17.70 | 12.30 | 26.71 | 21.80 |
| May | 18.63 | 14.73 | 494.61 | 121.56 | 214.27 | 52.66 | 18.60 | 12.40 | 39.98 | 35.06 |
| June | 23.43 | 19.70 | 430.09 | 169.94 | 185.38 | 81.87 | 18.60 | 11.40 | 52.74 | 49.03 |
| July | 26.20 | 22.60 | 443.06 | 158.39 | 191.94 | 68.62 | 20.46 | 10.54 | 59.60 | 58.33 |
| August | 25.38 | 21.90 | 406.90 | 112.21 | 173.15 | 47.75 | 19.84 | 11.16 | 59.06 | 57.18 |
| September | 21.80 | 18.37 | 339.72 | 61.63 | 143.54 | 26.04 | 18.90 | 11.10 | 49.48 | 46.90 |
| October | 16.38 | 12.90 | 265.55 | 25.46 | 116.38 | 11.16 | 19.22 | 11.78 | 35.84 | 32.04 |
| November | 10.03 | 6.81 | 206.39 | 0.86 | 95.44 | 0.40 | 17.10 | 12.90 | 22.45 | 18.01 |
| December | 3.98 | 1.02 | 176.40 | 0.00 | 84.00 | 0.00 | 15.80 | 15.20 | 11.26 | 7.09 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -1.76 | 45.00 | 43.24 | -2.97 | 4.50 | 1.53 | 0.00 | 6.85 | -7.96 | 0.00 |
| February | -1.12 | 45.00 | 43.88 | -2.89 | 4.50 | 1.61 | 0.00 | 7.36 | -8.54 | 0.00 |
| March | 0.17 | 45.00 | 45.17 | -1.94 | 4.50 | 2.56 | 0.00 | 8.62 | -7.04 | 0.00 |
| April | 2.03 | 45.00 | 47.03 | -0.75 | 4.50 | 3.75 | 0.00 | 9.25 | -3.30 | 0.00 |
| May | 3.31 | 45.00 | 48.31 | -0.21 | 4.50 | 4.29 | 0.00 | 10.10 | 0.00 | 0.00 |
| June | 3.69 | 45.00 | 48.69 | 0.60 | 4.50 | 5.10 | 0.00 | 10.38 | 0.00 | 1.90 |
| July | 4.29 | 45.00 | 49.29 | 0.59 | 4.50 | 5.09 | 0.00 | 11.54 | 0.00 | 4.78 |
| August | 3.86 | 45.00 | 48.86 | 0.41 | 4.50 | 4.91 | 0.00 | 11.06 | 0.00 | 4.43 |
| September | 2.71 | 45.00 | 47.71 | -0.01 | 4.50 | 4.49 | 0.00 | 10.21 | 0.00 | 0.75 |
| October | 1.18 | 45.00 | 46.18 | -0.36 | 4.50 | 4.14 | 0.00 | 9.99 | -0.21 | 0.00 |
| November | -0.42 | 45.00 | 44.58 | -1.65 | 4.50 | 2.85 | 0.00 | 8.31 | -4.58 | 0.00 |
| December | -1.73 | 45.00 | 43.27 | -2.70 | 4.50 | 1.80 | 0.00 | 7.24 | -7.63 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -2.60 | 45.00 | 42.40 | -2.97 | 4.50 | 1.53 | 0.00 | 7.08 | -8.38 | 0.00 |
| February | -2.36 | 45.00 | 42.64 | -2.92 | 4.50 | 1.58 | 0.00 | 5.40 | -6.44 | 0.00 |
| March | -1.40 | 45.00 | 43.60 | -2.14 | 4.50 | 2.36 | 0.00 | 6.25 | -5.31 | 0.00 |
| April | 0.01 | 45.00 | 45.01 | -1.05 | 4.50 | 3.45 | 0.00 | 6.13 | -2.29 | 0.00 |
| May | 1.19 | 45.00 | 46.19 | 0.17 | 4.50 | 4.67 | 0.00 | 6.54 | 0.00 | 0.00 |
| June | 1.84 | 45.00 | 46.84 | 0.29 | 4.50 | 4.79 | 0.00 | 6.10 | 0.00 | 1.16 |
| July | 2.39 | 45.00 | 47.39 | 0.36 | 4.50 | 4.86 | 0.00 | 5.71 | 0.00 | 2.46 |
| August | 2.10 | 45.00 | 47.10 | 0.22 | 4.50 | 4.72 | 0.00 | 5.99 | 0.00 | 2.49 |
| September | 1.23 | 45.00 | 46.23 | -0.19 | 4.50 | 4.31 | 0.00 | 5.80 | 0.00 | 0.44 |
| October | 0.05 | 45.00 | 45.05 | -0.47 | 4.50 | 4.03 | 0.00 | 5.97 | -0.13 | 0.00 |
| November | -1.25 | 45.00 | 43.75 | -1.65 | 4.50 | 2.85 | 0.00 | 6.16 | -3.46 | 0.00 |
| December | -2.43 | 45.00 | 42.57 | -2.70 | 4.50 | 1.80 | 0.00 | 6.85 | -7.34 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 3.63 | 3.71 | 8.84 | 16.18 |
| February | 0.00 | 0.00 | 0.22 | 3.33 | 3.35 | 7.98 | 14.66 |
| March | 0.00 | 0.00 | 0.22 | 2.74 | 3.71 | 8.84 | 15.29 |
| April | 0.00 | 0.00 | 0.22 | 1.24 | 3.59 | 8.55 | 13.38 |
| May | 0.29 | 4.75 | 0.22 | 0.00 | 3.71 | 8.84 | 17.30 |
| June | 0.29 | 5.59 | 0.22 | 0.00 | 3.59 | 8.55 | 17.73 |
| July | 0.29 | 7.00 | 0.22 | 0.00 | 3.71 | 8.84 | 19.54 |
| August | 0.29 | 6.85 | 0.22 | 0.00 | 3.71 | 8.84 | 19.39 |
| September | 0.29 | 4.91 | 0.22 | 0.00 | 3.59 | 8.55 | 17.05 |
| October | 0.29 | 4.56 | 0.22 | 0.08 | 3.71 | 8.84 | 17.18 |
| November | 0.00 | 0.00 | 0.22 | 1.79 | 3.59 | 8.55 | 13.93 |
| December | 0.00 | 0.00 | 0.22 | 3.33 | 3.71 | 8.84 | 15.87 |
| TOTAL/m2 | | 33.66 | | 16.14 | 43.66 | 104.03 | 197.49 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 3: FLAT INSULATED PV ROOF

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Phoenix | Longitude | 33.43 N | | | | |
| | | Latitude | 112.02 W | Direct Radiation Factor | 1.10 | | |
| Climate | Temperate arid | Altitude | 340.00 m | Diffuse Radiation Factor | 0.90 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 17.80 | 1.80 | 105.00 | 25.00 | 262.00 | 10.84 | 24.18 | 6.82 | 44 | 72 |
| February | 20.10 | 3.80 | 150.00 | 30.00 | 271.00 | 12.41 | 21.84 | 6.16 | 42 | 71 |
| March | 23.90 | 6.10 | 205.00 | 35.00 | 331.00 | 12.56 | 26.35 | 4.65 | 31 | 60 |
| April | 28.80 | 10.20 | 260.00 | 45.00 | 360.00 | 13.48 | 26.70 | 3.30 | 26 | 50 |
| May | 33.80 | 13.90 | 295.00 | 45.00 | 408.00 | 14.00 | 29.14 | 1.86 | 19 | 41 |
| June | 38.70 | 18.60 | 305.00 | 50.00 | 411.00 | 14.57 | 28.20 | 1.80 | 17 | 37 |
| July | 40.30 | 23.90 | 295.00 | 45.00 | 390.00 | 14.30 | 27.28 | 3.72 | 29 | 51 |
| August | 38.70 | 23.00 | 260.00 | 45.00 | 379.00 | 14.22 | 26.66 | 4.34 | 35 | 60 |
| September | 36.80 | 19.60 | 205.00 | 35.00 | 354.00 | 13.11 | 27.00 | 3.00 | 29 | 66 |
| October | 30.40 | 12.60 | 150.00 | 30.00 | 323.00 | 11.98 | 26.97 | 4.03 | 30 | 58 |
| November | 23.20 | 5.80 | 105.00 | 25.00 | 282.00 | 10.93 | 25.80 | 4.20 | 33 | 83 |
| December | 18.90 | 2.80 | 90.00 | 25.00 | 260.00 | 10.75 | 24.18 | 6.82 | 42 | 70 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

**PV PANEL DATA**

| | | | | |
|---|---|---|---|---|
| Conversion Efficiency | % | 10.00 | %RH | 35 |
| Direct Transmittance | % | 0.00 | Enthalpy | 36.41 |
| Thermal Transmittance | W/m2oC | 0.18 | | |
| PV slope (°) | | 0.00 | | |

**INTERNAL TEMPERATURES** — **HUMIDITY-WINTER**

| | | | | |
|---|---|---|---|---|
| Occupied Period Set Point | oC | 21.00 | %RH | 60 |
| Unoccupied Period Offset | oC | 5.00 | Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 13.80 | 6.94 | 305.66 | 18.24 | 110.75 | 6.61 | 24.18 | 6.82 | 25.94 | 18.43 |
| February | 16.03 | 9.04 | 371.36 | 63.89 | 116.05 | 19.96 | 21.84 | 6.16 | 29.56 | 22.60 |
| March | 19.45 | 11.82 | 491.02 | 89.84 | 133.74 | 24.47 | 26.35 | 4.65 | 31.89 | 26.13 |
| April | 24.15 | 16.18 | 581.17 | 144.59 | 160.20 | 39.86 | 26.70 | 3.30 | 37.82 | 32.46 |
| May | 28.83 | 20.30 | 625.65 | 178.82 | 154.27 | 44.09 | 29.14 | 1.86 | 41.52 | 37.62 |
| June | 33.68 | 25.06 | 626.58 | 204.73 | 164.67 | 53.81 | 28.20 | 1.80 | 47.87 | 45.49 |
| July | 36.20 | 29.17 | 612.75 | 188.04 | 151.09 | 46.36 | 27.28 | 3.72 | 63.15 | 63.82 |
| August | 34.78 | 28.05 | 551.21 | 165.99 | 151.94 | 45.76 | 26.66 | 4.34 | 65.41 | 66.63 |
| September | 32.50 | 25.13 | 470.44 | 104.54 | 128.14 | 28.47 | 27.00 | 3.00 | 55.49 | 61.70 |
| October | 25.95 | 18.32 | 384.76 | 54.31 | 120.24 | 16.97 | 26.97 | 4.03 | 43.31 | 40.03 |
| November | 18.85 | 11.39 | 303.01 | 20.13 | 109.79 | 7.29 | 25.80 | 4.20 | 31.61 | 30.54 |
| December | 14.88 | 7.98 | 271.19 | 14.58 | 111.60 | 6.00 | 24.18 | 6.82 | 27.38 | 20.20 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | 1.01 | 45.00 | 46.01 | -1.49 | 4.50 | 3.01 | 0.00 | 12.14 | -4.86 | 0.00 |
| February | 1.91 | 45.00 | 46.91 | -0.77 | 4.50 | 3.73 | 0.00 | 11.39 | -2.88 | 0.00 |
| March | 3.43 | 45.00 | 48.43 | -0.07 | 4.50 | 4.43 | 0.00 | 14.40 | -2.29 | 0.00 |
| April | 4.96 | 45.00 | 49.96 | 0.23 | 4.50 | 4.73 | 0.00 | 15.11 | 0.00 | 0.00 |
| May | 6.14 | 45.00 | 51.14 | 1.23 | 4.50 | 5.73 | 0.00 | 17.24 | 0.00 | 0.00 |
| June | 7.02 | 45.00 | 52.02 | 1.38 | 4.50 | 5.88 | 0.00 | 16.99 | 0.00 | 0.24 |
| July | 7.37 | 45.00 | 52.37 | 1.99 | 4.50 | 6.49 | 0.00 | 16.77 | 0.00 | 8.24 |
| August | 6.65 | 45.00 | 51.65 | 1.62 | 4.50 | 6.12 | 0.00 | 16.05 | 0.00 | 9.21 |
| September | 5.63 | 45.00 | 50.63 | 0.63 | 4.50 | 5.13 | 0.00 | 15.61 | 0.00 | 4.18 |
| October | 3.80 | 45.00 | 48.80 | -0.07 | 4.50 | 4.43 | 0.00 | 14.83 | 0.00 | 0.00 |
| November | 1.90 | 45.00 | 46.90 | -0.68 | 4.50 | 3.82 | 0.00 | 13.48 | -2.38 | 0.00 |
| December | 0.95 | 45.00 | 45.95 | -1.33 | 4.50 | 3.17 | 0.00 | 12.18 | -4.19 | 0.00 |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -0.46 | 45.00 | 44.54 | -1.58 | 4.50 | 2.92 | 0.00 | 3.32 | -1.37 | 0.00 |
| February | -0.02 | 45.00 | 44.98 | -1.10 | 4.50 | 3.40 | 0.00 | 3.06 | -0.81 | 0.00 |
| March | 0.73 | 45.00 | 45.73 | -0.57 | 4.50 | 3.93 | 0.00 | 2.38 | -0.40 | 0.00 |
| April | 1.78 | 45.00 | 46.78 | -0.12 | 4.50 | 4.38 | 0.00 | 1.75 | 0.00 | 0.00 |
| May | 2.57 | 45.00 | 47.57 | 0.21 | 4.50 | 4.71 | 0.00 | 1.01 | 0.00 | 0.00 |
| June | 3.53 | 45.00 | 48.53 | 0.69 | 4.50 | 5.19 | 0.00 | 1.00 | 0.00 | 0.02 |
| July | 3.88 | 45.00 | 48.88 | 0.92 | 4.50 | 5.42 | 0.00 | 2.10 | 0.00 | 1.12 |
| August | 3.63 | 45.00 | 48.63 | 0.71 | 4.50 | 5.21 | 0.00 | 2.43 | 0.00 | 1.50 |
| September | 3.04 | 45.00 | 48.04 | 0.06 | 4.50 | 4.56 | 0.00 | 1.63 | 0.00 | 0.46 |
| October | 1.80 | 45.00 | 46.80 | -0.35 | 4.50 | 4.15 | 0.00 | 2.12 | 0.00 | 0.00 |
| November | 0.44 | 45.00 | 45.44 | -0.77 | 4.50 | 3.73 | 0.00 | 2.13 | -0.39 | 0.00 |
| December | -0.26 | 45.00 | 44.74 | -1.40 | 4.50 | 3.10 | 0.00 | 3.35 | -1.18 | 0.00 |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 1.38 | 3.96 | 8.84 | 14.18 |
| February | 0.29 | 4.13 | 0.22 | 0.82 | 3.58 | 7.98 | 16.51 |
| March | 0.29 | 4.79 | 0.22 | 0.60 | 3.96 | 8.84 | 18.19 |
| April | 0.29 | 4.81 | 0.22 | 0.00 | 3.83 | 8.55 | 17.20 |
| May | 0.29 | 5.21 | 0.22 | 0.00 | 3.96 | 8.84 | 18.01 |
| June | 0.29 | 5.21 | 0.22 | 0.00 | 3.83 | 8.55 | 17.60 |
| July | 0.29 | 8.06 | 0.22 | 0.00 | 3.96 | 8.84 | 20.86 |
| August | 0.29 | 8.34 | 0.22 | 0.00 | 3.96 | 8.84 | 21.14 |
| September | 0.29 | 6.25 | 0.22 | 0.00 | 3.83 | 8.55 | 18.64 |
| October | 0.29 | 4.84 | 0.22 | 0.00 | 3.96 | 8.84 | 17.64 |
| November | 0.29 | 4.46 | 0.22 | 0.61 | 3.83 | 8.55 | 17.46 |
| December | 0.00 | 0.00 | 0.22 | 1.19 | 3.96 | 8.84 | 13.99 |
| TOTAL/m2 | | 56.12 | | 4.61 | 46.65 | 104.03 | 211.41 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 3: FLAT INSULATED PV ROOF

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Miami | Longitude | 25.80 N | | | | |
| | | Latitude | 80.27 W | Direct Radiation Factor | 0.50 | | |
| Climate | Sub-tropical | Altitude | 2.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 24.30 | 14.40 | 150.00 | 65.00 | 239.00 | 11.51 | 20.77 | 10.23 | 59 | 84 |
| February | 25.00 | 14.90 | 195.00 | 80.00 | 233.00 | 11.72 | 19.88 | 8.12 | 56 | 84 |
| March | 26.60 | 16.20 | 235.00 | 95.00 | 269.00 | 12.22 | 22.01 | 8.99 | 56 | 82 |
| April | 28.10 | 18.80 | 275.00 | 115.00 | 283.00 | 13.10 | 21.60 | 8.40 | 56 | 79 |
| May | 29.70 | 20.90 | 295.00 | 125.00 | 276.00 | 13.49 | 20.46 | 10.54 | 59 | 78 |
| June | 31.10 | 23.10 | 295.00 | 125.00 | 255.00 | 13.93 | 18.30 | 11.70 | 64 | 81 |
| July | 31.60 | 23.70 | 295.00 | 125.00 | 270.00 | 13.82 | 19.53 | 11.47 | 64 | 81 |
| August | 32.10 | 23.80 | 275.00 | 115.00 | 261.00 | 13.16 | 19.84 | 11.16 | 63 | 83 |
| September | 31.10 | 23.70 | 235.00 | 95.00 | 212.00 | 11.98 | 17.70 | 12.30 | 66 | 85 |
| October | 29.30 | 21.60 | 195.00 | 80.00 | 200.00 | 11.73 | 17.05 | 13.95 | 64 | 85 |
| November | 26.80 | 18.10 | 150.00 | 65.00 | 224.00 | 11.31 | 19.80 | 10.20 | 60 | 84 |
| December | 26.10 | 15.10 | 135.00 | 55.00 | 221.00 | 11.14 | 19.84 | 11.16 | 60 | 85 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.00 |
| Thermal Transmittance W/m2oC | | 0.18 |
| PV slope (°) | | 0.00 |

### INTERNAL TEMPERATURES

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 21.83 | 17.58 | 305.55 | 32.89 | 135.57 | 14.59 | 20.77 | 10.23 | 49.08 | 47.57 |
| February | 22.48 | 18.15 | 379.85 | 46.68 | 163.82 | 20.13 | 19.88 | 8.12 | 49.32 | 49.23 |
| March | 24.00 | 19.54 | 435.95 | 69.18 | 186.55 | 29.60 | 22.01 | 8.99 | 53.21 | 52.64 |
| April | 25.78 | 21.79 | 483.60 | 107.15 | 210.66 | 46.67 | 21.60 | 8.40 | 57.88 | 58.21 |
| May | 27.50 | 23.73 | 507.05 | 126.39 | 222.39 | 55.43 | 20.46 | 10.54 | 64.43 | 63.82 |
| June | 29.10 | 25.67 | 490.87 | 137.95 | 215.29 | 60.50 | 18.30 | 11.70 | 72.43 | 71.86 |
| July | 29.63 | 26.24 | 494.76 | 135.17 | 217.00 | 59.29 | 19.53 | 11.47 | 74.06 | 73.80 |
| August | 30.03 | 26.47 | 481.63 | 108.55 | 209.80 | 47.28 | 19.84 | 11.16 | 74.60 | 75.78 |
| September | 29.25 | 26.08 | 444.84 | 62.83 | 190.36 | 26.89 | 17.70 | 12.30 | 74.26 | 75.58 |
| October | 27.38 | 24.06 | 379.53 | 46.91 | 163.68 | 20.23 | 17.05 | 13.95 | 67.19 | 68.60 |
| November | 24.63 | 20.90 | 310.79 | 29.15 | 137.89 | 12.93 | 19.80 | 10.20 | 57.00 | 57.67 |
| December | 23.35 | 18.64 | 275.78 | 22.44 | 118.50 | 9.64 | 19.84 | 11.16 | 53.56 | 51.06 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | 2.46 | 45.00 | 47.46 | -0.19 | 4.50 | 4.31 | 0.00 | 11.11 | 0.00 | 0.66 |
| February | 3.14 | 45.00 | 48.14 | 0.02 | 4.50 | 4.52 | 0.00 | 10.83 | 0.00 | 0.72 |
| March | 3.84 | 45.00 | 48.84 | 0.17 | 4.50 | 4.67 | 0.00 | 12.19 | 0.00 | 2.45 |
| April | 4.52 | 45.00 | 49.52 | 0.50 | 4.50 | 5.00 | 0.00 | 12.21 | 0.00 | 4.34 |
| May | 5.00 | 45.00 | 50.00 | 0.85 | 4.50 | 5.35 | 0.00 | 11.76 | 0.00 | 6.68 |
| June | 5.17 | 45.00 | 50.17 | 0.98 | 4.50 | 5.48 | 0.00 | 10.59 | 0.00 | 8.78 |
| July | 5.29 | 45.00 | 50.29 | 1.06 | 4.50 | 5.56 | 0.00 | 11.34 | 0.00 | 9.99 |
| August | 5.27 | 45.00 | 50.27 | 0.90 | 4.50 | 5.40 | 0.00 | 11.47 | 0.00 | 10.35 |
| September | 4.85 | 45.00 | 49.85 | 0.49 | 4.50 | 4.99 | 0.00 | 10.06 | 0.00 | 9.12 |
| October | 4.02 | 45.00 | 49.02 | 0.31 | 4.50 | 4.81 | 0.00 | 9.51 | 0.00 | 6.47 |
| November | 3.00 | 45.00 | 48.00 | 0.02 | 4.50 | 4.52 | 0.00 | 10.76 | 0.00 | 3.64 |
| December | 2.51 | 45.00 | 47.51 | -0.08 | 4.50 | 4.42 | 0.00 | 10.65 | 0.00 | 2.34 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | 1.17 | 45.00 | 46.17 | -0.05 | 4.50 | 4.45 | 0.00 | 5.36 | 0.00 | 0.33 |
| February | 1.50 | 45.00 | 46.50 | -0.06 | 4.50 | 4.44 | 0.00 | 4.28 | 0.00 | 0.30 |
| March | 1.95 | 45.00 | 46.95 | 0.05 | 4.50 | 4.55 | 0.00 | 4.79 | 0.00 | 1.00 |
| April | 2.45 | 45.00 | 47.45 | 0.19 | 4.50 | 4.69 | 0.00 | 4.54 | 0.00 | 1.69 |
| May | 2.85 | 45.00 | 47.85 | 0.31 | 4.50 | 4.81 | 0.00 | 5.75 | 0.00 | 3.44 |
| June | 3.09 | 45.00 | 48.09 | 0.40 | 4.50 | 4.90 | 0.00 | 6.43 | 0.00 | 5.62 |
| July | 3.19 | 45.00 | 48.19 | 0.49 | 4.50 | 4.99 | 0.00 | 6.33 | 0.00 | 5.86 |
| August | 3.21 | 45.00 | 48.21 | 0.44 | 4.50 | 4.94 | 0.00 | 6.15 | 0.00 | 5.82 |
| September | 2.92 | 45.00 | 47.92 | 0.22 | 4.50 | 4.72 | 0.00 | 6.71 | 0.00 | 6.34 |
| October | 2.38 | 45.00 | 47.38 | 0.11 | 4.50 | 4.61 | 0.00 | 7.51 | 0.00 | 5.29 |
| November | 1.69 | 45.00 | 46.69 | -0.01 | 4.50 | 4.49 | 0.00 | 5.40 | 0.00 | 1.87 |
| December | 1.32 | 45.00 | 46.32 | -0.05 | 4.50 | 4.45 | 0.00 | 5.86 | 0.00 | 1.31 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.29 | 4.99 | 0.22 | 0.00 | 3.82 | 8.84 | 17.64 |
| February | 0.29 | 4.61 | 0.22 | 0.00 | 3.45 | 7.98 | 16.04 |
| March | 0.29 | 5.84 | 0.22 | 0.00 | 3.82 | 8.84 | 18.49 |
| April | 0.29 | 6.50 | 0.22 | 0.00 | 3.70 | 8.55 | 18.75 |
| May | 0.29 | 7.90 | 0.22 | 0.00 | 3.82 | 8.84 | 20.55 |
| June | 0.29 | 8.98 | 0.22 | 0.00 | 3.70 | 8.55 | 21.22 |
| July | 0.29 | 9.58 | 0.22 | 0.00 | 3.82 | 8.84 | 22.23 |
| August | 0.29 | 9.66 | 0.22 | 0.00 | 3.82 | 8.84 | 22.31 |
| September | 0.29 | 9.21 | 0.22 | 0.00 | 3.70 | 8.55 | 21.45 |
| October | 0.29 | 8.22 | 0.22 | 0.00 | 3.82 | 8.84 | 20.88 |
| November | 0.29 | 6.19 | 0.22 | 0.00 | 3.70 | 8.55 | 18.44 |
| December | 0.29 | 5.76 | 0.22 | 0.00 | 3.82 | 8.84 | 18.42 |
| TOTAL/m2 | | 87.43 | | 0.00 | 44.99 | 104.03 | 236.44 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 3: FLAT INSULATED PV ROOF

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Chicago | Longitude | 41.78 N | | | | |
| | | Latitude | 87.75 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate continental | Altitude | 186.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 0.60 | -7.20 | 85.00 | 40.00 | 125.00 | 10.00 | 12.50 | 18.50 | 70 | 80 |
| February | 1.50 | -6.30 | 130.00 | 55.00 | 141.00 | 10.49 | 13.44 | 14.56 | 67 | 79 |
| March | 6.40 | -1.70 | 190.00 | 75.00 | 206.00 | 12.78 | 16.12 | 14.88 | 61 | 77 |
| April | 14.10 | 4.70 | 250.00 | 100.00 | 206.00 | 12.48 | 16.50 | 13.50 | 56 | 74 |
| May | 20.60 | 10.50 | 290.00 | 120.00 | 275.00 | 14.54 | 18.91 | 12.09 | 55 | 75 |
| June | 26.40 | 15.40 | 305.00 | 125.00 | 307.00 | 15.51 | 19.80 | 10.20 | 56 | 77 |
| July | 28.90 | 19.50 | 290.00 | 120.00 | 310.00 | 13.89 | 22.32 | 8.68 | 53 | 77 |
| August | 28.00 | 18.80 | 250.00 | 100.00 | 285.00 | 13.13 | 21.70 | 9.30 | 56 | 81 |
| September | 23.80 | 14.10 | 190.00 | 75.00 | 246.00 | 12.42 | 19.80 | 10.20 | 53 | 81 |
| October | 17.40 | 8.20 | 130.00 | 55.00 | 214.00 | 11.13 | 19.22 | 11.78 | 54 | 79 |
| November | 8.40 | 0.30 | 85.00 | 40.00 | 135.00 | 10.00 | 13.50 | 16.50 | 62 | 78 |
| December | 2.10 | -5.30 | 70.00 | 35.00 | 115.00 | 10.00 | 11.50 | 19.50 | 69 | 80 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | | | |
|---|---|---|---|---|
| Conversion Efficiency | % | 10.00 | HUMIDITY-WINTER %RH | 35 |
| Direct Transmittance | % | 0.00 | Enthalpy | 36.41 |
| Thermal Transmittance | W/m2oC | 0.18 | | |
| PV slope | (°) | 0.00 | | |

### INTERNAL TEMPERATURES

| | | | | |
|---|---|---|---|---|
| Occupied Period Set Point | oC | 21.00 | HUMIDITY-SUMMER %RH | 60 |
| Unoccupied Period Offset | oC | 5.00 | Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | -1.35 | -4.69 | 207.60 | 0.00 | 96.00 | 0.00 | 12.50 | 18.50 | 3.63 | -0.55 |
| February | -0.45 | -3.79 | 287.10 | 10.07 | 125.82 | 4.41 | 13.44 | 14.56 | 4.78 | 0.64 |
| March | 4.38 | 0.90 | 333.36 | 66.17 | 140.85 | 27.96 | 16.12 | 14.88 | 12.07 | 7.80 |
| April | 11.75 | 7.72 | 451.75 | 80.18 | 182.23 | 34.12 | 16.50 | 13.50 | 25.03 | 20.36 |
| May | 18.08 | 13.75 | 457.14 | 148.33 | 188.04 | 64.26 | 18.91 | 12.09 | 38.34 | 34.37 |
| June | 23.65 | 18.94 | 448.89 | 176.51 | 193.49 | 76.08 | 19.80 | 10.20 | 52.31 | 48.88 |
| July | 26.55 | 22.52 | 478.66 | 132.96 | 207.36 | 57.60 | 22.32 | 8.68 | 58.17 | 59.53 |
| August | 25.70 | 21.76 | 429.43 | 96.12 | 182.74 | 40.90 | 21.70 | 9.30 | 57.68 | 59.03 |
| September | 21.33 | 17.22 | 342.88 | 59.37 | 144.88 | 25.09 | 19.80 | 10.20 | 45.23 | 45.46 |
| October | 15.10 | 11.16 | 270.52 | 21.92 | 118.55 | 9.60 | 19.22 | 11.78 | 31.44 | 29.05 |
| November | 6.38 | 2.90 | 207.60 | 0.00 | 96.00 | 0.00 | 13.50 | 16.50 | 15.78 | 11.43 |
| December | 0.25 | -2.92 | 176.40 | 0.00 | 84.00 | 0.00 | 11.50 | 19.50 | 6.03 | 1.95 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -2.45 | 45.00 | 42.55 | -3.72 | 4.50 | 0.78 | 0.00 | 5.45 | -7.87 | 0.00 |
| February | -1.69 | 45.00 | 43.31 | -3.49 | 4.50 | 1.01 | 0.00 | 6.01 | -8.16 | 0.00 |
| March | -0.47 | 45.00 | 44.53 | -2.22 | 4.50 | 2.28 | 0.00 | 7.69 | -7.54 | 0.00 |
| April | 1.75 | 45.00 | 46.75 | -0.88 | 4.50 | 3.62 | 0.00 | 8.55 | -3.61 | 0.00 |
| May | 2.93 | 45.00 | 47.93 | 0.27 | 4.50 | 4.77 | 0.00 | 10.33 | 0.00 | 0.00 |
| June | 3.87 | 45.00 | 48.87 | 0.66 | 4.50 | 5.16 | 0.00 | 11.11 | 0.00 | 1.86 |
| July | 4.62 | 45.00 | 49.62 | 0.68 | 4.50 | 5.18 | 0.00 | 12.69 | 0.00 | 4.61 |
| August | 4.09 | 45.00 | 49.09 | 0.41 | 4.50 | 4.91 | 0.00 | 12.15 | 0.00 | 4.27 |
| September | 2.66 | 45.00 | 47.66 | 0.22 | 4.50 | 4.72 | 0.00 | 10.74 | 0.00 | 0.00 |
| October | 0.98 | 45.00 | 45.98 | -0.71 | 4.50 | 3.79 | 0.00 | 9.86 | -1.84 | 0.00 |
| November | -1.06 | 45.00 | 43.94 | -2.36 | 4.50 | 2.14 | 0.00 | 6.34 | -5.35 | 0.00 |
| December | -2.40 | 45.00 | 42.60 | -3.41 | 4.50 | 1.09 | 0.00 | 5.07 | -6.71 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -3.30 | 45.00 | 41.70 | -3.72 | 4.50 | 0.78 | 0.00 | 7.92 | -11.64 | 0.00 |
| February | -2.91 | 45.00 | 42.09 | -3.53 | 4.50 | 0.97 | 0.00 | 6.33 | -8.84 | 0.00 |
| March | -1.93 | 45.00 | 43.07 | -2.51 | 4.50 | 1.99 | 0.00 | 6.82 | -6.96 | 0.00 |
| April | -0.21 | 45.00 | 44.79 | -1.23 | 4.50 | 3.27 | 0.00 | 6.66 | -2.95 | 0.00 |
| May | 0.97 | 45.00 | 45.97 | 0.08 | 4.50 | 4.58 | 0.00 | 6.33 | 0.00 | 0.00 |
| June | 1.94 | 45.00 | 46.94 | 0.29 | 4.50 | 4.79 | 0.00 | 5.47 | 0.00 | 0.96 |
| July | 2.57 | 45.00 | 47.57 | 0.26 | 4.50 | 4.76 | 0.00 | 4.71 | 0.00 | 1.79 |
| August | 2.23 | 45.00 | 47.23 | 0.15 | 4.50 | 4.65 | 0.00 | 5.00 | 0.00 | 1.83 |
| September | 1.16 | 45.00 | 46.16 | -0.04 | 4.50 | 4.46 | 0.00 | 5.35 | 0.00 | 0.00 |
| October | -0.17 | 45.00 | 44.83 | -0.80 | 4.50 | 3.70 | 0.00 | 5.89 | -1.13 | 0.00 |
| November | -1.91 | 45.00 | 43.09 | -2.36 | 4.50 | 2.14 | 0.00 | 7.61 | -6.54 | 0.00 |
| December | -3.10 | 45.00 | 41.90 | -3.41 | 4.50 | 1.09 | 0.00 | 8.47 | -11.38 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and Power kWh | Total kWh Consumed |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | | |
| January | 0.00 | 0.00 | 0.22 | 4.34 | 3.72 | 8.84 | 16.89 |
| February | 0.00 | 0.00 | 0.22 | 3.78 | 3.36 | 7.98 | 15.12 |
| March | 0.00 | 0.00 | 0.22 | 3.22 | 3.72 | 8.84 | 15.78 |
| April | 0.00 | 0.00 | 0.22 | 1.46 | 3.60 | 8.55 | 13.61 |
| May | 0.29 | 4.76 | 0.22 | 0.00 | 3.72 | 8.84 | 17.32 |
| June | 0.29 | 5.54 | 0.22 | 0.00 | 3.60 | 8.55 | 17.69 |
| July | 0.29 | 6.80 | 0.22 | 0.00 | 3.72 | 8.84 | 19.36 |
| August | 0.29 | 6.64 | 0.22 | 0.00 | 3.72 | 8.84 | 19.20 |
| September | 0.29 | 4.60 | 0.22 | 0.00 | 3.60 | 8.55 | 16.75 |
| October | 0.29 | 4.50 | 0.22 | 0.66 | 3.72 | 8.84 | 17.72 |
| November | 0.00 | 0.00 | 0.22 | 2.64 | 3.60 | 8.55 | 14.79 |
| December | 0.00 | 0.00 | 0.22 | 4.02 | 3.72 | 8.84 | 16.58 |
| TOTAL/m2 | | 32.84 | | 20.11 | 43.83 | 104.03 | 200.80 |

## OPTION 3: FLAT INSULATED PV ROOF

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Cincinnati | Longitude | 39.15 N | | | | |
| | | Latitude | 84.52 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate continental | Altitude | 232.00 m | Diffuse Radiation Factor | 1.10 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 6.20 | -3.30 | 85.00 | 40.00 | 108.00 | 10.00 | 10.80 | 20.20 | 68 | 83 |
| February | 6.30 | -2.90 | 130.00 | 55.00 | 129.00 | 10.24 | 12.60 | 15.40 | 64 | 81 |
| March | 11.10 | 0.70 | 190.00 | 75.00 | 173.00 | 11.16 | 15.50 | 15.50 | 57 | 79 |
| April | 18.00 | 6.60 | 250.00 | 100.00 | 201.00 | 11.96 | 16.80 | 13.20 | 53 | 76 |
| May | 23.80 | 11.90 | 290.00 | 120.00 | 241.00 | 12.74 | 18.91 | 12.09 | 53 | 78 |
| June | 28.80 | 17.20 | 305.00 | 125.00 | 305.00 | 14.73 | 20.70 | 9.30 | 55 | 80 |
| July | 30.80 | 19.10 | 290.00 | 120.00 | 322.00 | 14.43 | 22.32 | 8.68 | 52 | 82 |
| August | 30.20 | 18.30 | 250.00 | 100.00 | 291.00 | 13.41 | 21.70 | 9.30 | 52 | 86 |
| September | 26.80 | 14.20 | 190.00 | 75.00 | 254.00 | 12.45 | 20.40 | 9.60 | 50 | 86 |
| October | 20.50 | 8.20 | 130.00 | 55.00 | 213.00 | 11.26 | 18.91 | 12.09 | 61 | 85 |
| November | 11.80 | 2.20 | 85.00 | 40.00 | 145.00 | 10.51 | 13.80 | 16.20 | 60 | 81 |
| December | 5.90 | -2.30 | 70.00 | 35.00 | 126.00 | 10.16 | 12.40 | 18.60 | 68 | 82 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

**PV PANEL DATA**

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.00 |
| Thermal Transmittance W/m2oC | | 0.18 |
| PV slope (°) | | 0.00 |

**INTERNAL TEMPERATURES**

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

**HUMIDITY-WINTER**

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

**HUMIDITY-SUMMER**

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 3.83 | -0.25 | 207.60 | 0.00 | 96.00 | 0.00 | 10.80 | 20.20 | 11.96 | 6.36 |
| February | 4.00 | 0.06 | 294.20 | 5.00 | 128.93 | 2.19 | 12.60 | 15.40 | 11.79 | 6.71 |
| March | 8.50 | 4.04 | 381.68 | 31.66 | 161.27 | 13.38 | 15.50 | 15.50 | 18.91 | 13.69 |
| April | 15.15 | 10.26 | 471.40 | 66.14 | 200.60 | 28.14 | 16.80 | 13.20 | 31.24 | 25.31 |
| May | 20.83 | 15.73 | 521.63 | 102.26 | 225.98 | 44.30 | 18.91 | 12.09 | 43.93 | 40.35 |
| June | 25.90 | 20.93 | 472.37 | 159.74 | 203.61 | 68.85 | 20.70 | 9.30 | 57.64 | 56.01 |
| July | 27.88 | 22.86 | 460.82 | 145.70 | 199.63 | 63.12 | 22.32 | 8.68 | 61.04 | 63.03 |
| August | 27.23 | 22.13 | 420.58 | 102.44 | 178.97 | 43.59 | 21.70 | 9.30 | 59.33 | 62.55 |
| September | 23.65 | 18.25 | 342.14 | 59.90 | 144.57 | 25.31 | 20.40 | 9.60 | 49.24 | 50.29 |
| October | 17.43 | 12.15 | 267.40 | 24.14 | 117.19 | 10.58 | 18.91 | 12.09 | 38.98 | 32.94 |
| November | 9.40 | 5.29 | 197.58 | 7.16 | 91.37 | 3.31 | 13.80 | 16.20 | 21.21 | 16.41 |
| December | 3.85 | 0.34 | 173.60 | 2.00 | 82.67 | 0.95 | 12.40 | 18.60 | 12.00 | 7.27 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -1.52 | 45.00 | 43.48 | -2.92 | 4.50 | 1.58 | 0.00 | 4.93 | -5.07 | 0.00 |
| February | -0.84 | 45.00 | 44.16 | -2.83 | 4.50 | 1.67 | 0.00 | 5.86 | -5.96 | 0.00 |
| March | 0.64 | 45.00 | 45.64 | -1.91 | 4.50 | 2.59 | 0.00 | 7.63 | -5.21 | 0.00 |
| April | 2.51 | 45.00 | 47.51 | -0.53 | 4.50 | 3.97 | 0.00 | 8.91 | -1.67 | 0.00 |
| May | 3.91 | 45.00 | 48.91 | 0.27 | 4.50 | 4.77 | 0.00 | 10.51 | 0.00 | 0.00 |
| June | 4.45 | 45.00 | 49.45 | 0.59 | 4.50 | 5.09 | 0.00 | 11.71 | 0.00 | 4.06 |
| July | 4.72 | 45.00 | 49.72 | 0.54 | 4.50 | 5.04 | 0.00 | 12.67 | 0.00 | 5.83 |
| August | 4.30 | 45.00 | 49.30 | 0.38 | 4.50 | 4.88 | 0.00 | 12.18 | 0.00 | 4.96 |
| September | 3.06 | 45.00 | 48.06 | 0.14 | 4.50 | 4.64 | 0.00 | 11.13 | 0.00 | 0.71 |
| October | 1.38 | 45.00 | 46.38 | -0.51 | 4.50 | 3.99 | 0.00 | 9.83 | 0.00 | 0.00 |
| November | -0.59 | 45.00 | 44.41 | -1.87 | 4.50 | 2.63 | 0.00 | 6.64 | -4.03 | 0.00 |
| December | -1.77 | 45.00 | 43.23 | -2.80 | 4.50 | 1.70 | 0.00 | 5.65 | -5.81 | 0.00 |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -2.37 | 45.00 | 42.63 | -2.92 | 4.50 | 1.58 | 0.00 | 9.06 | -9.48 | 0.00 |
| February | -2.09 | 45.00 | 42.91 | -2.85 | 4.50 | 1.65 | 0.00 | 6.96 | -7.28 | 0.00 |
| March | -1.03 | 45.00 | 43.97 | -2.05 | 4.50 | 2.45 | 0.00 | 7.35 | -5.21 | 0.00 |
| April | 0.46 | 45.00 | 45.46 | -0.82 | 4.50 | 3.68 | 0.00 | 6.68 | -1.31 | 0.00 |
| May | 1.68 | 45.00 | 46.68 | -0.16 | 4.50 | 4.34 | 0.00 | 6.38 | 0.00 | 0.00 |
| June | 2.42 | 45.00 | 47.42 | 0.33 | 4.50 | 4.83 | 0.00 | 5.04 | 0.00 | 1.82 |
| July | 2.75 | 45.00 | 47.75 | 0.36 | 4.50 | 4.86 | 0.00 | 4.74 | 0.00 | 2.27 |
| August | 2.47 | 45.00 | 47.47 | 0.23 | 4.50 | 4.73 | 0.00 | 5.03 | 0.00 | 2.13 |
| September | 1.57 | 45.00 | 46.57 | -0.12 | 4.50 | 4.38 | 0.00 | 5.06 | 0.00 | 0.33 |
| October | 0.24 | 45.00 | 45.24 | -0.61 | 4.50 | 3.89 | 0.00 | 6.13 | 0.00 | 0.00 |
| November | -1.40 | 45.00 | 43.60 | -1.90 | 4.50 | 2.60 | 0.00 | 7.65 | -4.73 | 0.00 |
| December | -2.46 | 45.00 | 42.54 | -2.81 | 4.50 | 1.69 | 0.00 | 8.35 | -8.72 | 0.00 |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 3.23 | 3.77 | 8.84 | 15.84 |
| February | 0.00 | 0.00 | 0.22 | 2.94 | 3.40 | 7.98 | 14.32 |
| March | 0.00 | 0.00 | 0.22 | 2.32 | 3.77 | 8.84 | 14.92 |
| April | 0.29 | 4.46 | 0.22 | 0.66 | 3.65 | 8.55 | 17.31 |
| May | 0.29 | 4.83 | 0.22 | 0.00 | 3.77 | 8.84 | 17.43 |
| June | 0.29 | 6.47 | 0.22 | 0.00 | 3.65 | 8.55 | 18.66 |
| July | 0.29 | 7.29 | 0.22 | 0.00 | 3.77 | 8.84 | 19.89 |
| August | 0.29 | 6.94 | 0.22 | 0.00 | 3.77 | 8.84 | 19.54 |
| September | 0.29 | 4.92 | 0.22 | 0.00 | 3.65 | 8.55 | 17.12 |
| October | 0.29 | 4.56 | 0.22 | 0.00 | 3.77 | 8.84 | 17.16 |
| November | 0.00 | 0.00 | 0.22 | 1.95 | 3.65 | 8.55 | 14.14 |
| December | 0.00 | 0.00 | 0.22 | 3.23 | 3.77 | 8.84 | 15.83 |
| TOTAL/m2 | | 39.46 | | 14.33 | 44.35 | 104.03 | 202.16 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 4: PV ROOF MONITORS

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | San Francisco | Longitude | 37.62 N | | | | |
| | | Latitude | 122.38 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate costal warm | Altitude | 2.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 13.00 | 5.40 | 85.00 | 40.00 | 154.00 | 10.00 | 15.40 | 15.60 | 75 | 85 |
| February | 14.70 | 6.30 | 130.00 | 55.00 | 191.00 | 11.56 | 16.52 | 11.48 | 71 | 85 |
| March | 16.40 | 7.20 | 190.00 | 75.00 | 262.00 | 12.43 | 21.08 | 9.92 | 66 | 83 |
| April | 17.90 | 8.40 | 250.00 | 100.00 | 297.00 | 13.94 | 21.30 | 8.70 | 66 | 85 |
| May | 19.40 | 9.80 | 290.00 | 120.00 | 328.00 | 14.90 | 22.01 | 8.99 | 66 | 85 |
| June | 21.20 | 11.30 | 305.00 | 125.00 | 341.00 | 15.36 | 22.20 | 7.80 | 65 | 87 |
| July | 22.20 | 11.90 | 290.00 | 120.00 | 295.00 | 14.20 | 20.77 | 10.23 | 69 | 90 |
| August | 22.10 | 12.10 | 250.00 | 100.00 | 275.00 | 13.55 | 20.15 | 10.85 | 69 | 90 |
| September | 23.20 | 12.20 | 190.00 | 75.00 | 275.00 | 12.73 | 21.60 | 8.40 | 66 | 88 |
| October | 21.40 | 10.30 | 130.00 | 55.00 | 242.00 | 11.31 | 21.39 | 9.61 | 65 | 86 |
| November | 17.80 | 7.70 | 85.00 | 40.00 | 198.00 | 10.00 | 19.80 | 10.20 | 68 | 84 |
| December | 14.00 | 6.10 | 70.00 | 35.00 | 179.00 | 10.31 | 17.36 | 13.64 | 74 | 86 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.15 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.00 |
| Thermal Transmittance | W/m2oC | 0.20 |
| PV slope | (°) | 15.00 |

### INTERNAL TEMPERATURES

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 11.10 | 7.84 | 207.60 | 0.00 | 96.00 | 0.00 | 15.40 | 15.60 | 28.01 | 22.52 |
| February | 12.60 | 9.00 | 260.51 | 29.06 | 114.17 | 12.74 | 16.52 | 11.48 | 30.55 | 25.19 |
| March | 14.10 | 10.16 | 342.75 | 59.46 | 144.82 | 25.13 | 21.08 | 9.92 | 32.71 | 27.53 |
| April | 15.53 | 11.45 | 404.48 | 113.94 | 172.12 | 48.48 | 21.30 | 8.70 | 36.08 | 31.15 |
| May | 17.00 | 12.89 | 446.11 | 156.21 | 193.26 | 67.67 | 22.01 | 8.99 | 39.69 | 34.84 |
| June | 18.73 | 14.48 | 453.11 | 173.49 | 195.31 | 74.78 | 22.20 | 7.80 | 43.67 | 39.69 |
| July | 19.63 | 15.21 | 468.06 | 140.53 | 202.77 | 60.88 | 20.77 | 10.23 | 47.62 | 42.64 |
| August | 19.60 | 15.31 | 413.26 | 107.67 | 175.85 | 45.82 | 20.15 | 10.85 | 47.55 | 42.94 |
| September | 20.45 | 15.74 | 334.60 | 65.28 | 141.38 | 27.58 | 21.60 | 8.40 | 48.59 | 43.54 |
| October | 18.63 | 13.87 | 266.23 | 24.98 | 116.67 | 10.95 | 21.39 | 9.61 | 43.42 | 37.72 |
| November | 15.28 | 10.95 | 207.60 | 0.00 | 96.00 | 0.00 | 19.80 | 10.20 | 36.10 | 29.66 |
| December | 12.03 | 8.64 | 171.08 | 3.80 | 81.47 | 1.81 | 17.36 | 13.64 | 29.94 | 24.53 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -4.69 | 25.00 | 20.31 | -5.30 | 4.50 | -0.80 | -0.17 | 3.13 | -2.48 | 0.00 |
| February | -3.27 | 25.00 | 21.73 | -4.31 | 4.50 | 0.19 | 0.00 | 3.63 | -1.86 | 0.00 |
| March | -1.61 | 25.00 | 23.39 | -3.30 | 4.50 | 1.20 | 0.00 | 5.29 | -1.50 | 0.00 |
| April | -0.16 | 25.00 | 24.84 | -2.00 | 4.50 | 2.50 | 0.00 | 6.04 | -0.14 | 0.00 |
| May | 1.15 | 25.00 | 26.15 | -1.80 | 4.50 | 2.70 | 0.00 | 6.59 | 0.00 | 0.00 |
| June | 2.33 | 25.00 | 27.33 | -1.15 | 4.50 | 3.35 | 0.00 | 7.11 | 0.00 | 0.00 |
| July | 3.04 | 25.00 | 28.04 | -0.96 | 4.50 | 3.54 | 0.00 | 6.85 | 0.00 | 0.08 |
| August | 2.56 | 25.00 | 27.56 | -1.17 | 4.50 | 3.33 | 0.00 | 6.49 | 0.00 | 0.05 |
| September | 2.45 | 25.00 | 27.45 | -1.25 | 4.50 | 3.25 | 0.00 | 6.91 | 0.00 | 0.48 |
| October | 0.69 | 25.00 | 25.69 | -1.18 | 4.50 | 3.32 | 0.00 | 6.49 | 0.00 | 0.00 |
| November | -1.98 | 25.00 | 23.02 | -3.28 | 4.50 | 1.22 | 0.00 | 4.90 | -0.12 | 0.00 |
| December | -4.40 | 25.00 | 20.60 | -4.75 | 4.50 | -0.25 | -0.06 | 3.58 | -2.16 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -5.63 | 45.00 | 39.37 | -5.30 | 4.50 | -0.80 | -0.18 | 6.14 | -2.52 | 0.00 |
| February | -4.50 | 40.00 | 35.50 | -4.44 | 4.50 | 0.06 | 0.00 | 4.08 | -1.28 | 0.00 |
| March | -3.27 | 35.00 | 31.73 | -3.59 | 4.50 | 0.91 | 0.00 | 3.27 | -0.71 | 0.00 |
| April | -2.11 | 30.00 | 27.89 | -2.55 | 4.50 | 1.95 | 0.00 | 2.66 | -0.06 | 0.00 |
| May | -0.98 | 25.00 | 24.02 | -1.46 | 4.50 | 3.04 | 0.00 | 2.54 | 0.00 | 0.00 |
| June | 0.16 | 25.00 | 25.16 | -0.36 | 4.50 | 4.14 | 0.00 | 2.41 | 0.00 | 0.00 |
| July | 0.81 | 25.00 | 25.81 | 0.00 | 4.50 | 4.50 | 0.00 | 3.28 | 0.00 | 0.04 |
| August | 0.57 | 25.00 | 25.57 | -0.06 | 4.50 | 4.44 | 0.00 | 3.45 | 0.00 | 0.03 |
| September | 0.83 | 30.00 | 30.83 | 0.06 | 4.50 | 4.56 | 0.00 | 3.13 | 0.00 | 0.19 |
| October | -0.56 | 35.00 | 34.44 | -1.29 | 4.50 | 3.21 | 0.00 | 3.74 | 0.00 | 0.00 |
| November | -2.91 | 40.00 | 37.09 | -3.28 | 4.50 | 1.22 | 0.00 | 3.96 | -0.06 | 0.00 |
| December | -5.15 | 45.00 | 39.85 | -4.77 | 4.50 | -0.27 | -0.05 | 5.44 | -1.69 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 1.19 | 2.08 | 5.76 | 9.03 |
| February | 0.00 | 0.00 | 0.22 | 0.70 | 1.88 | 4.10 | 6.68 |
| March | 0.00 | 0.00 | 0.22 | 0.49 | 2.08 | 3.63 | 6.20 |
| April | 0.29 | 2.49 | 0.22 | 0.04 | 2.01 | 2.99 | 7.53 |
| May | 0.29 | 2.61 | 0.22 | 0.00 | 2.08 | 2.64 | 7.33 |
| June | 0.29 | 2.72 | 0.22 | 0.00 | 2.01 | 2.55 | 7.28 |
| July | 0.29 | 2.93 | 0.22 | 0.00 | 2.08 | 2.64 | 7.65 |
| August | 0.29 | 2.86 | 0.22 | 0.00 | 2.08 | 2.64 | 7.58 |
| September | 0.29 | 3.06 | 0.22 | 0.00 | 2.01 | 2.97 | 8.04 |
| October | 0.29 | 2.92 | 0.22 | 0.00 | 2.08 | 3.60 | 8.60 |
| November | 0.29 | 2.53 | 0.22 | 0.04 | 2.01 | 4.08 | 8.66 |
| December | 0.00 | 0.00 | 0.22 | 0.88 | 2.08 | 5.36 | 8.33 |
| TOTAL/m2 | | 22.12 | | 3.34 | 24.51 | 42.93 | 92.90 |

# OPTION 4: PV ROOF MONITORS

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | New York | Longitude | 40.70 N | | | | |
| | | Latitude | 74.02 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate costal cold | Altitude | 3.00 m | Diffuse Radiation Factor | 1.10 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 4.30 | -2.80 | 85.00 | 40.00 | 151.00 | 10.00 | 15.10 | 15.90 | 61 | 69 |
| February | 4.10 | -2.40 | 130.00 | 55.00 | 164.00 | 10.28 | 15.96 | 12.04 | 58 | 67 |
| March | 8.90 | 0.50 | 190.00 | 75.00 | 209.00 | 11.83 | 17.67 | 13.33 | 56 | 67 |
| April | 14.90 | 6.10 | 250.00 | 100.00 | 214.00 | 12.09 | 17.70 | 12.30 | 55 | 68 |
| May | 20.90 | 11.80 | 290.00 | 120.00 | 250.00 | 13.44 | 18.60 | 12.40 | 56 | 69 |
| June | 25.60 | 16.90 | 305.00 | 125.00 | 301.00 | 16.18 | 18.60 | 11.40 | 58 | 72 |
| July | 28.30 | 19.90 | 290.00 | 120.00 | 307.00 | 15.00 | 20.46 | 10.54 | 57 | 74 |
| August | 27.40 | 19.30 | 250.00 | 100.00 | 275.00 | 13.86 | 19.84 | 11.16 | 60 | 76 |
| September | 23.80 | 15.80 | 190.00 | 75.00 | 237.00 | 12.54 | 18.90 | 11.10 | 60 | 76 |
| October | 18.40 | 10.30 | 130.00 | 55.00 | 218.00 | 11.34 | 19.22 | 11.78 | 59 | 74 |
| November | 11.90 | 4.40 | 85.00 | 40.00 | 172.00 | 10.06 | 17.10 | 12.90 | 60 | 71 |
| December | 5.70 | -1.20 | 70.00 | 35.00 | 158.00 | 10.00 | 15.80 | 15.20 | 60 | 67 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.15 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

**PV PANEL DATA**

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.00 |
| Thermal Transmittance | W/m2oC | 0.20 |
| PV slope | (°) | 15.00 |

**INTERNAL TEMPERATURES**

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

**HUMIDITY-WINTER**

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

**HUMIDITY-SUMMER**

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 2.53 | -0.52 | 207.60 | 0.00 | 96.00 | 0.00 | 15.10 | 15.90 | 8.95 | 4.83 |
| February | 2.48 | -0.31 | 293.12 | 5.77 | 128.46 | 2.53 | 15.96 | 12.04 | 8.56 | 4.99 |
| March | 6.83 | 3.27 | 360.16 | 47.03 | 152.18 | 19.87 | 17.67 | 13.33 | 15.67 | 10.86 |
| April | 12.70 | 8.93 | 456.49 | 69.65 | 198.50 | 29.64 | 17.70 | 12.30 | 26.71 | 21.80 |
| May | 18.63 | 14.73 | 494.61 | 121.56 | 214.27 | 52.66 | 18.60 | 12.40 | 39.98 | 35.06 |
| June | 23.43 | 19.70 | 430.09 | 189.94 | 185.38 | 81.87 | 18.60 | 11.40 | 52.74 | 49.03 |
| July | 26.20 | 22.60 | 443.06 | 158.39 | 191.94 | 68.62 | 20.46 | 10.54 | 59.60 | 58.33 |
| August | 25.38 | 21.90 | 406.90 | 112.21 | 173.15 | 47.75 | 19.84 | 11.16 | 59.06 | 57.18 |
| September | 21.80 | 18.37 | 339.72 | 61.63 | 143.54 | 26.04 | 18.90 | 11.10 | 49.48 | 46.90 |
| October | 16.38 | 12.90 | 265.55 | 25.46 | 116.38 | 11.16 | 19.22 | 11.78 | 35.84 | 32.04 |
| November | 10.03 | 6.81 | 206.39 | 0.86 | 85.44 | 0.40 | 17.10 | 12.90 | 22.45 | 18.01 |
| December | 3.98 | 1.02 | 176.40 | 0.00 | 84.00 | 0.00 | 15.80 | 15.20 | 11.26 | 7.09 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -10.26 | 25.00 | 14.74 | -10.74 | 4.50 | -6.24 | -1.32 | 2.22 | -7.96 | 0.00 |
| February | -9.58 | 25.00 | 15.42 | -10.55 | 4.50 | -6.05 | -1.35 | 2.46 | -8.54 | 0.00 |
| March | -6.19 | 25.00 | 18.81 | -7.88 | 4.50 | -3.38 | -0.84 | 3.32 | -7.04 | 0.00 |
| April | -1.48 | 25.00 | 23.52 | -4.01 | 4.50 | 0.49 | 0.00 | 4.28 | -3.30 | 0.00 |
| May | 2.61 | 25.00 | 27.61 | -3.06 | 4.50 | 1.44 | 0.00 | 5.51 | 0.00 | 0.00 |
| June | 5.19 | 25.00 | 30.19 | -1.42 | 4.50 | 3.08 | 0.00 | 6.42 | 0.00 | 1.90 |
| July | 7.10 | 25.00 | 32.10 | -0.88 | 4.50 | 3.62 | 0.00 | 7.61 | 0.00 | 4.78 |
| August | 6.26 | 25.00 | 31.26 | -0.64 | 4.50 | 3.86 | 0.00 | 7.28 | 0.00 | 4.43 |
| September | 3.37 | 25.00 | 28.37 | -1.19 | 4.50 | 3.31 | 0.00 | 6.24 | 0.00 | 0.75 |
| October | -0.78 | 25.00 | 24.22 | -1.80 | 4.50 | 2.70 | 0.00 | 5.38 | -0.21 | 0.00 |
| November | -5.40 | 25.00 | 19.60 | -5.97 | 4.50 | -1.47 | -0.35 | 3.35 | -4.58 | 0.00 |
| December | -9.58 | 25.00 | 15.42 | -9.74 | 4.50 | -5.24 | -1.16 | 2.44 | -7.63 | 0.00 |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -11.20 | 45.00 | 33.80 | -10.74 | 4.50 | -6.24 | -1.39 | 5.37 | -8.38 | 0.00 |
| February | -10.96 | 40.00 | 29.04 | -10.58 | 4.50 | -6.08 | -1.02 | 3.50 | -6.44 | 0.00 |
| March | -7.94 | 35.00 | 27.06 | -8.11 | 4.50 | -3.61 | -0.67 | 3.61 | -5.31 | 0.00 |
| April | -3.73 | 30.00 | 26.27 | -4.35 | 4.50 | 0.15 | 0.00 | 3.26 | -2.29 | 0.00 |
| May | 0.26 | 25.00 | 25.26 | -0.39 | 4.50 | 4.11 | 0.00 | 3.85 | 0.00 | 0.00 |
| June | 3.13 | 25.00 | 28.13 | -0.48 | 4.50 | 4.02 | 0.00 | 3.85 | 0.00 | 1.16 |
| July | 4.99 | 25.00 | 29.99 | -0.01 | 4.50 | 4.49 | 0.00 | 3.82 | 0.00 | 2.46 |
| August | 4.30 | 25.00 | 29.30 | -0.09 | 4.50 | 4.41 | 0.00 | 3.96 | 0.00 | 2.49 |
| September | 1.73 | 30.00 | 31.73 | -1.16 | 4.50 | 3.34 | 0.00 | 4.04 | 0.00 | 0.44 |
| October | -2.03 | 35.00 | 32.97 | -1.92 | 4.50 | 2.58 | 0.00 | 4.31 | -0.13 | 0.00 |
| November | -6.33 | 40.00 | 33.67 | -5.97 | 4.50 | -1.47 | -0.27 | 4.34 | -3.46 | 0.00 |
| December | -10.36 | 45.00 | 34.64 | -9.74 | 4.50 | -5.24 | -1.11 | 5.27 | -7.34 | 0.00 |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 4.23 | 2.30 | 5.82 | 12.35 |
| February | 0.00 | 0.00 | 0.22 | 3.86 | 2.08 | 4.19 | 10.12 |
| March | 0.00 | 0.00 | 0.22 | 3.08 | 2.30 | 3.97 | 9.35 |
| April | 0.00 | 0.00 | 0.22 | 1.24 | 2.23 | 3.17 | 6.63 |
| May | 0.29 | 2.67 | 0.22 | 0.00 | 2.30 | 2.64 | 7.61 |
| June | 0.29 | 3.81 | 0.22 | 0.00 | 2.23 | 2.55 | 8.58 |
| July | 0.29 | 5.34 | 0.22 | 0.00 | 2.30 | 2.64 | 10.27 |
| August | 0.29 | 5.19 | 0.22 | 0.00 | 2.30 | 2.64 | 10.12 |
| September | 0.29 | 3.27 | 0.22 | 0.00 | 2.23 | 3.11 | 8.61 |
| October | 0.29 | 2.77 | 0.22 | 0.08 | 2.30 | 3.81 | 8.96 |
| November | 0.00 | 0.00 | 0.22 | 1.92 | 2.23 | 4.49 | 8.63 |
| December | 0.00 | 0.00 | 0.22 | 3.83 | 2.30 | 5.68 | 11.81 |
| TOTAL/m2 | | 23.05 | | 18.25 | 27.07 | 44.67 | 113.04 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 4: PV ROOF MONITORS

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Phoenix | Longitude | 33.43 N | | | | |
| | | Latitude | 112.02 W | Direct Radiation Factor | 1.10 | | |
| Climate | Temperate arid | Altitude | 340.00 m | Diffuse Radiation Factor | 0.90 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 17.80 | 1.80 | 105.00 | 25.00 | 262.00 | 10.84 | 24.18 | 6.82 | 44 | 72 |
| February | 20.10 | 3.80 | 150.00 | 30.00 | 271.00 | 12.41 | 21.84 | 6.16 | 42 | 71 |
| March | 23.90 | 6.10 | 205.00 | 35.00 | 331.00 | 12.56 | 26.35 | 4.65 | 31 | 60 |
| April | 28.80 | 10.20 | 260.00 | 45.00 | 360.00 | 13.48 | 26.70 | 3.30 | 26 | 50 |
| May | 33.80 | 13.90 | 295.00 | 45.00 | 406.00 | 14.00 | 29.14 | 1.86 | 19 | 41 |
| June | 38.70 | 18.60 | 305.00 | 50.00 | 411.00 | 14.57 | 28.20 | 1.80 | 17 | 37 |
| July | 40.30 | 23.90 | 295.00 | 45.00 | 390.00 | 14.30 | 27.28 | 3.72 | 29 | 51 |
| August | 38.70 | 23.00 | 260.00 | 45.00 | 379.00 | 14.22 | 26.66 | 4.34 | 35 | 60 |
| September | 36.80 | 19.60 | 205.00 | 35.00 | 354.00 | 13.11 | 27.00 | 3.00 | 29 | 66 |
| October | 30.40 | 12.60 | 150.00 | 30.00 | 323.00 | 11.98 | 26.97 | 4.03 | 30 | 58 |
| November | 23.20 | 5.80 | 105.00 | 25.00 | 282.00 | 10.93 | 25.80 | 4.20 | 33 | 63 |
| December | 18.90 | 2.80 | 90.00 | 25.00 | 260.00 | 10.75 | 24.18 | 6.82 | 42 | 70 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.15 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | | | |
|---|---|---|---|---|
| Conversion Efficiency | % | 10.00 | %RH | 35 |
| Direct Transmittance | % | 0.00 | Enthalpy | 36.41 |
| Thermal Transmittance W/m2oC | | 0.20 | | |
| PV slope (°) | | 15.00 | | |

### INTERNAL TEMPERATURES

| | | | | |
|---|---|---|---|---|
| Occupied Period Set Point | oC | 21.00 | %RH | 60 |
| Unoccupied Period Offset | oC | 5.00 | Enthalpy | 47.425 |

HUMIDITY-WINTER

HUMIDITY-SUMMER

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 13.80 | 6.94 | 305.66 | 18.24 | 110.75 | 6.61 | 24.18 | 6.82 | 25.94 | 18.43 |
| February | 16.03 | 9.04 | 371.36 | 63.89 | 116.05 | 19.96 | 21.84 | 6.16 | 29.56 | 22.60 |
| March | 19.45 | 11.82 | 491.02 | 89.84 | 133.74 | 24.47 | 26.35 | 4.65 | 31.89 | 26.13 |
| April | 24.15 | 16.18 | 581.17 | 144.59 | 160.20 | 39.86 | 26.70 | 3.30 | 37.82 | 32.46 |
| May | 28.83 | 20.30 | 625.65 | 178.82 | 154.27 | 44.09 | 29.14 | 1.86 | 41.52 | 37.62 |
| June | 33.68 | 25.06 | 626.58 | 204.73 | 164.67 | 53.81 | 28.20 | 1.80 | 47.87 | 45.49 |
| July | 36.20 | 29.17 | 612.75 | 188.04 | 151.09 | 46.36 | 27.28 | 3.72 | 63.15 | 63.82 |
| August | 34.78 | 28.05 | 551.21 | 165.89 | 151.84 | 45.76 | 26.66 | 4.34 | 65.41 | 66.63 |
| September | 32.50 | 25.13 | 470.44 | 104.54 | 128.14 | 28.47 | 27.00 | 3.00 | 55.49 | 61.70 |
| October | 25.95 | 18.32 | 384.76 | 54.31 | 120.24 | 16.97 | 26.97 | 4.03 | 43.31 | 40.03 |
| November | 18.65 | 11.39 | 303.01 | 20.13 | 109.79 | 7.29 | 25.80 | 4.20 | 31.61 | 30.54 |
| December | 14.88 | 7.98 | 271.19 | 14.58 | 111.60 | 6.00 | 24.18 | 6.82 | 27.38 | 20.20 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -2.11 | 25.00 | 22.89 | -5.73 | 4.50 | -1.23 | -0.42 | 5.53 | -4.86 | 0.00 |
| February | -0.11 | 25.00 | 24.89 | -3.99 | 4.50 | 0.51 | 0.00 | 5.59 | -2.88 | 0.00 |
| March | 3.12 | 25.00 | 28.12 | -1.96 | 4.50 | 2.54 | 0.00 | 8.35 | -2.29 | 0.00 |
| April | 6.93 | 25.00 | 31.93 | -1.92 | 4.50 | 2.58 | 0.00 | 9.49 | 0.00 | 0.00 |
| May | 10.34 | 25.00 | 35.34 | 1.04 | 4.50 | 5.54 | 0.00 | 12.56 | 0.00 | 0.00 |
| June | 13.50 | 25.00 | 38.50 | 1.11 | 4.50 | 5.61 | 0.00 | 13.07 | 0.00 | 0.24 |
| July | 15.03 | 25.00 | 40.03 | 3.64 | 4.50 | 8.14 | 0.00 | 14.03 | 0.00 | 8.24 |
| August | 13.58 | 25.00 | 38.58 | 2.72 | 4.50 | 7.22 | 0.00 | 12.98 | 0.00 | 9.21 |
| September | 11.43 | 25.00 | 36.43 | 0.31 | 4.50 | 4.81 | 0.00 | 11.65 | 0.00 | 4.18 |
| October | 6.45 | 25.00 | 31.45 | -1.28 | 4.50 | 3.22 | 0.00 | 9.70 | 0.00 | 0.00 |
| November | 1.15 | 25.00 | 26.15 | -2.83 | 4.50 | 1.67 | 0.00 | 7.35 | -2.38 | 0.00 |
| December | -1.70 | 25.00 | 23.30 | -5.09 | 4.50 | -0.59 | -0.20 | 5.63 | -4.19 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -3.75 | 45.00 | 41.25 | -5.83 | 4.50 | -1.33 | -0.13 | 2.81 | -1.37 | 0.00 |
| February | -2.26 | 40.00 | 37.74 | -4.36 | 4.50 | 0.14 | 0.00 | 2.34 | -0.81 | 0.00 |
| March | 0.12 | 35.00 | 35.12 | -2.51 | 4.50 | 1.99 | 0.00 | 1.76 | -0.40 | 0.00 |
| April | 3.39 | 30.00 | 33.39 | -1.17 | 4.50 | 3.33 | 0.00 | 1.26 | 0.00 | 0.00 |
| May | 6.38 | 25.00 | 31.38 | -0.09 | 4.50 | 4.41 | 0.00 | 0.70 | 0.00 | 0.00 |
| June | 9.62 | 25.00 | 34.62 | 1.47 | 4.50 | 5.97 | 0.00 | 0.77 | 0.00 | 0.02 |
| July | 11.15 | 25.00 | 36.15 | 2.45 | 4.50 | 6.95 | 0.00 | 1.71 | 0.00 | 1.12 |
| August | 10.23 | 25.00 | 35.23 | 1.71 | 4.50 | 6.21 | 0.00 | 1.91 | 0.00 | 1.50 |
| September | 8.55 | 30.00 | 38.55 | -0.33 | 4.50 | 4.17 | 0.00 | 1.33 | 0.00 | 0.46 |
| October | 4.23 | 35.00 | 39.23 | -1.60 | 4.50 | 2.90 | 0.00 | 1.74 | 0.00 | 0.00 |
| November | -0.48 | 40.00 | 39.52 | -2.93 | 4.50 | 1.57 | 0.00 | 1.75 | -0.39 | 0.00 |
| December | -3.04 | 45.00 | 41.96 | -5.17 | 4.50 | -0.67 | -0.06 | 2.86 | -1.18 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 1.51 | 2.93 | 4.00 | 8.44 |
| February | 0.29 | 2.27 | 0.22 | 0.82 | 2.65 | 3.30 | 9.04 |
| March | 0.29 | 2.89 | 0.22 | 0.60 | 2.93 | 3.10 | 9.52 |
| April | 0.29 | 3.07 | 0.22 | 0.00 | 2.84 | 2.72 | 8.62 |
| May | 0.29 | 3.79 | 0.22 | 0.00 | 2.93 | 2.64 | 9.36 |
| June | 0.29 | 4.03 | 0.22 | 0.00 | 2.84 | 2.55 | 9.42 |
| July | 0.29 | 7.17 | 0.22 | 0.00 | 2.93 | 2.64 | 12.74 |
| August | 0.29 | 7.31 | 0.22 | 0.00 | 2.93 | 2.64 | 12.88 |
| September | 0.29 | 5.04 | 0.22 | 0.00 | 2.84 | 2.70 | 10.57 |
| October | 0.29 | 3.27 | 0.22 | 0.00 | 2.93 | 3.04 | 9.24 |
| November | 0.29 | 2.60 | 0.22 | 0.61 | 2.84 | 3.18 | 9.23 |
| December | 0.00 | 0.00 | 0.22 | 1.25 | 2.93 | 4.00 | 8.18 |
| TOTAL/m2 | | 41.43 | | 4.79 | 34.53 | 36.49 | 117.24 |

## OPTION 4: PV ROOF MONITORS

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Miami | Longitude | 25.80 N | | | | |
| | | Latitude | 80.27 W | Direct Radiation Factor | 0.50 | | |
| Climate | Sub-tropical | Altitude | 2.00 m | Diffuse Radiation Factor | 1.10 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 24.30 | 14.40 | 150.00 | 65.00 | 239.00 | 11.51 | 20.77 | 10.23 | 59 | 84 |
| February | 25.00 | 14.90 | 195.00 | 80.00 | 233.00 | 11.72 | 19.88 | 8.12 | 56 | 84 |
| March | 26.60 | 16.20 | 235.00 | 95.00 | 269.00 | 12.22 | 22.01 | 8.99 | 56 | 82 |
| April | 28.10 | 18.80 | 275.00 | 115.00 | 283.00 | 13.10 | 21.60 | 8.40 | 56 | 79 |
| May | 29.70 | 20.90 | 295.00 | 125.00 | 276.00 | 13.49 | 20.46 | 10.54 | 59 | 78 |
| June | 31.10 | 23.10 | 295.00 | 125.00 | 255.00 | 13.93 | 18.30 | 11.70 | 64 | 81 |
| July | 31.60 | 23.70 | 295.00 | 125.00 | 270.00 | 13.62 | 19.53 | 11.47 | 64 | 81 |
| August | 32.10 | 23.80 | 275.00 | 115.00 | 261.00 | 13.16 | 19.84 | 11.16 | 63 | 83 |
| September | 31.10 | 23.70 | 235.00 | 95.00 | 212.00 | 11.98 | 17.70 | 12.30 | 66 | 85 |
| October | 29.30 | 21.60 | 195.00 | 80.00 | 200.00 | 11.73 | 17.05 | 13.95 | 64 | 85 |
| November | 26.80 | 18.10 | 150.00 | 65.00 | 224.00 | 11.31 | 19.80 | 10.20 | 60 | 84 |
| December | 26.10 | 15.10 | 135.00 | 55.00 | 221.00 | 11.14 | 19.84 | 11.16 | 60 | 85 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.15 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

**PV PANEL DATA**

| | | | | |
|---|---|---|---|---|
| Conversion Efficiency | % | 10.00 | %RH | 35 |
| Direct Transmittance | % | 0.00 | Enthalpy | 36.41 |
| Thermal Transmittance W/m2oC | | 0.20 | | |
| PV slope (°) | | 15.00 | | |

**INTERNAL TEMPERATURES** — **HUMIDITY-SUMMER**

| | | | | |
|---|---|---|---|---|
| Occupied Period Set Point | oC | 21.00 | %RH | 60 |
| Unoccupied Period Offset | oC | 5.00 | Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 21.83 | 17.58 | 305.55 | 32.89 | 135.57 | 14.59 | 20.77 | 10.23 | 49.08 | 47.57 |
| February | 22.48 | 18.15 | 379.85 | 46.68 | 163.82 | 20.13 | 19.88 | 8.12 | 49.32 | 49.23 |
| March | 24.00 | 19.54 | 435.95 | 69.18 | 186.55 | 29.60 | 22.01 | 8.99 | 53.21 | 52.64 |
| April | 25.78 | 21.79 | 483.60 | 107.15 | 210.66 | 46.67 | 21.60 | 8.40 | 57.88 | 58.21 |
| May | 27.50 | 23.73 | 507.05 | 126.39 | 222.39 | 55.43 | 20.46 | 10.54 | 64.43 | 63.82 |
| June | 29.10 | 25.67 | 490.87 | 137.95 | 215.29 | 60.50 | 18.30 | 11.70 | 72.43 | 71.86 |
| July | 29.53 | 26.24 | 494.76 | 135.17 | 217.00 | 59.29 | 19.53 | 11.47 | 74.06 | 73.80 |
| August | 30.03 | 26.47 | 481.63 | 108.55 | 209.80 | 47.28 | 19.84 | 11.16 | 74.60 | 75.78 |
| September | 29.25 | 26.08 | 444.84 | 62.83 | 190.36 | 26.89 | 17.70 | 12.30 | 74.26 | 75.58 |
| October | 27.38 | 24.08 | 379.53 | 46.91 | 163.68 | 20.23 | 17.05 | 13.95 | 67.19 | 68.60 |
| November | 24.63 | 20.80 | 310.78 | 29.15 | 137.89 | 12.93 | 19.80 | 10.20 | 57.00 | 57.67 |
| December | 23.35 | 18.64 | 275.78 | 22.44 | 118.50 | 9.64 | 19.84 | 11.16 | 53.56 | 51.08 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | 3.10 | 25.00 | 28.10 | -1.30 | 4.50 | 3.20 | 0.00 | 6.77 | 0.00 | 0.66 |
| February | 4.15 | 25.00 | 29.15 | -0.81 | 4.50 | 3.69 | 0.00 | 6.82 | 0.00 | 0.72 |
| March | 5.61 | 25.00 | 30.61 | -0.69 | 4.50 | 3.81 | 0.00 | 7.91 | 0.00 | 2.45 |
| April | 7.17 | 25.00 | 32.17 | -0.21 | 4.50 | 4.29 | 0.00 | 8.24 | 0.00 | 4.34 |
| May | 8.48 | 25.00 | 33.48 | 0.67 | 4.50 | 5.17 | 0.00 | 8.33 | 0.00 | 6.68 |
| June | 9.39 | 25.00 | 34.39 | 0.95 | 4.50 | 5.45 | 0.00 | 7.69 | 0.00 | 8.78 |
| July | 9.76 | 25.00 | 34.76 | 1.29 | 4.50 | 5.79 | 0.00 | 8.37 | 0.00 | 9.99 |
| August | 9.91 | 25.00 | 34.91 | 1.22 | 4.50 | 5.72 | 0.00 | 8.51 | 0.00 | 10.35 |
| September | 9.10 | 25.00 | 34.10 | 0.58 | 4.50 | 5.08 | 0.00 | 7.29 | 0.00 | 9.12 |
| October | 7.33 | 25.00 | 32.33 | 0.23 | 4.50 | 4.73 | 0.00 | 6.64 | 0.00 | 6.47 |
| November | 4.97 | 25.00 | 29.97 | -0.47 | 4.50 | 4.03 | 0.00 | 7.05 | 0.00 | 3.64 |
| December | 3.84 | 25.00 | 28.84 | -0.70 | 4.50 | 3.80 | 0.00 | 6.78 | 0.00 | 2.34 |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | 1.68 | 45.00 | 46.68 | -0.47 | 4.50 | 4.03 | 0.00 | 5.35 | 0.00 | 0.33 |
| February | 2.33 | 40.00 | 42.33 | -0.60 | 4.50 | 3.90 | 0.00 | 3.88 | 0.00 | 0.30 |
| March | 3.52 | 35.00 | 38.52 | -0.37 | 4.50 | 4.13 | 0.00 | 3.98 | 0.00 | 1.00 |
| April | 4.87 | 30.00 | 34.87 | -0.18 | 4.50 | 4.32 | 0.00 | 3.44 | 0.00 | 1.69 |
| May | 6.09 | 25.00 | 31.09 | 0.07 | 4.50 | 4.57 | 0.00 | 3.95 | 0.00 | 3.44 |
| June | 7.07 | 25.00 | 32.07 | 0.29 | 4.50 | 4.79 | 0.00 | 4.54 | 0.00 | 5.62 |
| July | 7.43 | 25.00 | 32.43 | 0.65 | 4.50 | 5.15 | 0.00 | 4.55 | 0.00 | 5.86 |
| August | 7.63 | 25.00 | 32.63 | 0.70 | 4.50 | 5.20 | 0.00 | 4.45 | 0.00 | 5.82 |
| September | 6.96 | 30.00 | 36.96 | 0.28 | 4.50 | 4.78 | 0.00 | 5.37 | 0.00 | 6.34 |
| October | 5.52 | 35.00 | 40.52 | 0.00 | 4.50 | 4.50 | 0.00 | 6.53 | 0.00 | 5.29 |
| November | 3.51 | 40.00 | 43.51 | -0.28 | 4.50 | 4.22 | 0.00 | 5.04 | 0.00 | 1.87 |
| December | 2.52 | 45.00 | 47.52 | -0.37 | 4.50 | 4.13 | 0.00 | 5.95 | 0.00 | 1.31 |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.29 | 3.75 | 0.22 | 0.00 | 2.62 | 4.68 | 11.05 |
| February | 0.29 | 3.35 | 0.22 | 0.00 | 2.37 | 3.60 | 9.31 |
| March | 0.29 | 4.38 | 0.22 | 0.00 | 2.62 | 3.53 | 10.54 |
| April | 0.29 | 5.06 | 0.22 | 0.00 | 2.53 | 2.97 | 10.56 |
| May | 0.29 | 6.40 | 0.22 | 0.00 | 2.62 | 2.64 | 11.66 |
| June | 0.29 | 7.61 | 0.22 | 0.00 | 2.53 | 2.55 | 12.69 |
| July | 0.29 | 8.22 | 0.22 | 0.00 | 2.62 | 2.64 | 13.47 |
| August | 0.29 | 8.33 | 0.22 | 0.00 | 2.62 | 2.64 | 13.58 |
| September | 0.29 | 8.03 | 0.22 | 0.00 | 2.53 | 3.17 | 13.73 |
| October | 0.29 | 7.12 | 0.22 | 0.00 | 2.62 | 4.03 | 13.77 |
| November | 0.29 | 5.03 | 0.22 | 0.00 | 2.53 | 4.08 | 11.64 |
| December | 0.29 | 4.68 | 0.22 | 0.00 | 2.62 | 4.87 | 12.17 |
| TOTAL/m2 | | 71.96 | | 0.00 | 30.84 | 41.38 | 144.17 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 4: PV ROOF MONITORS

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Chicago | Longitude | 41.78 N | | | | |
| | | Latitude | 87.75 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate continental | Altitude | 186.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 0.60 | -7.20 | 85.00 | 40.00 | 125.00 | 10.00 | 12.50 | 18.50 | 70 | 80 |
| February | 1.50 | -6.30 | 130.00 | 55.00 | 141.00 | 10.49 | 13.44 | 14.56 | 67 | 79 |
| March | 6.40 | -1.70 | 190.00 | 75.00 | 206.00 | 12.78 | 16.12 | 14.88 | 61 | 77 |
| April | 14.10 | 4.70 | 250.00 | 100.00 | 206.00 | 12.48 | 16.50 | 13.50 | 56 | 74 |
| May | 20.60 | 10.50 | 290.00 | 120.00 | 275.00 | 14.54 | 18.91 | 12.09 | 55 | 75 |
| June | 26.40 | 15.40 | 305.00 | 125.00 | 307.00 | 15.51 | 19.80 | 10.20 | 56 | 77 |
| July | 28.90 | 19.50 | 290.00 | 120.00 | 310.00 | 13.89 | 22.32 | 8.68 | 53 | 77 |
| August | 28.00 | 18.80 | 250.00 | 100.00 | 285.00 | 13.13 | 21.70 | 9.30 | 56 | 81 |
| September | 23.80 | 14.10 | 190.00 | 75.00 | 246.00 | 12.42 | 19.80 | 10.20 | 53 | 81 |
| October | 17.40 | 8.20 | 130.00 | 55.00 | 214.00 | 11.13 | 19.22 | 11.78 | 54 | 78 |
| November | 8.40 | 0.30 | 85.00 | 40.00 | 135.00 | 10.00 | 13.50 | 16.50 | 62 | 78 |
| December | 2.10 | -5.30 | 70.00 | 35.00 | 115.00 | 10.00 | 11.50 | 19.50 | 69 | 80 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.15 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.00 |
| Thermal Transmittance | W/m2oC | 0.20 |
| PV slope | (°) | 15.00 |

### INTERNAL TEMPERATURES

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | -1.35 | -4.69 | 207.60 | 0.00 | 96.00 | 0.00 | 12.50 | 18.50 | 3.63 | -0.55 |
| February | -0.45 | -3.79 | 287.10 | 10.07 | 125.82 | 4.41 | 13.44 | 14.56 | 4.78 | 0.64 |
| March | 4.38 | 0.90 | 333.36 | 66.17 | 140.85 | 27.96 | 16.12 | 14.88 | 12.07 | 7.80 |
| April | 11.75 | 7.72 | 451.75 | 80.18 | 182.23 | 34.12 | 16.50 | 13.50 | 25.03 | 20.36 |
| May | 18.08 | 13.75 | 457.14 | 148.33 | 198.04 | 64.26 | 18.91 | 12.09 | 38.34 | 34.37 |
| June | 23.65 | 18.94 | 448.89 | 176.51 | 193.49 | 76.08 | 19.80 | 10.20 | 52.31 | 48.88 |
| July | 26.55 | 22.52 | 478.66 | 132.96 | 207.36 | 57.60 | 22.32 | 8.68 | 58.17 | 59.53 |
| August | 25.70 | 21.76 | 429.43 | 96.12 | 182.74 | 40.90 | 21.70 | 9.30 | 57.68 | 59.03 |
| September | 21.38 | 17.22 | 342.88 | 59.37 | 144.88 | 25.09 | 19.80 | 10.20 | 45.23 | 45.46 |
| October | 15.10 | 11.16 | 270.52 | 21.92 | 118.55 | 9.50 | 19.22 | 11.78 | 31.44 | 29.05 |
| November | 6.38 | 2.90 | 207.60 | 0.00 | 96.00 | 0.00 | 13.50 | 16.50 | 15.78 | 11.43 |
| December | 0.25 | -2.92 | 176.40 | 0.00 | 84.00 | 0.00 | 11.50 | 19.50 | 6.03 | 1.95 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -12.78 | 25.00 | 12.22 | -13.45 | 4.50 | -8.95 | -1.57 | 1.53 | -7.87 | 0.00 |
| February | -11.53 | 25.00 | 13.47 | -12.78 | 4.50 | -8.28 | -1.56 | 1.81 | -8.16 | 0.00 |
| March | -8.01 | 25.00 | 16.99 | -9.26 | 4.50 | -4.76 | -1.07 | 2.74 | -7.54 | 0.00 |
| April | -2.22 | 25.00 | 22.78 | -4.71 | 4.50 | -0.21 | -0.05 | 3.76 | -3.61 | 0.00 |
| May | 1.94 | 25.00 | 26.94 | -1.84 | 4.50 | 2.66 | 0.00 | 5.80 | 0.00 | 0.00 |
| June | 5.49 | 25.00 | 30.49 | -0.94 | 4.50 | 3.56 | 0.00 | 7.02 | 0.00 | 1.86 |
| July | 7.63 | 25.00 | 32.63 | -0.06 | 4.50 | 4.44 | 0.00 | 8.67 | 0.00 | 4.61 |
| August | 6.66 | 25.00 | 31.66 | -0.33 | 4.50 | 4.17 | 0.00 | 8.14 | 0.00 | 4.27 |
| September | 3.12 | 25.00 | 28.12 | -0.33 | 4.50 | 4.17 | 0.00 | 6.72 | 0.00 | 0.00 |
| October | -1.56 | 25.00 | 23.44 | -2.96 | 4.50 | 1.54 | 0.00 | 4.82 | -1.84 | 0.00 |
| November | -7.76 | 25.00 | 17.24 | -8.51 | 4.50 | -4.01 | -0.76 | 2.33 | -5.35 | 0.00 |
| December | -12.01 | 25.00 | 12.99 | -12.30 | 4.50 | -7.80 | -1.26 | 1.49 | -6.71 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -13.72 | 45.00 | 31.28 | -13.45 | 4.50 | -8.95 | -2.32 | 5.78 | -11.64 | 0.00 |
| February | -12.89 | 40.00 | 27.11 | -12.83 | 4.50 | -8.33 | -1.70 | 3.95 | -8.84 | 0.00 |
| March | -9.62 | 35.00 | 25.38 | -9.58 | 4.50 | -5.08 | -1.06 | 3.78 | -6.96 | 0.00 |
| April | -4.40 | 30.00 | 25.60 | -5.09 | 4.50 | -0.59 | -0.11 | 3.46 | -2.95 | 0.00 |
| May | -0.24 | 25.00 | 24.76 | -0.93 | 4.50 | 3.57 | 0.00 | 3.50 | 0.00 | 0.00 |
| June | 3.35 | 25.00 | 28.35 | -0.38 | 4.50 | 4.12 | 0.00 | 3.48 | 0.00 | 0.96 |
| July | 5.35 | 25.00 | 30.35 | -0.15 | 4.50 | 4.35 | 0.00 | 3.16 | 0.00 | 1.78 |
| August | 4.59 | 25.00 | 29.59 | -0.25 | 4.50 | 4.25 | 0.00 | 3.31 | 0.00 | 1.83 |
| September | 1.46 | 30.00 | 31.46 | -0.62 | 4.50 | 3.88 | 0.00 | 3.76 | 0.00 | 0.00 |
| October | -2.84 | 35.00 | 32.16 | -3.07 | 4.50 | 1.43 | 0.00 | 4.02 | -1.13 | 0.00 |
| November | -8.70 | 40.00 | 31.30 | -8.51 | 4.50 | -4.01 | -0.93 | 5.16 | -6.54 | 0.00 |
| December | -12.78 | 45.00 | 32.22 | -12.30 | 4.50 | -7.80 | -2.13 | 6.28 | -11.38 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 5.20 | 2.32 | 6.34 | 13.86 |
| February | 0.00 | 0.00 | 0.22 | 4.50 | 2.10 | 4.56 | 11.16 |
| March | 0.00 | 0.00 | 0.22 | 3.69 | 2.32 | 4.12 | 10.14 |
| April | 0.00 | 0.00 | 0.22 | 1.49 | 2.25 | 3.23 | 6.97 |
| May | 0.29 | 2.68 | 0.22 | 0.00 | 2.32 | 2.64 | 7.64 |
| June | 0.29 | 3.81 | 0.22 | 0.00 | 2.25 | 2.55 | 8.60 |
| July | 0.29 | 5.21 | 0.22 | 0.00 | 2.32 | 2.64 | 10.17 |
| August | 0.29 | 5.01 | 0.22 | 0.00 | 2.32 | 2.64 | 9.97 |
| September | 0.29 | 3.00 | 0.22 | 0.00 | 2.25 | 3.06 | 8.30 |
| October | 0.29 | 2.56 | 0.22 | 0.66 | 2.32 | 3.81 | 9.35 |
| November | 0.00 | 0.00 | 0.22 | 3.02 | 2.25 | 5.03 | 10.29 |
| December | 0.00 | 0.00 | 0.22 | 4.77 | 2.32 | 6.54 | 13.63 |
| TOTAL/m2 | | 22.26 | | 23.33 | 27.35 | 47.14 | 120.08 |

## OPTION 4: PV ROOF MONITORS

(R36 equiv. insulation)

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Cincinnati | Longitude | 39.15 N | | | | |
| | | Latitude | 84.52 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate continental | Altitude | 232.00 m | Diffuse Radiation Factor | 1.10 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 6.20 | -3.30 | 85.00 | 40.00 | 108.00 | 10.00 | 10.80 | 20.20 | 68 | 83 |
| February | 6.30 | -2.90 | 130.00 | 55.00 | 129.00 | 10.24 | 12.60 | 15.40 | 64 | 81 |
| March | 11.10 | 0.70 | 190.00 | 75.00 | 173.00 | 11.16 | 15.50 | 15.50 | 57 | 79 |
| April | 18.00 | 6.60 | 250.00 | 100.00 | 201.00 | 11.96 | 16.80 | 13.20 | 53 | 76 |
| May | 23.80 | 11.90 | 290.00 | 120.00 | 241.00 | 12.74 | 18.91 | 12.09 | 53 | 78 |
| June | 28.80 | 17.20 | 305.00 | 125.00 | 305.00 | 14.73 | 20.70 | 9.30 | 55 | 80 |
| July | 30.80 | 19.10 | 290.00 | 120.00 | 322.00 | 14.43 | 22.32 | 8.68 | 52 | 82 |
| August | 30.20 | 18.30 | 250.00 | 100.00 | 291.00 | 13.41 | 21.70 | 9.30 | 52 | 86 |
| September | 26.80 | 14.20 | 190.00 | 75.00 | 254.00 | 12.45 | 20.40 | 9.60 | 50 | 86 |
| October | 20.50 | 8.20 | 130.00 | 55.00 | 213.00 | 11.26 | 18.91 | 12.09 | 61 | 85 |
| November | 11.80 | 2.20 | 85.00 | 40.00 | 145.00 | 10.51 | 13.80 | 16.20 | 60 | 81 |
| December | 5.90 | -2.30 | 70.00 | 35.00 | 126.00 | 10.16 | 12.40 | 18.60 | 68 | 82 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.15 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

**PV PANEL DATA**

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.00 |
| Thermal Transmittance W/m2oC | | 0.20 |
| PV slope (°) | | 15.00 |

**INTERNAL TEMPERATURES**

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

**HUMIDITY-WINTER**

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

**HUMIDITY-SUMMER**

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 3.83 | -0.25 | 207.60 | 0.00 | 96.00 | 0.00 | 10.80 | 20.20 | 11.96 | 6.35 |
| February | 4.00 | 0.06 | 294.20 | 5.00 | 128.93 | 2.19 | 12.60 | 15.40 | 11.79 | 6.71 |
| March | 8.50 | 4.04 | 381.68 | 31.66 | 161.27 | 13.38 | 15.50 | 15.50 | 18.91 | 13.69 |
| April | 15.15 | 10.26 | 471.40 | 66.14 | 200.60 | 28.14 | 16.80 | 13.20 | 31.24 | 26.31 |
| May | 20.83 | 15.73 | 521.63 | 102.26 | 225.98 | 44.30 | 18.91 | 12.09 | 43.93 | 40.35 |
| June | 25.90 | 20.93 | 472.37 | 159.74 | 203.61 | 68.85 | 20.70 | 9.30 | 57.64 | 56.01 |
| July | 27.88 | 22.86 | 460.82 | 145.70 | 199.63 | 63.12 | 22.32 | 8.68 | 61.04 | 63.03 |
| August | 27.23 | 22.13 | 420.58 | 102.44 | 178.97 | 43.59 | 21.70 | 9.30 | 59.33 | 62.55 |
| September | 23.65 | 18.25 | 342.14 | 59.90 | 144.57 | 25.31 | 20.40 | 9.60 | 49.24 | 50.29 |
| October | 17.43 | 12.15 | 267.40 | 24.14 | 117.19 | 10.58 | 18.91 | 12.09 | 38.98 | 32.94 |
| November | 9.40 | 5.29 | 197.58 | 7.16 | 91.37 | 3.31 | 13.80 | 16.20 | 21.21 | 16.41 |
| December | 3.85 | 0.34 | 173.60 | 2.00 | 82.67 | 0.95 | 12.40 | 18.60 | 12.00 | 7.27 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -9.42 | 25.00 | 15.58 | -10.56 | 4.50 | -6.06 | -0.82 | 1.68 | -5.07 | 0.00 |
| February | -8.58 | 25.00 | 16.42 | -10.32 | 4.50 | -5.82 | -1.03 | 2.07 | -5.96 | 0.00 |
| March | -4.92 | 25.00 | 20.08 | -7.51 | 4.50 | -3.01 | -0.65 | 3.11 | -5.21 | 0.00 |
| April | 0.16 | 25.00 | 25.16 | -3.17 | 4.50 | 1.33 | 0.00 | 4.54 | -1.67 | 0.00 |
| May | 4.27 | 25.00 | 29.27 | -0.94 | 4.50 | 3.56 | 0.00 | 6.48 | 0.00 | 0.00 |
| June | 7.15 | 25.00 | 32.15 | -0.87 | 4.50 | 3.63 | 0.00 | 7.71 | 0.00 | 4.06 |
| July | 8.34 | 25.00 | 33.34 | -0.82 | 4.50 | 3.68 | 0.00 | 8.59 | 0.00 | 5.83 |
| August | 7.58 | 25.00 | 32.58 | -0.57 | 4.50 | 3.93 | 0.00 | 8.26 | 0.00 | 4.96 |
| September | 4.60 | 25.00 | 29.60 | -0.63 | 4.50 | 3.87 | 0.00 | 7.14 | 0.00 | 0.71 |
| October | -0.08 | 25.00 | 24.92 | -2.30 | 4.50 | 2.20 | 0.00 | 5.30 | 0.00 | 0.00 |
| November | -5.88 | 25.00 | 19.12 | -6.90 | 4.50 | -2.40 | -0.46 | 2.64 | -4.03 | 0.00 |
| December | -9.69 | 25.00 | 15.31 | -10.16 | 4.50 | -5.66 | -0.98 | 1.90 | -5.81 | 0.00 |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -10.36 | 45.00 | 34.64 | -10.56 | 4.50 | -6.06 | -1.71 | 7.00 | -9.48 | 0.00 |
| February | -9.97 | 40.00 | 30.03 | -10.34 | 4.50 | -5.84 | -1.26 | 4.63 | -7.28 | 0.00 |
| March | -6.77 | 35.00 | 28.23 | -7.66 | 4.50 | -3.16 | -0.69 | 4.38 | -5.21 | 0.00 |
| April | -2.12 | 30.00 | 27.88 | -3.49 | 4.50 | 1.01 | 0.00 | 3.87 | -1.31 | 0.00 |
| May | 1.78 | 25.00 | 26.78 | -1.43 | 4.50 | 3.07 | 0.00 | 3.76 | 0.00 | 0.00 |
| June | 4.90 | 25.00 | 29.90 | -0.12 | 4.50 | 4.38 | 0.00 | 3.35 | 0.00 | 1.82 |
| July | 6.15 | 25.00 | 31.15 | 0.11 | 4.50 | 4.61 | 0.00 | 3.26 | 0.00 | 2.27 |
| August | 5.55 | 25.00 | 30.55 | 0.01 | 4.50 | 4.51 | 0.00 | 3.43 | 0.00 | 2.13 |
| September | 2.94 | 30.00 | 32.94 | -0.92 | 4.50 | 3.58 | 0.00 | 3.64 | 0.00 | 0.33 |
| October | -1.34 | 35.00 | 33.66 | -2.41 | 4.50 | 2.09 | 0.00 | 4.42 | 0.00 | 0.00 |
| November | -6.77 | 40.00 | 33.23 | -6.94 | 4.50 | -2.44 | -0.55 | 5.38 | -4.73 | 0.00 |
| December | -10.45 | 45.00 | 34.55 | -10.17 | 4.50 | -5.67 | -1.48 | 6.43 | -8.72 | 0.00 |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 3.82 | 2.45 | 6.68 | 12.94 |
| February | 0.00 | 0.00 | 0.22 | 3.45 | 2.21 | 4.69 | 10.35 |
| March | 0.00 | 0.00 | 0.22 | 2.61 | 2.45 | 4.19 | 9.25 |
| April | 0.29 | 2.40 | 0.22 | 0.66 | 2.37 | 3.21 | 8.64 |
| May | 0.29 | 2.92 | 0.22 | 0.00 | 2.45 | 2.64 | 8.01 |
| June | 0.29 | 4.84 | 0.22 | 0.00 | 2.37 | 2.55 | 9.76 |
| July | 0.29 | 5.70 | 0.22 | 0.00 | 2.45 | 2.64 | 10.79 |
| August | 0.29 | 5.36 | 0.22 | 0.00 | 2.45 | 2.64 | 10.45 |
| September | 0.29 | 3.38 | 0.22 | 0.00 | 2.37 | 3.03 | 8.78 |
| October | 0.29 | 2.78 | 0.22 | 0.00 | 2.45 | 3.84 | 9.07 |
| November | 0.00 | 0.00 | 0.22 | 2.17 | 2.37 | 4.98 | 9.52 |
| December | 0.00 | 0.00 | 0.22 | 3.78 | 2.45 | 6.36 | 12.58 |
| TOTAL/m2 | | 27.39 | | 16.49 | 28.83 | 47.42 | 120.14 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 5: PV ROOF MONITORS WITH ACTIVE HEAT RECOVERY

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | San Francisco | Longitude | 37.62 N | | | | |
| | | Latitude | 122.38 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate costal warm | Altitude | 2.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 13.00 | 5.40 | 85.00 | 40.00 | 154.00 | 10.00 | 15.40 | 15.60 | 75 | 85 |
| February | 14.70 | 6.30 | 130.00 | 55.00 | 191.00 | 11.56 | 16.52 | 11.48 | 71 | 85 |
| March | 16.40 | 7.20 | 190.00 | 75.00 | 262.00 | 12.43 | 21.08 | 9.92 | 66 | 83 |
| April | 17.90 | 8.40 | 250.00 | 100.00 | 297.00 | 13.94 | 21.30 | 8.70 | 66 | 85 |
| May | 19.40 | 9.80 | 290.00 | 120.00 | 328.00 | 14.90 | 22.01 | 8.99 | 66 | 85 |
| June | 21.20 | 11.30 | 305.00 | 125.00 | 341.00 | 15.36 | 22.20 | 7.80 | 65 | 87 |
| July | 22.20 | 11.90 | 290.00 | 120.00 | 295.00 | 14.20 | 20.77 | 10.23 | 69 | 90 |
| August | 22.10 | 12.10 | 250.00 | 100.00 | 275.00 | 13.65 | 20.15 | 10.85 | 69 | 90 |
| September | 23.20 | 12.20 | 190.00 | 75.00 | 275.00 | 12.73 | 21.60 | 8.40 | 66 | 88 |
| October | 21.40 | 10.30 | 130.00 | 55.00 | 242.00 | 11.31 | 21.39 | 9.61 | 65 | 86 |
| November | 17.80 | 7.70 | 85.00 | 40.00 | 198.00 | 10.00 | 19.80 | 10.20 | 68 | 84 |
| December | 14.00 | 6.10 | 70.00 | 35.00 | 179.00 | 10.31 | 17.36 | 13.64 | 74 | 86 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.15 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | | |
|---|---|---|---|
| Conversion Efficiency | % | 10.00 | |
| Direct Transmittance | % | 0.00 | |
| Thermal Transmittance W/m2oC | | 0.20 | |
| PV slope (°) | | 15.00 | |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### INTERNAL TEMPERATURES

| | | | |
|---|---|---|---|
| Occupied Period Set Point | oC | 21.00 | |
| Unoccupied Period Offset | oC | 5.00 | |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 11.10 | 7.84 | 207.60 | 0.00 | 96.00 | 0.00 | 15.40 | 15.60 | 28.01 | 22.52 |
| February | 12.60 | 9.00 | 260.51 | 29.06 | 114.17 | 12.74 | 16.52 | 11.48 | 30.55 | 25.19 |
| March | 14.10 | 10.16 | 342.75 | 59.46 | 144.82 | 25.13 | 21.08 | 9.92 | 32.71 | 27.53 |
| April | 15.53 | 11.45 | 404.48 | 113.94 | 172.12 | 48.48 | 21.30 | 8.70 | 36.08 | 31.15 |
| May | 17.00 | 12.89 | 446.11 | 156.21 | 193.26 | 67.67 | 22.01 | 8.99 | 39.69 | 34.84 |
| June | 18.73 | 14.48 | 453.11 | 173.49 | 195.31 | 74.78 | 22.20 | 7.80 | 43.67 | 39.69 |
| July | 19.63 | 15.21 | 468.06 | 140.53 | 202.77 | 60.88 | 20.77 | 10.23 | 47.62 | 42.64 |
| August | 19.60 | 15.31 | 413.26 | 107.67 | 175.85 | 45.82 | 20.15 | 10.85 | 47.55 | 42.94 |
| September | 20.45 | 15.74 | 334.60 | 65.28 | 141.38 | 27.58 | 21.60 | 8.40 | 48.59 | 43.54 |
| October | 18.63 | 13.87 | 266.23 | 24.98 | 116.67 | 10.95 | 21.39 | 9.61 | 43.42 | 37.72 |
| November | 15.28 | 10.95 | 207.60 | 0.00 | 96.00 | 0.00 | 19.80 | 10.20 | 36.10 | 29.66 |
| December | 12.03 | 8.64 | 171.08 | 3.80 | 81.47 | 1.81 | 17.36 | 13.64 | 29.94 | 24.53 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | | Thermal | Total Reqmnt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling | kWh Available | kWh Heating |
| January | -4.69 | 25.00 | 20.31 | -5.30 | 4.50 | -0.80 | -0.17 | 3.13 | -2.48 | 0.00 | 12.04 | (2.66) |
| February | -3.27 | 25.00 | 21.73 | -4.31 | 4.50 | 0.19 | 0.00 | 3.63 | -1.86 | 0.00 | 16.06 | (1.86) |
| March | -1.61 | 25.00 | 23.39 | -3.30 | 4.50 | 1.20 | 0.00 | 5.29 | -1.50 | 0.00 | 26.76 | (1.50) |
| April | -0.16 | 25.00 | 24.84 | -2.00 | 4.50 | 2.50 | 0.00 | 6.04 | -0.14 | 0.00 | 31.78 | (0.14) |
| May | 1.15 | 25.00 | 26.15 | -1.80 | 4.50 | 2.70 | 0.00 | 6.59 | 0.00 | 0.00 | 36.12 | 0.00 |
| June | 2.33 | 25.00 | 27.33 | -1.15 | 4.50 | 3.35 | 0.00 | 7.11 | 0.00 | 0.00 | 36.91 | 0.00 |
| July | 3.04 | 25.00 | 28.04 | -0.96 | 4.50 | 3.54 | 0.00 | 6.85 | 0.00 | 0.08 | 35.63 | 0.00 |
| August | 2.56 | 25.00 | 27.56 | -1.17 | 4.50 | 3.33 | 0.00 | 6.49 | 0.00 | 0.05 | 30.52 | 0.00 |
| September | 2.45 | 25.00 | 27.45 | -1.25 | 4.50 | 3.25 | 0.00 | 6.91 | 0.00 | 0.48 | 26.46 | 0.00 |
| October | 0.69 | 25.00 | 25.69 | -1.18 | 4.50 | 3.32 | 0.00 | 6.49 | 0.00 | 0.00 | 20.95 | 0.00 |
| November | -1.98 | 25.00 | 23.02 | -3.28 | 4.50 | 1.22 | 0.00 | 4.90 | -0.12 | 0.00 | 15.29 | (0.12) |
| December | -4.40 | 25.00 | 20.60 | -4.75 | 4.50 | -0.25 | -0.05 | 3.58 | -2.16 | 0.00 | 11.21 | (2.22) |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | | Thermal | Total Reqmnt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling | kWh Available | kWh Heating |
| January | -5.63 | 45.00 | 39.37 | -5.30 | 4.50 | -0.80 | -0.18 | 6.14 | -2.52 | 0.00 | 2.91 | (2.69) |
| February | -4.50 | 40.00 | 35.50 | -4.44 | 4.50 | 0.06 | 0.00 | 4.08 | -1.29 | 0.00 | 4.47 | (1.29) |
| March | -3.27 | 35.00 | 31.73 | -3.59 | 4.50 | 0.91 | 0.00 | 3.27 | -0.71 | 0.00 | 5.92 | (0.71) |
| April | -2.11 | 30.00 | 27.89 | -2.55 | 4.50 | 1.95 | 0.00 | 2.66 | -0.06 | 0.00 | 5.39 | (0.06) |
| May | -0.98 | 25.00 | 24.02 | -1.46 | 4.50 | 3.04 | 0.00 | 2.54 | 0.00 | 0.00 | 6.88 | 0.00 |
| June | 0.16 | 25.00 | 25.16 | -0.36 | 4.50 | 4.14 | 0.00 | 2.41 | 0.00 | 0.00 | 7.34 | 0.00 |
| July | 0.81 | 25.00 | 25.81 | 0.00 | 4.50 | 4.50 | 0.00 | 3.28 | 0.00 | 0.04 | 10.16 | 0.00 |
| August | 0.57 | 25.00 | 25.57 | -0.06 | 4.50 | 4.44 | 0.00 | 3.45 | 0.00 | 0.03 | 0.00 | 0.00 |
| September | 0.83 | 30.00 | 30.83 | 0.06 | 4.50 | 4.56 | 0.00 | 3.13 | 0.00 | 0.19 | 5.18 | 0.00 |
| October | -0.56 | 35.00 | 34.44 | -1.29 | 4.50 | 3.21 | 0.00 | 3.74 | 0.00 | 0.00 | 0.00 | 0.00 |
| November | -2.91 | 40.00 | 37.09 | -3.28 | 4.50 | 1.22 | 0.00 | 3.96 | -0.06 | 0.00 | 0.07 | (0.06) |
| December | -5.15 | 45.00 | 39.85 | -4.77 | 4.50 | -0.27 | -0.05 | 5.44 | -1.69 | 0.00 | 4.77 | (1.75) |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and Power kWh | Total kWh Consumed | Thermal Avail kWh Electric | Total kWh Consumed |
|---|---|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | | | | |
| January | 0.00 | 0.00 | 0.22 | 1.19 | 2.08 | 5.76 | 9.03 | 3.29 | 7.84 |
| February | 0.00 | 0.00 | 0.22 | 0.70 | 1.88 | 4.10 | 6.68 | 4.51 | 5.98 |
| March | 0.00 | 0.00 | 0.22 | 0.49 | 2.08 | 3.63 | 6.20 | 7.19 | 5.71 |
| April | 0.29 | 2.49 | 0.22 | 0.04 | 2.01 | 2.99 | 7.53 | 8.18 | 7.49 |
| May | 0.29 | 2.61 | 0.22 | 0.00 | 2.08 | 2.64 | 7.33 | 9.46 | 7.33 |
| June | 0.29 | 2.72 | 0.22 | 0.00 | 2.01 | 2.55 | 7.28 | 9.73 | 7.28 |
| July | 0.29 | 2.93 | 0.22 | 0.00 | 2.08 | 2.64 | 7.65 | 10.07 | 7.65 |
| August | 0.29 | 2.86 | 0.22 | 0.00 | 2.08 | 2.64 | 7.58 | 6.72 | 7.58 |
| September | 0.29 | 3.06 | 0.22 | 0.00 | 2.01 | 2.97 | 8.04 | 6.96 | 8.04 |
| October | 0.29 | 2.92 | 0.22 | 0.00 | 2.08 | 3.60 | 8.60 | 4.61 | 8.60 |
| November | 0.29 | 2.53 | 0.22 | 0.04 | 2.01 | 4.08 | 8.66 | 3.38 | 8.62 |
| December | 0.00 | 0.00 | 0.22 | 0.88 | 2.08 | 5.36 | 8.33 | 3.52 | 7.44 |
| TOTAL/m2 | | 22.12 | | 3.34 | 24.51 | 42.93 | 92.90 | 77.62 | 89.56 |

## OPTION 5: PV ROOF MONITORS WITH ACTIVE HEAT RECOVERY

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | New York | Longitude | 40.70 N | | | | |
| | | Latitude | 74.02 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate costal cold | Altitude | 3.00 m | Diffuse Radiation Factor | 1.10 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 4.30 | -2.80 | 85.00 | 40.00 | 151.00 | 10.00 | 15.10 | 15.90 | 61 | 69 |
| February | 4.10 | -2.40 | 130.00 | 55.00 | 164.00 | 10.28 | 15.96 | 12.04 | 58 | 67 |
| March | 8.90 | 0.60 | 190.00 | 75.00 | 209.00 | 11.83 | 17.67 | 13.33 | 56 | 67 |
| April | 14.90 | 6.10 | 250.00 | 100.00 | 214.00 | 12.09 | 17.70 | 12.30 | 55 | 68 |
| May | 20.90 | 11.80 | 290.00 | 120.00 | 250.00 | 13.44 | 18.60 | 12.40 | 56 | 69 |
| June | 25.60 | 16.90 | 305.00 | 125.00 | 301.00 | 16.18 | 18.60 | 11.40 | 58 | 72 |
| July | 28.30 | 19.90 | 290.00 | 120.00 | 307.00 | 15.00 | 20.46 | 10.54 | 57 | 74 |
| August | 27.40 | 19.30 | 250.00 | 100.00 | 275.00 | 13.86 | 19.84 | 11.16 | 60 | 76 |
| September | 23.80 | 15.80 | 190.00 | 75.00 | 237.00 | 12.54 | 18.90 | 11.10 | 60 | 76 |
| October | 18.40 | 10.30 | 130.00 | 55.00 | 218.00 | 11.34 | 19.22 | 11.78 | 59 | 74 |
| November | 11.90 | 4.40 | 85.00 | 40.00 | 172.00 | 10.06 | 17.10 | 12.90 | 60 | 71 |
| December | 5.70 | -1.20 | 70.00 | 35.00 | 158.00 | 10.00 | 15.80 | 15.20 | 60 | 67 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.15 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 18.00 |

**PV PANEL DATA**

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.00 |
| Thermal Transmittance W/m2oC | | 0.20 |
| PV slope (°) | | 15.00 |

**INTERNAL TEMPERATURES**

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

**HUMIDITY-WINTER**

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

**HUMIDITY-SUMMER**

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 2.53 | -0.52 | 207.60 | 0.00 | 96.00 | 0.00 | 15.10 | 15.90 | 8.95 | 4.83 |
| February | 2.48 | -0.31 | 293.12 | 5.77 | 128.46 | 2.53 | 15.96 | 12.04 | 8.56 | 4.99 |
| March | 6.83 | 3.27 | 360.16 | 47.03 | 152.18 | 19.87 | 17.67 | 13.33 | 15.67 | 10.86 |
| April | 12.70 | 8.93 | 466.49 | 69.65 | 198.50 | 29.64 | 17.70 | 12.30 | 26.71 | 21.80 |
| May | 18.63 | 14.73 | 494.61 | 121.56 | 214.27 | 52.66 | 18.60 | 12.40 | 39.98 | 35.06 |
| June | 23.43 | 19.70 | 430.09 | 189.94 | 185.38 | 81.87 | 18.60 | 11.40 | 52.74 | 49.03 |
| July | 26.20 | 22.60 | 443.06 | 158.39 | 191.94 | 68.62 | 20.46 | 10.54 | 59.60 | 58.33 |
| August | 25.38 | 21.90 | 406.90 | 112.21 | 173.15 | 47.75 | 19.84 | 11.16 | 59.06 | 57.18 |
| September | 21.80 | 18.37 | 339.72 | 61.53 | 143.54 | 26.04 | 18.90 | 11.10 | 49.48 | 46.90 |
| October | 16.38 | 12.90 | 265.55 | 25.46 | 116.38 | 11.16 | 19.22 | 11.78 | 35.84 | 32.04 |
| November | 10.03 | 6.81 | 206.39 | 0.86 | 95.44 | 0.40 | 17.10 | 12.90 | 22.45 | 18.01 |
| December | 3.98 | 1.02 | 176.40 | 0.00 | 84.00 | 0.00 | 15.80 | 15.20 | 11.26 | 7.09 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | | Thermal | Total Reqmnt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling | kWh Availabl | kWh Heating |
| January | -10.26 | 25.00 | 14.74 | -10.74 | 4.50 | -6.24 | -1.32 | 2.22 | -7.96 | 0.00 | 12.09 | (9.28) |
| February | -9.58 | 25.00 | 15.42 | -10.55 | 4.50 | -6.05 | -1.35 | 2.46 | -8.54 | 0.00 | 17.78 | (9.89) |
| March | -6.19 | 25.00 | 18.81 | -7.88 | 4.50 | -3.38 | -0.84 | 3.32 | -7.04 | 0.00 | 23.84 | (7.87) |
| April | -1.48 | 25.00 | 23.52 | -4.01 | 4.50 | 0.49 | 0.00 | 4.28 | -3.30 | 0.00 | 30.53 | (3.30) |
| May | 2.61 | 25.00 | 27.61 | -3.06 | 4.50 | 1.44 | 0.00 | 5.51 | 0.00 | 0.00 | 33.75 | 0.00 |
| June | 5.19 | 25.00 | 30.19 | -1.42 | 4.50 | 3.08 | 0.00 | 6.42 | 0.00 | 1.90 | 29.16 | 0.00 |
| July | 7.10 | 25.00 | 32.10 | -0.88 | 4.50 | 3.62 | 0.00 | 7.61 | 0.00 | 4.78 | 32.92 | 0.00 |
| August | 6.26 | 25.00 | 31.26 | -0.64 | 4.50 | 3.86 | 0.00 | 7.28 | 0.00 | 4.43 | 29.34 | 0.00 |
| September | 3.37 | 25.00 | 28.37 | -1.19 | 4.50 | 3.31 | 0.00 | 6.24 | 0.00 | 0.75 | 23.45 | 0.00 |
| October | -0.78 | 25.00 | 24.22 | -1.80 | 4.50 | 2.70 | 0.00 | 5.38 | -0.21 | 0.00 | 18.87 | (0.21) |
| November | -5.40 | 25.00 | 19.60 | -5.97 | 4.50 | -1.47 | -0.35 | 3.35 | -4.58 | 0.00 | 13.33 | (4.94) |
| December | -9.58 | 25.00 | 15.42 | -9.74 | 4.50 | -5.24 | -1.16 | 2.44 | -7.53 | 0.00 | 10.80 | (8.79) |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | | Thermal | Total Reqmnt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling | kWh Availabl | kWh Heating |
| January | -11.20 | 45.00 | 33.80 | -10.74 | 4.50 | -6.24 | -1.39 | 5.37 | -8.38 | 0.00 | 4.48 | (9.77) |
| February | -10.96 | 40.00 | 29.04 | -10.58 | 4.50 | -6.08 | -1.02 | 3.50 | -6.44 | 0.00 | 5.39 | (7.46) |
| March | -7.94 | 35.00 | 27.06 | -8.11 | 4.50 | -3.61 | -0.67 | 3.61 | -5.31 | 0.00 | 6.57 | (5.96) |
| April | -3.73 | 30.00 | 26.27 | -4.35 | 4.50 | 0.15 | 0.00 | 3.26 | -2.29 | 0.00 | 8.27 | (2.29) |
| May | 0.26 | 25.00 | 25.26 | -0.39 | 4.50 | 4.11 | 0.00 | 3.85 | 0.00 | 0.00 | 9.30 | 0.00 |
| June | 3.13 | 25.00 | 28.13 | -0.48 | 4.50 | 4.02 | 0.00 | 3.85 | 0.00 | 1.16 | 8.68 | 0.00 |
| July | 4.99 | 25.00 | 29.99 | -0.01 | 4.50 | 4.49 | 0.00 | 3.82 | 0.00 | 2.45 | 10.49 | 0.00 |
| August | 4.30 | 25.00 | 29.30 | -0.09 | 4.50 | 4.41 | 0.00 | 3.96 | 0.00 | 2.49 | 0.00 | 0.00 |
| September | 1.73 | 30.00 | 31.73 | -1.16 | 4.50 | 3.34 | 0.00 | 4.04 | 0.00 | 0.44 | 5.23 | 0.00 |
| October | -2.03 | 35.00 | 32.97 | -1.92 | 4.50 | 2.58 | 0.00 | 4.31 | -0.13 | 0.00 | 0.00 | (0.13) |
| November | -6.33 | 40.00 | 33.67 | -5.97 | 4.50 | -1.47 | -0.27 | 4.34 | -3.46 | 0.00 | 0.07 | (3.72) |
| December | -10.36 | 45.00 | 34.64 | -9.74 | 4.50 | -5.24 | -1.11 | 5.27 | -7.34 | 0.00 | 5.18 | (8.46) |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh | Thermal Avai | Total kWh |
|---|---|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed | kWh Electric | Consumed |
| January | 0.00 | 0.00 | 0.22 | 4.23 | 2.30 | 5.82 | 12.35 | 3.65 | 8.11 |
| February | 0.00 | 0.00 | 0.22 | 3.86 | 2.08 | 4.19 | 10.12 | 5.10 | 6.26 |
| March | 0.00 | 0.00 | 0.22 | 3.08 | 2.30 | 3.97 | 9.35 | 6.69 | 6.27 |
| April | 0.00 | 0.00 | 0.22 | 1.24 | 2.23 | 3.17 | 6.63 | 8.54 | 5.39 |
| May | 0.29 | 2.67 | 0.22 | 0.00 | 2.30 | 2.64 | 7.61 | 9.47 | 7.61 |
| June | 0.29 | 3.81 | 0.22 | 0.00 | 2.23 | 2.55 | 8.58 | 8.32 | 8.58 |
| July | 0.29 | 5.34 | 0.22 | 0.00 | 2.30 | 2.64 | 10.27 | 9.55 | 10.27 |
| August | 0.29 | 5.19 | 0.22 | 0.00 | 2.30 | 2.64 | 10.12 | 6.45 | 10.12 |
| September | 0.29 | 3.27 | 0.22 | 0.00 | 2.23 | 3.11 | 8.61 | 6.31 | 8.61 |
| October | 0.29 | 2.77 | 0.22 | 0.08 | 2.30 | 3.81 | 8.96 | 4.15 | 8.88 |
| November | 0.00 | 0.00 | 0.22 | 1.92 | 2.23 | 4.49 | 8.63 | 2.95 | 6.71 |
| December | 0.00 | 0.00 | 0.22 | 3.83 | 2.30 | 5.68 | 11.81 | 3.52 | 7.97 |
| TOTAL/m2 | | 23.05 | | 18.25 | 27.07 | 44.67 | 113.04 | 74.70 | 94.79 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 5: PV ROOF MONITORS WITH ACTIVE HEAT RECOVERY

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Phoenix | Longitude | 33.43 N | | | | |
| | | Latitude | 112.02 W | Direct Radiation Factor | 1.10 | | |
| Climate | Temperate arid | Altitude | 340.00 m | Diffuse Radiation Factor | 0.90 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 17.80 | 1.80 | 105.00 | 25.00 | 262.00 | 10.84 | 24.18 | 6.82 | 44 | 72 |
| February | 20.10 | 3.80 | 150.00 | 30.00 | 271.00 | 12.41 | 21.84 | 6.16 | 42 | 71 |
| March | 23.90 | 6.10 | 205.00 | 35.00 | 331.00 | 12.56 | 26.35 | 4.65 | 31 | 60 |
| April | 28.80 | 10.20 | 260.00 | 45.00 | 360.00 | 13.48 | 26.70 | 3.30 | 26 | 50 |
| May | 33.80 | 13.90 | 295.00 | 45.00 | 408.00 | 14.00 | 29.14 | 1.86 | 19 | 41 |
| June | 38.70 | 18.60 | 305.00 | 50.00 | 411.00 | 14.57 | 28.20 | 1.80 | 17 | 37 |
| July | 40.30 | 23.90 | 295.00 | 45.00 | 390.00 | 14.30 | 27.28 | 3.72 | 29 | 51 |
| August | 38.70 | 23.00 | 260.00 | 45.00 | 379.00 | 14.22 | 26.66 | 4.34 | 35 | 60 |
| September | 36.80 | 19.60 | 205.00 | 35.00 | 354.00 | 13.11 | 27.00 | 3.00 | 29 | 66 |
| October | 30.40 | 12.60 | 150.00 | 30.00 | 323.00 | 11.98 | 26.97 | 4.03 | 30 | 58 |
| November | 23.20 | 5.80 | 105.00 | 25.00 | 282.00 | 10.93 | 25.80 | 4.20 | 33 | 83 |
| December | 18.90 | 2.80 | 90.00 | 25.00 | 260.00 | 10.75 | 24.18 | 6.82 | 42 | 70 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.15 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | | | |
|---|---|---|---|---|
| Conversion Efficiency | % | 10.00 | %RH | 35 |
| Direct Transmittance | % | 0.00 | Enthalpy | 36.41 |
| Thermal Transmittance | W/m2oC | 0.20 | | |
| PV slope | (°) | 15.00 | | |

### INTERNAL TEMPERATURES

| | | | | |
|---|---|---|---|---|
| Occupied Period Set Point | oC | 21.00 | %RH | 60 |
| Unoccupied Period Offset | oC | 5.00 | Enthalpy | 47.425 |

HUMIDITY-WINTER

HUMIDITY-SUMMER

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 13.80 | 6.94 | 305.66 | 18.24 | 110.75 | 6.61 | 24.18 | 6.82 | 25.94 | 18.43 |
| February | 16.03 | 9.04 | 371.36 | 63.89 | 116.05 | 19.96 | 21.84 | 6.16 | 29.56 | 22.60 |
| March | 19.45 | 11.82 | 491.02 | 89.84 | 133.74 | 24.47 | 26.35 | 4.65 | 31.89 | 26.13 |
| April | 24.15 | 16.18 | 581.17 | 144.59 | 160.20 | 39.86 | 26.70 | 3.30 | 37.82 | 32.46 |
| May | 28.83 | 20.30 | 625.65 | 178.82 | 154.27 | 44.09 | 29.14 | 1.86 | 41.52 | 37.62 |
| June | 33.68 | 25.06 | 626.58 | 204.73 | 164.67 | 53.81 | 28.20 | 1.80 | 47.87 | 45.49 |
| July | 36.20 | 29.17 | 612.75 | 188.04 | 151.09 | 46.36 | 27.28 | 3.72 | 63.15 | 63.82 |
| August | 34.78 | 28.05 | 551.21 | 165.99 | 151.94 | 45.76 | 26.66 | 4.34 | 65.41 | 66.63 |
| September | 32.50 | 25.13 | 470.44 | 104.54 | 128.14 | 28.47 | 27.00 | 3.00 | 55.49 | 61.70 |
| October | 25.95 | 18.32 | 384.76 | 54.31 | 120.24 | 16.97 | 26.97 | 4.03 | 43.31 | 40.03 |
| November | 18.85 | 11.39 | 303.01 | 20.13 | 109.79 | 7.29 | 25.80 | 4.20 | 31.61 | 30.54 |
| December | 14.88 | 7.98 | 271.19 | 14.58 | 111.60 | 6.00 | 24.18 | 6.82 | 27.38 | 20.20 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | | Thermal | Total Reqmnt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling | kWh Available | kWh Heating |
| January | -2.11 | 25.00 | 22.89 | -5.73 | 4.50 | -1.23 | -0.42 | 5.53 | -4.86 | 0.00 | 27.43 | (5.28) |
| February | -0.11 | 25.00 | 24.89 | -3.99 | 4.50 | 0.51 | 0.00 | 5.59 | -2.88 | 0.00 | 29.91 | (2.88) |
| March | 3.12 | 25.00 | 28.12 | -1.96 | 4.50 | 2.54 | 0.00 | 8.35 | -2.29 | 0.00 | 47.42 | (2.29) |
| April | 6.93 | 25.00 | 31.93 | -1.92 | 4.50 | 2.58 | 0.00 | 9.49 | 0.00 | 0.00 | 56.57 | 0.00 |
| May | 10.34 | 25.00 | 35.34 | 1.04 | 4.50 | 5.54 | 0.00 | 12.56 | 0.00 | 0.00 | 66.18 | 0.00 |
| June | 13.50 | 25.00 | 38.50 | 1.11 | 4.50 | 5.61 | 0.00 | 13.07 | 0.00 | 0.24 | 63.83 | 0.00 |
| July | 15.03 | 25.00 | 40.03 | 3.64 | 4.50 | 8.14 | 0.00 | 14.03 | 0.00 | 8.24 | 60.21 | 0.00 |
| August | 13.58 | 25.00 | 38.58 | 2.72 | 4.50 | 7.22 | 0.00 | 12.98 | 0.00 | 9.21 | 52.93 | 0.00 |
| September | 11.43 | 25.00 | 36.43 | 0.31 | 4.50 | 4.81 | 0.00 | 11.65 | 0.00 | 4.18 | 45.76 | 0.00 |
| October | 6.45 | 25.00 | 31.45 | -1.28 | 4.50 | 3.22 | 0.00 | 9.70 | 0.00 | 0.00 | 37.66 | 0.00 |
| November | 1.15 | 25.00 | 26.15 | -2.83 | 4.50 | 1.67 | 0.00 | 7.35 | -2.38 | 0.00 | 28.72 | (2.38) |
| December | -1.70 | 25.00 | 23.30 | -5.09 | 4.50 | -0.59 | -0.20 | 5.63 | -4.19 | 0.00 | 24.32 | (4.39) |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | | Thermal | Total Reqmnt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling | kWh Available | kWh Heating |
| January | -3.75 | 45.00 | 41.25 | -5.83 | 4.50 | -1.33 | -0.13 | 2.81 | -1.37 | 0.00 | 0.76 | (1.50) |
| February | -2.26 | 40.00 | 37.74 | -4.36 | 4.50 | 0.14 | 0.00 | 2.34 | -0.81 | 0.00 | 1.62 | (0.81) |
| March | 0.12 | 35.00 | 35.12 | -2.51 | 4.50 | 1.99 | 0.00 | 1.76 | -0.40 | 0.00 | 2.14 | (0.40) |
| April | 3.39 | 30.00 | 33.39 | -1.17 | 4.50 | 3.33 | 0.00 | 1.26 | 0.00 | 0.00 | 1.74 | 0.00 |
| May | 6.38 | 25.00 | 31.38 | -0.09 | 4.50 | 4.41 | 0.00 | 0.70 | 0.00 | 0.00 | 2.20 | 0.00 |
| June | 9.62 | 25.00 | 34.62 | 1.47 | 4.50 | 5.97 | 0.00 | 0.77 | 0.00 | 0.02 | 2.41 | 0.00 |
| July | 11.15 | 25.00 | 36.15 | 2.45 | 4.50 | 6.95 | 0.00 | 1.71 | 0.00 | 1.12 | 3.54 | 0.00 |
| August | 10.23 | 25.00 | 35.23 | 1.71 | 4.50 | 6.21 | 0.00 | 1.91 | 0.00 | 1.50 | 0.00 | 0.00 |
| September | 8.55 | 30.00 | 38.55 | -0.33 | 4.50 | 4.17 | 0.00 | 1.33 | 0.00 | 0.46 | 4.43 | 0.00 |
| October | 4.23 | 35.00 | 39.23 | -1.60 | 4.50 | 2.90 | 0.00 | 1.74 | 0.00 | 0.00 | 0.00 | 0.00 |
| November | -0.48 | 40.00 | 39.52 | -2.93 | 4.50 | 1.57 | 0.00 | 1.75 | -0.39 | 0.00 | 0.08 | (0.39) |
| December | -3.04 | 45.00 | 41.96 | -5.17 | 4.50 | -0.67 | -0.06 | 2.86 | -1.18 | 0.00 | 6.33 | (1.25) |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh | Thermal Avail | Total kWh |
|---|---|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed | kWh Electric | Consumed |
| January | 0.00 | 0.00 | 0.22 | 1.51 | 2.93 | 4.00 | 8.44 | 6.20 | 6.93 |
| February | 0.29 | 2.27 | 0.22 | 0.82 | 2.65 | 3.30 | 9.04 | 6.94 | 8.22 |
| March | 0.29 | 2.89 | 0.22 | 0.60 | 2.93 | 3.10 | 9.52 | 10.90 | 8.92 |
| April | 0.29 | 3.07 | 0.22 | 0.00 | 2.84 | 2.72 | 8.62 | 12.83 | 8.62 |
| May | 0.29 | 3.79 | 0.22 | 0.00 | 2.93 | 2.64 | 9.36 | 15.04 | 9.36 |
| June | 0.29 | 4.03 | 0.22 | 0.00 | 2.84 | 2.55 | 9.42 | 14.57 | 9.42 |
| July | 0.29 | 7.17 | 0.22 | 0.00 | 2.93 | 2.64 | 12.74 | 14.02 | 12.74 |
| August | 0.29 | 7.31 | 0.22 | 0.00 | 2.93 | 2.64 | 12.88 | 11.64 | 12.88 |
| September | 0.29 | 5.04 | 0.22 | 0.00 | 2.84 | 2.70 | 10.57 | 11.04 | 10.57 |
| October | 0.29 | 3.27 | 0.22 | 0.00 | 2.93 | 3.04 | 9.24 | 8.28 | 9.24 |
| November | 0.29 | 2.60 | 0.22 | 0.61 | 2.84 | 3.18 | 9.23 | 6.34 | 8.62 |
| December | 0.00 | 0.00 | 0.22 | 1.25 | 2.93 | 4.00 | 8.18 | 6.74 | 6.93 |
| TOTAL/m2 | | 41.43 | | 4.79 | 34.53 | 36.49 | 117.24 | 124.56 | 112.45 |

## OPTION 5: PV ROOF MONITORS WITH ACTIVE HEAT RECOVERY

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Miami | Longitude | 25.80 N | | | | |
| | | Latitude | 80.27 W | Direct Radiation Factor | 0.50 | | |
| Climate | Sub-tropical | Altitude | 2.00 m | Diffuse Radiation Factor | 1.10 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 24.30 | 14.40 | 150.00 | 65.00 | 239.00 | 11.51 | 20.77 | 10.23 | 59 | 84 |
| February | 25.00 | 14.90 | 185.00 | 80.00 | 233.00 | 11.72 | 19.88 | 8.12 | 56 | 84 |
| March | 26.60 | 16.20 | 235.00 | 95.00 | 269.00 | 12.22 | 22.01 | 8.99 | 56 | 82 |
| April | 28.10 | 18.80 | 275.00 | 115.00 | 283.00 | 13.10 | 21.60 | 8.40 | 56 | 79 |
| May | 29.70 | 20.90 | 295.00 | 125.00 | 276.00 | 13.49 | 20.46 | 10.54 | 59 | 78 |
| June | 31.10 | 23.10 | 295.00 | 125.00 | 255.00 | 13.93 | 18.30 | 11.70 | 64 | 81 |
| July | 31.60 | 23.70 | 295.00 | 125.00 | 270.00 | 13.82 | 19.53 | 11.47 | 64 | 81 |
| August | 32.10 | 23.80 | 275.00 | 115.00 | 261.00 | 13.16 | 19.84 | 11.16 | 63 | 83 |
| September | 31.10 | 23.70 | 235.00 | 95.00 | 212.00 | 11.98 | 17.70 | 12.30 | 66 | 85 |
| October | 29.30 | 21.60 | 195.00 | 80.00 | 200.00 | 11.73 | 17.05 | 13.95 | 64 | 85 |
| November | 26.80 | 18.10 | 150.00 | 65.00 | 224.00 | 11.31 | 19.80 | 10.20 | 60 | 84 |
| December | 26.10 | 15.10 | 135.00 | 55.00 | 221.00 | 11.14 | 19.84 | 11.16 | 60 | 85 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.15 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

**PV PANEL DATA**

| | | | | |
|---|---|---|---|---|
| Conversion Efficiency | % | 10.00 | HUMIDITY-WINTER | |
| Direct Transmittance | % | 0.00 | %RH | 35 |
| Thermal Transmittance W/m2oC | | 0.20 | Enthalpy | 36.41 |
| PV slope (°) | | 15.00 | | |
| INTERNAL TEMPERATURES | | | HUMIDITY-SUMMER | |
| Occupied Period Set Point | oC | 21.00 | %RH | 60 |
| Unoccupied Period Offset | oC | 5.00 | Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 21.83 | 17.58 | 305.55 | 32.89 | 135.57 | 14.59 | 20.77 | 10.23 | 49.08 | 47.57 |
| February | 22.48 | 18.15 | 379.85 | 46.68 | 163.82 | 20.13 | 19.88 | 8.12 | 49.32 | 49.23 |
| March | 24.00 | 19.54 | 435.95 | 69.18 | 186.55 | 29.60 | 22.01 | 8.99 | 53.21 | 52.64 |
| April | 25.78 | 21.79 | 483.60 | 107.15 | 210.66 | 46.67 | 21.60 | 8.40 | 57.88 | 58.21 |
| May | 27.50 | 23.73 | 507.05 | 126.39 | 222.39 | 55.43 | 20.46 | 10.54 | 64.43 | 63.82 |
| June | 29.10 | 25.57 | 490.87 | 137.95 | 215.29 | 60.50 | 18.30 | 11.70 | 72.43 | 71.86 |
| July | 29.63 | 26.24 | 494.76 | 135.17 | 217.00 | 59.29 | 19.53 | 11.47 | 74.06 | 73.80 |
| August | 30.03 | 26.47 | 481.63 | 108.55 | 209.80 | 47.28 | 19.84 | 11.16 | 74.60 | 75.78 |
| September | 29.25 | 26.08 | 444.84 | 62.83 | 190.36 | 26.89 | 17.70 | 12.30 | 74.25 | 75.58 |
| October | 27.38 | 24.08 | 379.53 | 46.91 | 163.68 | 20.23 | 17.05 | 13.95 | 67.19 | 68.60 |
| November | 24.63 | 20.90 | 310.79 | 29.15 | 137.89 | 12.93 | 19.80 | 10.20 | 57.00 | 57.67 |
| December | 23.35 | 18.64 | 275.78 | 22.44 | 118.50 | 9.64 | 19.84 | 11.16 | 53.56 | 51.08 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | | Thermal | Total Reqmnt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling | kWh Availabl | kWh Heating |
| January | 3.10 | 25.00 | 28.10 | -1.30 | 4.50 | 3.20 | 0.00 | 6.77 | 0.00 | 0.56 | 23.18 | 0.00 |
| February | 4.15 | 25.00 | 29.15 | -0.81 | 4.50 | 3.69 | 0.00 | 6.82 | 0.00 | 0.72 | 27.56 | 0.00 |
| March | 5.61 | 25.00 | 30.61 | -0.69 | 4.50 | 3.81 | 0.00 | 7.91 | 0.00 | 2.45 | 34.95 | 0.00 |
| April | 7.17 | 25.00 | 32.17 | -0.21 | 4.50 | 4.29 | 0.00 | 8.24 | 0.00 | 4.34 | 37.98 | 0.00 |
| May | 8.48 | 25.00 | 33.48 | 0.67 | 4.50 | 5.17 | 0.00 | 8.33 | 0.00 | 6.68 | 37.65 | 0.00 |
| June | 9.39 | 25.00 | 34.39 | 0.85 | 4.50 | 5.45 | 0.00 | 7.69 | 0.00 | 8.78 | 32.53 | 0.00 |
| July | 9.76 | 25.00 | 34.76 | 1.29 | 4.50 | 5.79 | 0.00 | 8.37 | 0.00 | 9.99 | 34.97 | 0.00 |
| August | 9.91 | 25.00 | 34.91 | 1.22 | 4.50 | 5.72 | 0.00 | 8.51 | 0.00 | 10.35 | 34.55 | 0.00 |
| September | 9.10 | 25.00 | 34.10 | 0.58 | 4.50 | 5.08 | 0.00 | 7.29 | 0.00 | 9.12 | 28.47 | 0.00 |
| October | 7.33 | 25.00 | 32.33 | 0.23 | 4.50 | 4.73 | 0.00 | 6.64 | 0.00 | 6.47 | 23.43 | 0.00 |
| November | 4.97 | 25.00 | 29.97 | -0.47 | 4.50 | 4.03 | 0.00 | 7.05 | 0.00 | 3.64 | 22.35 | 0.00 |
| December | 3.84 | 25.00 | 28.84 | -0.70 | 4.50 | 3.80 | 0.00 | 6.78 | 0.00 | 2.34 | 19.91 | 0.00 |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | | Thermal | Total Reqmnt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling | kWh Availabl | kWh Heating |
| January | 1.68 | 45.00 | 46.68 | -0.47 | 4.50 | 4.03 | 0.00 | 5.35 | 0.00 | 0.33 | 5.78 | 0.00 |
| February | 2.33 | 40.00 | 42.33 | -0.60 | 4.50 | 3.90 | 0.00 | 3.88 | 0.00 | 0.30 | 6.84 | 0.00 |
| March | 3.52 | 35.00 | 38.52 | -0.37 | 4.50 | 4.13 | 0.00 | 3.98 | 0.00 | 1.00 | 7.54 | 0.00 |
| April | 4.87 | 30.00 | 34.87 | -0.18 | 4.50 | 4.32 | 0.00 | 3.44 | 0.00 | 1.69 | 9.35 | 0.00 |
| May | 6.09 | 25.00 | 31.09 | 0.07 | 4.50 | 4.57 | 0.00 | 3.95 | 0.00 | 3.44 | 11.14 | 0.00 |
| June | 7.07 | 25.00 | 32.07 | 0.29 | 4.50 | 4.79 | 0.00 | 4.54 | 0.00 | 5.62 | 7.85 | 0.00 |
| July | 7.43 | 25.00 | 32.43 | 0.65 | 4.50 | 5.15 | 0.00 | 4.55 | 0.00 | 5.86 | 8.64 | 0.00 |
| August | 7.63 | 25.00 | 32.63 | 0.70 | 4.50 | 5.20 | 0.00 | 4.45 | 0.00 | 5.82 | 0.00 | 0.00 |
| September | 6.96 | 30.00 | 36.96 | 0.28 | 4.50 | 4.78 | 0.00 | 5.37 | 0.00 | 6.34 | 6.78 | 0.00 |
| October | 5.52 | 35.00 | 40.52 | 0.00 | 4.50 | 4.50 | 0.00 | 6.53 | 0.00 | 5.29 | 0.00 | 0.00 |
| November | 3.51 | 40.00 | 43.51 | -0.28 | 4.50 | 4.22 | 0.00 | 5.04 | 0.00 | 1.87 | 0.10 | 0.00 |
| December | 2.52 | 45.00 | 47.52 | -0.37 | 4.50 | 4.13 | 0.00 | 5.95 | 0.00 | 1.31 | 6.42 | 0.00 |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh | Thermal Avai | Total kWh |
|---|---|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed | kWh Electric | Consumed |
| January | 0.29 | 3.75 | 0.22 | 0.00 | 2.62 | 4.68 | 11.05 | 6.37 | 11.05 |
| February | 0.29 | 3.35 | 0.22 | 0.00 | 2.37 | 3.60 | 9.31 | 7.57 | 9.31 |
| March | 0.29 | 4.38 | 0.22 | 0.00 | 2.62 | 3.53 | 10.54 | 9.35 | 10.54 |
| April | 0.29 | 5.06 | 0.22 | 0.00 | 2.53 | 2.97 | 10.56 | 10.41 | 10.56 |
| May | 0.29 | 6.40 | 0.22 | 0.00 | 2.62 | 2.64 | 11.66 | 10.73 | 11.66 |
| June | 0.29 | 7.61 | 0.22 | 0.00 | 2.53 | 2.55 | 12.69 | 8.88 | 12.69 |
| July | 0.29 | 8.22 | 0.22 | 0.00 | 2.62 | 2.64 | 13.47 | 9.59 | 13.47 |
| August | 0.29 | 8.33 | 0.22 | 0.00 | 2.62 | 2.64 | 13.58 | 7.60 | 13.58 |
| September | 0.29 | 8.03 | 0.22 | 0.00 | 2.53 | 3.17 | 13.73 | 7.76 | 13.73 |
| October | 0.29 | 7.12 | 0.22 | 0.00 | 2.62 | 4.03 | 13.77 | 5.15 | 13.77 |
| November | 0.29 | 5.03 | 0.22 | 0.00 | 2.53 | 4.08 | 11.64 | 4.94 | 11.64 |
| December | 0.29 | 4.68 | 0.22 | 0.00 | 2.62 | 4.87 | 12.17 | 5.79 | 12.17 |
| TOTAL/m2 | | 71.96 | | 0.00 | 30.84 | 41.38 | 144.17 | 94.15 | 144.17 |

BUILDING ENERGY BALANCE CALCULATIONS

## OPTION 5: PV ROOF MONITORS WITH ACTIVE HEAT RECOVERY

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Chicago | Longitude | 41.78 N | | | | |
| | | Latitude | 87.75 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate continental | Altitude | 186.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 0.60 | -7.20 | 85.00 | 40.00 | 125.00 | 10.00 | 12.50 | 18.50 | 70 | 80 |
| February | 1.50 | -6.30 | 130.00 | 55.00 | 141.00 | 10.49 | 13.44 | 14.56 | 67 | 79 |
| March | 6.40 | -1.70 | 190.00 | 75.00 | 206.00 | 12.78 | 16.12 | 14.88 | 61 | 77 |
| April | 14.10 | 4.70 | 250.00 | 100.00 | 206.00 | 12.48 | 16.50 | 13.50 | 56 | 74 |
| May | 20.60 | 10.50 | 290.00 | 120.00 | 275.00 | 14.54 | 18.91 | 12.09 | 55 | 75 |
| June | 26.40 | 15.40 | 305.00 | 125.00 | 307.00 | 15.51 | 19.80 | 10.20 | 56 | 77 |
| July | 28.90 | 19.50 | 290.00 | 120.00 | 310.00 | 13.89 | 22.32 | 8.68 | 53 | 77 |
| August | 28.00 | 18.80 | 250.00 | 100.00 | 285.00 | 13.13 | 21.70 | 9.30 | 56 | 81 |
| September | 23.80 | 14.10 | 190.00 | 75.00 | 246.00 | 12.42 | 19.80 | 10.20 | 53 | 81 |
| October | 17.40 | 8.20 | 130.00 | 55.00 | 214.00 | 11.13 | 19.22 | 11.78 | 54 | 79 |
| November | 8.40 | 0.30 | 85.00 | 40.00 | 135.00 | 10.00 | 13.50 | 16.50 | 62 | 78 |
| December | 2.10 | -5.30 | 70.00 | 35.00 | 115.00 | 10.00 | 11.50 | 19.50 | 69 | 80 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.15 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.00 |
| Thermal Transmittance | W/m2oC | 0.20 |
| PV slope | (°) | 15.00 |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### INTERNAL TEMPERATURES

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | -1.35 | -4.69 | 207.60 | 0.00 | 96.00 | 0.00 | 12.50 | 18.50 | 3.63 | -0.55 |
| February | -0.45 | -3.79 | 287.10 | 10.07 | 125.82 | 4.41 | 13.44 | 14.56 | 4.78 | 0.64 |
| March | 4.38 | 0.90 | 333.36 | 66.17 | 140.85 | 27.96 | 16.12 | 14.88 | 12.07 | 7.80 |
| April | 11.75 | 7.72 | 451.75 | 80.18 | 182.23 | 34.12 | 16.50 | 13.50 | 25.03 | 20.36 |
| May | 18.08 | 13.75 | 457.14 | 148.33 | 198.04 | 64.26 | 18.91 | 12.09 | 38.34 | 34.37 |
| June | 23.65 | 18.84 | 448.89 | 176.51 | 193.49 | 76.08 | 19.80 | 10.20 | 52.31 | 48.88 |
| July | 26.55 | 22.52 | 478.66 | 132.96 | 207.36 | 57.60 | 22.32 | 8.68 | 58.17 | 59.53 |
| August | 25.70 | 21.76 | 429.43 | 96.12 | 182.74 | 40.90 | 21.70 | 9.30 | 57.68 | 59.03 |
| September | 21.38 | 17.22 | 342.88 | 59.37 | 144.88 | 25.09 | 19.80 | 10.20 | 45.23 | 45.46 |
| October | 15.10 | 11.16 | 270.52 | 21.92 | 118.55 | 9.60 | 19.22 | 11.78 | 31.44 | 29.05 |
| November | 6.38 | 2.90 | 207.60 | 0.00 | 96.00 | 0.00 | 13.50 | 16.50 | 15.78 | 11.43 |
| December | 0.25 | -2.92 | 176.40 | 0.00 | 84.00 | 0.00 | 11.50 | 19.50 | 6.03 | 1.95 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | | Thermal | Total Reqmnt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling | kWh Available | kWh Heating |
| January | -12.78 | 25.00 | 12.22 | -13.45 | 4.50 | -8.95 | -1.57 | 1.53 | -7.87 | 0.00 | 10.12 | (9.43) |
| February | -11.53 | 25.00 | 13.47 | -12.78 | 4.50 | -8.28 | -1.56 | 1.81 | -8.16 | 0.00 | 14.76 | (9.72) |
| March | -8.01 | 25.00 | 16.99 | -9.26 | 4.50 | -4.76 | -1.07 | 2.74 | -7.54 | 0.00 | 20.26 | (8.61) |
| April | -2.22 | 25.00 | 22.78 | -4.71 | 4.50 | -0.21 | -0.05 | 3.76 | -3.61 | 0.00 | 27.61 | (3.66) |
| May | 1.94 | 25.00 | 26.94 | -1.84 | 4.50 | 2.66 | 0.00 | 5.80 | 0.00 | 0.00 | 31.75 | 0.00 |
| June | 5.49 | 25.00 | 30.49 | -0.94 | 4.50 | 3.56 | 0.00 | 7.02 | 0.00 | 1.86 | 32.39 | 0.00 |
| July | 7.63 | 25.00 | 32.63 | -0.06 | 4.50 | 4.44 | 0.00 | 8.67 | 0.00 | 4.61 | 33.80 | 0.00 |
| August | 6.66 | 25.00 | 31.66 | -0.33 | 4.50 | 4.17 | 0.00 | 8.14 | 0.00 | 4.27 | 33.86 | 0.00 |
| September | 3.12 | 25.00 | 28.12 | -0.33 | 4.50 | 4.17 | 0.00 | 6.72 | 0.00 | 0.00 | 24.82 | 0.00 |
| October | -1.56 | 25.00 | 23.44 | -2.96 | 4.50 | 1.54 | 0.00 | 4.92 | -1.84 | 0.00 | 19.27 | (1.84) |
| November | -7.76 | 25.00 | 17.24 | -8.51 | 4.50 | -4.01 | -0.76 | 2.33 | -5.35 | 0.00 | 10.70 | (6.11) |
| December | -12.01 | 25.00 | 12.99 | -12.30 | 4.50 | -7.80 | -1.26 | 1.49 | -6.71 | 0.00 | 7.96 | (7.96) |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | | Thermal | Total Reqmnt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling | kWh Available | kWh Heating |
| January | -13.72 | 45.00 | 31.28 | -13.45 | 4.50 | -8.95 | -2.32 | 5.79 | -11.64 | 0.00 | 4.09 | (13.96) |
| February | -12.89 | 40.00 | 27.11 | -12.83 | 4.50 | -8.33 | -1.70 | 3.95 | -8.84 | 0.00 | 4.41 | (10.54) |
| March | -9.62 | 35.00 | 25.38 | -9.58 | 4.50 | -5.08 | -1.06 | 3.78 | -6.96 | 0.00 | 5.14 | (8.01) |
| April | -4.40 | 30.00 | 25.60 | -5.09 | 4.50 | -0.59 | -0.11 | 3.46 | -2.95 | 0.00 | 7.38 | (3.06) |
| May | -0.24 | 25.00 | 24.76 | -0.93 | 4.50 | 3.57 | 0.00 | 3.60 | 0.00 | 0.00 | 8.61 | 0.00 |
| June | 3.35 | 25.00 | 28.35 | -0.38 | 4.50 | 4.12 | 0.00 | 3.48 | 0.00 | 0.96 | 11.58 | 0.00 |
| July | 5.35 | 25.00 | 30.35 | -0.15 | 4.50 | 4.35 | 0.00 | 3.16 | 0.00 | 1.79 | 14.55 | 0.00 |
| August | 4.59 | 25.00 | 29.59 | -0.25 | 4.50 | 4.25 | 0.00 | 3.31 | 0.00 | 1.83 | 0.00 | 0.00 |
| September | 1.46 | 30.00 | 31.46 | -0.62 | 4.50 | 3.88 | 0.00 | 3.76 | 0.00 | 0.00 | 5.29 | 0.00 |
| October | -2.84 | 35.00 | 32.16 | -3.07 | 4.50 | 1.43 | 0.00 | 4.02 | -1.13 | 0.00 | 0.00 | (1.13) |
| November | -8.70 | 40.00 | 31.30 | -8.51 | 4.50 | -4.01 | -0.93 | 5.16 | -6.54 | 0.00 | 0.98 | (7.46) |
| December | -12.78 | 45.00 | 32.22 | -12.30 | 4.50 | -7.80 | -2.13 | 6.28 | -11.38 | 0.00 | 5.31 | (13.50) |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and Power kWh | Total kWh Consumed | Thermal Avai kWh Electric | Total kWh Consumed |
|---|---|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | | | | |
| January | 0.00 | 0.00 | 0.22 | 5.20 | 2.32 | 6.34 | 13.86 | 3.13 | 8.66 |
| February | 0.00 | 0.00 | 0.22 | 4.50 | 2.10 | 4.56 | 11.16 | 4.22 | 6.66 |
| March | 0.00 | 0.00 | 0.22 | 3.69 | 2.32 | 4.12 | 10.14 | 5.59 | 6.45 |
| April | 0.00 | 0.00 | 0.22 | 1.49 | 2.25 | 3.23 | 6.97 | 7.70 | 5.47 |
| May | 0.29 | 2.68 | 0.22 | 0.00 | 2.32 | 2.64 | 7.64 | 8.88 | 7.64 |
| June | 0.29 | 3.81 | 0.22 | 0.00 | 2.25 | 2.55 | 8.60 | 9.57 | 8.60 |
| July | 0.29 | 5.21 | 0.22 | 0.00 | 2.32 | 2.64 | 10.17 | 11.74 | 10.17 |
| August | 0.29 | 5.01 | 0.22 | 0.00 | 2.32 | 2.64 | 9.97 | 7.45 | 9.97 |
| September | 0.29 | 3.00 | 0.22 | 0.00 | 2.25 | 3.06 | 8.30 | 6.62 | 8.30 |
| October | 0.29 | 2.56 | 0.22 | 0.66 | 2.32 | 3.81 | 9.35 | 4.24 | 8.69 |
| November | 0.00 | 0.00 | 0.22 | 3.02 | 2.25 | 5.03 | 10.29 | 2.37 | 7.27 |
| December | 0.00 | 0.00 | 0.22 | 4.77 | 2.32 | 6.54 | 13.63 | 2.92 | 8.86 |
| TOTAL/m2 | | 22.26 | | 23.33 | 27.35 | 47.14 | 120.08 | 74.52 | 96.74 |

## OPTION 5: PV ROOF MONITORS WITH ACTIVE HEAT RECOVERY

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Cincinnati | Longitude | 39.15 N | | | | |
| | | Latitude | 84.52 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate continental | Altitude | 232.00 m | Diffuse Radiation Factor | 1.10 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 6.20 | -3.30 | 85.00 | 40.00 | 108.00 | 10.00 | 10.80 | 20.20 | 68 | 83 |
| February | 6.30 | -2.90 | 130.00 | 55.00 | 129.00 | 10.24 | 12.60 | 15.40 | 64 | 81 |
| March | 11.10 | 0.70 | 190.00 | 75.00 | 173.00 | 11.16 | 15.50 | 15.50 | 57 | 79 |
| April | 18.00 | 6.60 | 250.00 | 100.00 | 201.00 | 11.96 | 16.80 | 13.20 | 53 | 76 |
| May | 23.80 | 11.90 | 290.00 | 120.00 | 241.00 | 12.74 | 18.91 | 12.09 | 53 | 78 |
| June | 28.80 | 17.20 | 305.00 | 125.00 | 305.00 | 14.73 | 20.70 | 9.30 | 55 | 80 |
| July | 30.80 | 19.10 | 290.00 | 120.00 | 322.00 | 14.43 | 22.32 | 8.68 | 52 | 82 |
| August | 30.20 | 18.30 | 250.00 | 100.00 | 291.00 | 13.41 | 21.70 | 9.30 | 52 | 86 |
| September | 26.80 | 14.20 | 190.00 | 75.00 | 254.00 | 12.45 | 20.40 | 9.60 | 50 | 86 |
| October | 20.50 | 8.20 | 130.00 | 55.00 | 213.00 | 11.26 | 18.91 | 12.09 | 61 | 85 |
| November | 11.80 | 2.20 | 85.00 | 40.00 | 145.00 | 10.51 | 13.80 | 16.20 | 60 | 81 |
| December | 5.90 | -2.30 | 70.00 | 35.00 | 126.00 | 10.16 | 12.40 | 18.60 | 68 | 82 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.15 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

**PV PANEL DATA**

| | | | | |
|---|---|---|---|---|
| Conversion Efficiency | % | 10.00 | %RH | 35 |
| Direct Transmittance | % | 0.00 | Enthalpy | 36.41 |
| Thermal Transmittance W/m2oC | | 0.20 | | |
| PV slope (°) | | 15.00 | | |

**INTERNAL TEMPERATURES** — **HUMIDITY-WINTER**

| | | | | |
|---|---|---|---|---|
| Occupied Period Set Point | oC | 21.00 | %RH | 60 |
| Unoccupied Period Offset | oC | 5.00 | Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 3.83 | -0.25 | 207.60 | 0.00 | 96.00 | 0.00 | 10.80 | 20.20 | 11.96 | 6.36 |
| February | 4.00 | 0.06 | 294.20 | 5.00 | 128.83 | 2.19 | 12.60 | 15.40 | 11.79 | 6.71 |
| March | 8.50 | 4.04 | 381.68 | 31.66 | 161.27 | 13.38 | 15.50 | 15.50 | 18.91 | 13.69 |
| April | 15.15 | 10.26 | 471.40 | 66.14 | 200.60 | 28.14 | 16.80 | 13.20 | 31.24 | 26.31 |
| May | 20.83 | 15.73 | 521.63 | 102.26 | 225.98 | 44.30 | 18.91 | 12.09 | 43.93 | 40.35 |
| June | 25.90 | 20.93 | 472.37 | 159.74 | 203.61 | 68.85 | 20.70 | 9.30 | 57.64 | 56.01 |
| July | 27.88 | 22.86 | 460.82 | 145.70 | 199.63 | 63.12 | 22.32 | 8.68 | 61.04 | 63.03 |
| August | 27.23 | 22.13 | 420.58 | 102.44 | 178.97 | 43.59 | 21.70 | 9.30 | 59.33 | 62.55 |
| September | 23.65 | 18.25 | 342.14 | 59.90 | 144.57 | 25.31 | 20.40 | 9.60 | 49.24 | 50.29 |
| October | 17.43 | 12.15 | 267.40 | 24.14 | 117.19 | 10.58 | 18.91 | 12.09 | 38.96 | 32.94 |
| November | 9.40 | 5.29 | 197.58 | 7.16 | 91.37 | 3.31 | 13.80 | 16.20 | 21.21 | 16.41 |
| December | 3.85 | 0.34 | 173.60 | 2.00 | 82.67 | 0.95 | 12.40 | 18.60 | 12.00 | 7.27 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | | Thermal | Total Reqmnt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling | kWh Availabl | kWh Heating |
| January | -9.42 | 25.00 | 15.58 | -10.56 | 4.50 | -6.06 | -0.92 | 1.68 | -5.07 | 0.00 | 8.62 | (5.99) |
| February | -8.58 | 25.00 | 16.42 | -10.32 | 4.50 | -5.82 | -1.03 | 2.07 | -5.96 | 0.00 | 14.04 | (6.98) |
| March | -4.92 | 25.00 | 20.08 | -7.51 | 4.50 | -3.01 | -0.65 | 3.11 | -5.21 | 0.00 | 22.08 | (5.86) |
| April | 0.16 | 25.00 | 25.16 | -3.17 | 4.50 | 1.33 | 0.00 | 4.54 | -1.67 | 0.00 | 29.19 | (1.67) |
| May | 4.27 | 25.00 | 29.27 | -0.94 | 4.50 | 3.56 | 0.00 | 6.48 | 0.00 | 0.00 | 36.09 | 0.00 |
| June | 7.15 | 25.00 | 32.15 | -0.87 | 4.50 | 3.63 | 0.00 | 7.71 | 0.00 | 4.06 | 35.54 | 0.00 |
| July | 8.34 | 25.00 | 33.34 | -0.82 | 4.50 | 3.68 | 0.00 | 8.59 | 0.00 | 5.83 | 37.28 | 0.00 |
| August | 7.58 | 25.00 | 32.58 | -0.57 | 4.50 | 3.93 | 0.00 | 8.26 | 0.00 | 4.96 | 33.08 | 0.00 |
| September | 4.60 | 25.00 | 29.60 | -0.63 | 4.50 | 3.87 | 0.00 | 7.14 | 0.00 | 0.71 | 25.41 | 0.00 |
| October | -0.08 | 25.00 | 24.92 | -2.30 | 4.50 | 2.20 | 0.00 | 5.30 | 0.00 | 0.00 | 18.65 | 0.00 |
| November | -5.88 | 25.00 | 19.12 | -6.90 | 4.50 | -2.40 | -0.46 | 2.64 | -4.03 | 0.00 | 10.33 | (4.49) |
| December | -9.69 | 25.00 | 15.31 | -10.16 | 4.50 | -5.66 | -0.98 | 1.90 | -5.81 | 0.00 | 8.35 | (6.79) |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | | Thermal | Total Reqmnt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling | kWh Availabl | kWh Heating |
| January | -10.36 | 45.00 | 34.64 | -10.56 | 4.50 | -6.06 | -1.71 | 7.00 | -8.48 | 0.00 | 3.63 | (11.20) |
| February | -9.97 | 40.00 | 30.03 | -10.34 | 4.50 | -5.84 | -1.26 | 4.63 | -7.28 | 0.00 | 4.43 | (8.54) |
| March | -6.77 | 35.00 | 28.23 | -7.66 | 4.50 | -3.16 | -0.68 | 4.38 | -5.21 | 0.00 | 5.75 | (5.90) |
| April | -2.12 | 30.00 | 27.88 | -3.49 | 4.50 | 1.01 | 0.00 | 3.87 | -1.31 | 0.00 | 7.17 | (1.31) |
| May | 1.78 | 25.00 | 26.78 | -1.43 | 4.50 | 3.07 | 0.00 | 3.76 | 0.00 | 0.00 | 10.00 | 0.00 |
| June | 4.90 | 25.00 | 29.90 | -0.12 | 4.50 | 4.38 | 0.00 | 3.25 | 0.00 | 1.82 | 11.89 | 0.00 |
| July | 6.15 | 25.00 | 31.15 | 0.11 | 4.50 | 4.61 | 0.00 | 3.26 | 0.00 | 2.27 | 13.30 | 0.00 |
| August | 5.55 | 25.00 | 30.55 | 0.01 | 4.50 | 4.51 | 0.00 | 3.43 | 0.00 | 2.13 | 0.00 | 0.00 |
| September | 2.94 | 30.00 | 32.94 | -0.92 | 4.50 | 3.58 | 0.00 | 3.64 | 0.00 | 0.33 | 5.23 | 0.00 |
| October | -1.34 | 35.00 | 33.66 | -2.41 | 4.50 | 2.09 | 0.00 | 4.42 | 0.00 | 0.00 | 0.00 | 0.00 |
| November | -6.77 | 40.00 | 33.23 | -6.94 | 4.50 | -2.44 | -0.55 | 5.38 | -4.73 | 0.00 | 0.07 | (5.28) |
| December | -10.45 | 45.00 | 34.55 | -10.17 | 4.50 | -5.67 | -1.48 | 6.43 | -8.72 | 0.00 | 5.11 | (10.19) |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh | Thermal Avai | Total kWh |
|---|---|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed | kWh Electric | Consumed |
| January | 0.00 | 0.00 | 0.22 | 3.82 | 2.45 | 6.68 | 12.94 | 2.69 | 9.12 |
| February | 0.00 | 0.00 | 0.22 | 3.45 | 2.21 | 4.69 | 10.35 | 4.06 | 6.90 |
| March | 0.00 | 0.00 | 0.22 | 2.61 | 2.45 | 4.19 | 9.25 | 6.12 | 6.63 |
| April | 0.29 | 2.40 | 0.22 | 0.66 | 2.37 | 3.21 | 8.64 | 8.00 | 7.98 |
| May | 0.29 | 2.92 | 0.22 | 0.00 | 2.45 | 2.64 | 8.01 | 10.14 | 8.01 |
| June | 0.29 | 4.84 | 0.22 | 0.00 | 2.37 | 2.55 | 9.76 | 10.43 | 9.76 |
| July | 0.29 | 5.70 | 0.22 | 0.00 | 2.45 | 2.64 | 10.79 | 11.13 | 10.79 |
| August | 0.29 | 5.36 | 0.22 | 0.00 | 2.45 | 2.64 | 10.45 | 7.28 | 10.45 |
| September | 0.29 | 3.38 | 0.22 | 0.00 | 2.37 | 3.03 | 8.78 | 6.74 | 8.78 |
| October | 0.29 | 2.78 | 0.22 | 0.00 | 2.45 | 3.84 | 9.07 | 4.10 | 9.07 |
| November | 0.00 | 0.00 | 0.22 | 2.17 | 2.37 | 4.98 | 9.52 | 2.29 | 7.35 |
| December | 0.00 | 0.00 | 0.22 | 3.78 | 2.45 | 6.36 | 12.58 | 2.96 | 8.80 |
| TOTAL/m2 | | 27.39 | | 16.49 | 28.83 | 47.42 | 120.14 | 75.95 | 103.65 |

BUILDING ENERGY BALANCE CALCULATIONS

## REF. DESIGN FLAT INSULATED NON-PV ROOF

SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | San Francisco | Longitude | 37.62 N | | | | |
| | | Latitude | 122.38 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate costal warm | Altitude | 2.00 m | Diffuse Radiation Factor | 1.10 | | |

WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 13.00 | 5.40 | 85.00 | 40.00 | 154.00 | 10.00 | 15.40 | 15.60 | 75 | 85 |
| February | 14.70 | 6.30 | 130.00 | 55.00 | 191.00 | 11.56 | 16.52 | 11.48 | 71 | 85 |
| March | 16.40 | 7.20 | 190.00 | 75.00 | 262.00 | 12.43 | 21.08 | 9.92 | 66 | 83 |
| April | 17.90 | 8.40 | 250.00 | 100.00 | 297.00 | 13.94 | 21.30 | 8.70 | 66 | 85 |
| May | 19.40 | 9.80 | 290.00 | 120.00 | 328.00 | 14.90 | 22.01 | 8.99 | 66 | 85 |
| June | 21.20 | 11.30 | 305.00 | 125.00 | 341.00 | 15.36 | 22.20 | 7.80 | 65 | 87 |
| July | 22.20 | 11.90 | 290.00 | 120.00 | 295.00 | 14.20 | 20.77 | 10.23 | 69 | 90 |
| August | 22.10 | 12.10 | 250.00 | 100.00 | 275.00 | 13.65 | 20.15 | 10.85 | 69 | 90 |
| September | 23.20 | 12.20 | 190.00 | 75.00 | 275.00 | 12.73 | 21.60 | 8.40 | 66 | 88 |
| October | 21.40 | 10.30 | 130.00 | 55.00 | 242.00 | 11.31 | 21.39 | 9.61 | 65 | 86 |
| November | 17.80 | 7.70 | 85.00 | 40.00 | 198.00 | 10.00 | 19.80 | 10.20 | 68 | 84 |
| December | 14.00 | 6.10 | 70.00 | 35.00 | 179.00 | 10.31 | 17.36 | 13.64 | 74 | 86 |

BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

PV PANEL DATA

| | | | | |
|---|---|---|---|---|
| Conversion Efficiency | % | 10.00 | %RH | 35 |
| Direct Transmittance | % | 0.00 | Enthalpy | 36.41 |
| Thermal Transmittance W/m2oC | | 0.20 | | |
| PV slope (°) | | 0.00 | | |

HUMIDITY-WINTER

INTERNAL TEMPERATURES

| | | | | |
|---|---|---|---|---|
| Occupied Period Set Point | oC | 21.00 | %RH | 60 |
| Unoccupied Period Offset | oC | 5.00 | Enthalpy | 47.425 |

HUMIDITY-SUMMER

CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 11.10 | 7.84 | 207.60 | 0.00 | 96.00 | 0.00 | 15.40 | 15.60 | 28.01 | 22.52 |
| February | 12.60 | 9.00 | 260.51 | 29.06 | 114.17 | 12.74 | 16.52 | 11.48 | 30.55 | 25.19 |
| March | 14.10 | 10.16 | 342.75 | 59.46 | 144.82 | 25.13 | 21.08 | 9.92 | 32.71 | 27.53 |
| April | 15.53 | 11.45 | 404.48 | 113.94 | 172.12 | 48.48 | 21.30 | 8.70 | 36.08 | 31.15 |
| May | 17.00 | 12.89 | 446.11 | 156.21 | 193.26 | 67.67 | 22.01 | 8.99 | 39.69 | 34.84 |
| June | 18.73 | 14.48 | 453.11 | 173.49 | 195.31 | 74.78 | 22.20 | 7.80 | 43.67 | 39.69 |
| July | 19.63 | 15.21 | 468.06 | 140.53 | 202.77 | 60.88 | 20.77 | 10.23 | 47.62 | 42.64 |
| August | 19.60 | 15.31 | 413.26 | 107.57 | 175.85 | 45.82 | 20.15 | 10.85 | 47.55 | 42.94 |
| September | 20.45 | 15.74 | 334.60 | 65.28 | 141.38 | 27.58 | 21.60 | 8.40 | 48.59 | 43.54 |
| October | 18.63 | 13.87 | 266.23 | 24.98 | 116.67 | 10.95 | 21.39 | 9.61 | 43.42 | 37.72 |
| November | 15.28 | 10.95 | 207.60 | 0.00 | 96.00 | 0.00 | 19.80 | 10.20 | 36.10 | 29.66 |
| December | 12.03 | 8.64 | 171.08 | 3.80 | 81.47 | 1.81 | 17.36 | 13.64 | 29.94 | 24.53 |

SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -0.24 | 45.00 | 44.76 | -1.63 | 4.50 | 2.87 | 0.00 | 7.51 | -2.48 | 0.00 |
| February | 0.51 | 45.00 | 45.51 | -1.16 | 4.50 | 3.34 | 0.00 | 8.29 | -1.86 | 0.00 |
| March | 1.50 | 45.00 | 46.50 | -0.67 | 4.50 | 3.83 | 0.00 | 10.93 | -1.50 | 0.00 |
| April | 2.30 | 45.00 | 47.30 | 0.05 | 4.50 | 4.55 | 0.00 | 11.43 | -0.14 | 0.00 |
| May | 2.95 | 45.00 | 47.95 | 0.36 | 4.50 | 4.86 | 0.00 | 12.05 | 0.00 | 0.00 |
| June | 3.35 | 45.00 | 48.35 | 0.65 | 4.50 | 5.15 | 0.00 | 12.34 | 0.00 | 0.00 |
| July | 3.66 | 45.00 | 48.66 | 0.52 | 4.50 | 5.02 | 0.00 | 11.57 | 0.00 | 0.08 |
| August | 3.19 | 45.00 | 48.19 | 0.27 | 4.50 | 4.77 | 0.00 | 11.06 | 0.00 | 0.05 |
| September | 2.70 | 45.00 | 47.70 | 0.00 | 4.50 | 4.50 | 0.00 | 11.66 | 0.00 | 0.48 |
| October | 1.76 | 45.00 | 46.76 | -0.22 | 4.50 | 4.28 | 0.00 | 11.28 | 0.00 | 0.00 |
| November | 0.60 | 45.00 | 45.60 | -1.01 | 4.50 | 3.49 | 0.00 | 10.00 | -0.12 | 0.00 |
| December | -0.36 | 45.00 | 44.64 | -1.44 | 4.50 | 3.06 | 0.00 | 8.49 | -2.16 | 0.00 |

CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -1.17 | 45.00 | 43.83 | -1.63 | 4.50 | 2.87 | 0.00 | 7.46 | -2.52 | 0.00 |
| February | -0.72 | 45.00 | 44.28 | -1.29 | 4.50 | 3.21 | 0.00 | 5.50 | -1.29 | 0.00 |
| March | -0.16 | 45.00 | 44.84 | -0.96 | 4.50 | 3.54 | 0.00 | 4.94 | -0.71 | 0.00 |
| April | 0.35 | 45.00 | 45.35 | -0.50 | 4.50 | 4.00 | 0.00 | 4.43 | -0.06 | 0.00 |
| May | 0.82 | 45.00 | 45.82 | -0.05 | 4.50 | 4.45 | 0.00 | 4.58 | 0.00 | 0.00 |
| June | 1.19 | 45.00 | 46.19 | 0.32 | 4.50 | 4.82 | 0.00 | 4.13 | 0.00 | 0.00 |
| July | 1.43 | 45.00 | 46.43 | 0.35 | 4.50 | 4.85 | 0.00 | 5.44 | 0.00 | 0.04 |
| August | 1.20 | 45.00 | 46.20 | 0.25 | 4.50 | 4.75 | 0.00 | 5.73 | 0.00 | 0.03 |
| September | 1.08 | 45.00 | 46.08 | 0.18 | 4.50 | 4.68 | 0.00 | 4.42 | 0.00 | 0.19 |
| October | 0.51 | 45.00 | 45.51 | -0.33 | 4.50 | 4.17 | 0.00 | 4.93 | 0.00 | 0.00 |
| November | -0.34 | 45.00 | 44.66 | -1.01 | 4.50 | 3.49 | 0.00 | 5.05 | -0.06 | 0.00 |
| December | -1.11 | 45.00 | 43.89 | -1.46 | 4.50 | 3.04 | 0.00 | 6.57 | -1.69 | 0.00 |

OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 1.11 | 3.68 | 8.84 | 13.63 |
| February | 0.00 | 0.00 | 0.22 | 0.70 | 3.33 | 7.98 | 12.01 |
| March | 0.00 | 0.00 | 0.22 | 0.49 | 3.68 | 8.84 | 13.01 |
| April | 0.29 | 4.53 | 0.22 | 0.04 | 3.56 | 8.55 | 16.69 |
| May | 0.29 | 4.78 | 0.22 | 0.00 | 3.68 | 8.84 | 17.30 |
| June | 0.29 | 4.70 | 0.22 | 0.00 | 3.56 | 8.55 | 16.82 |
| July | 0.29 | 4.89 | 0.22 | 0.00 | 3.68 | 8.84 | 17.41 |
| August | 0.29 | 4.82 | 0.22 | 0.00 | 3.68 | 8.84 | 17.34 |
| September | 0.29 | 4.79 | 0.22 | 0.00 | 3.56 | 8.55 | 16.90 |
| October | 0.29 | 4.63 | 0.22 | 0.00 | 3.68 | 8.84 | 17.15 |
| November | 0.29 | 4.30 | 0.22 | 0.04 | 3.56 | 8.55 | 16.45 |
| December | 0.00 | 0.00 | 0.22 | 0.86 | 3.68 | 8.84 | 13.37 |
| TOTAL/m2 | | 37.45 | | 3.24 | 43.36 | 104.03 | 188.08 |

## REF. DESIGN FLAT INSULATED NON-PV ROOF

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | New York | Longtude | 40.70 N | | | | |
| | | Latitude | 74.02 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate costal cold | Altitude | 3.00 m | Diffuse Radiation Factor | 1.10 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 4.30 | -2.80 | 85.00 | 40.00 | 151.00 | 10.00 | 15.10 | 15.90 | 61 | 69 |
| February | 4.10 | -2.40 | 130.00 | 55.00 | 164.00 | 10.28 | 15.96 | 12.04 | 58 | 67 |
| March | 8.90 | 0.60 | 190.00 | 75.00 | 209.00 | 11.83 | 17.67 | 13.33 | 56 | 67 |
| April | 14.90 | 6.10 | 250.00 | 100.00 | 214.00 | 12.09 | 17.70 | 12.30 | 55 | 68 |
| May | 20.90 | 11.80 | 290.00 | 120.00 | 250.00 | 13.44 | 18.60 | 12.40 | 56 | 69 |
| June | 25.60 | 16.90 | 305.00 | 125.00 | 301.00 | 16.18 | 18.60 | 11.40 | 58 | 72 |
| July | 28.30 | 19.90 | 290.00 | 120.00 | 307.00 | 15.00 | 20.46 | 10.54 | 57 | 74 |
| August | 27.40 | 19.30 | 250.00 | 100.00 | 275.00 | 13.86 | 19.84 | 11.16 | 60 | 76 |
| September | 23.80 | 15.80 | 190.00 | 75.00 | 237.00 | 12.54 | 18.90 | 11.10 | 60 | 76 |
| October | 18.40 | 10.30 | 130.00 | 55.00 | 218.00 | 11.34 | 19.22 | 11.78 | 59 | 74 |
| November | 11.90 | 4.40 | 85.00 | 40.00 | 172.00 | 10.06 | 17.10 | 12.90 | 60 | 71 |
| December | 5.70 | -1.20 | 70.00 | 35.00 | 158.00 | 10.00 | 15.80 | 15.20 | 60 | 67 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

**PV PANEL DATA**

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.00 |
| Thermal Transmittance W/m2oC | | 0.20 |
| PV slope (°) | | 0.00 |

**INTERNAL TEMPERATURES**

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

**HUMIDITY-WINTER**

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

**HUMIDITY-SUMMER**

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 2.53 | -0.52 | 207.60 | 0.00 | 96.00 | 0.00 | 15.10 | 15.90 | 8.95 | 4.83 |
| February | 2.48 | -0.31 | 293.12 | 5.77 | 128.46 | 2.53 | 15.96 | 12.04 | 8.56 | 4.99 |
| March | 6.83 | 3.27 | 360.16 | 47.03 | 152.18 | 19.87 | 17.67 | 13.33 | 15.67 | 10.86 |
| April | 12.70 | 8.93 | 466.49 | 69.65 | 198.50 | 29.64 | 17.70 | 12.30 | 26.71 | 21.80 |
| May | 18.63 | 14.73 | 494.61 | 121.56 | 214.27 | 52.66 | 18.60 | 12.40 | 39.98 | 35.06 |
| June | 23.43 | 19.70 | 430.09 | 189.94 | 185.38 | 81.87 | 18.60 | 11.40 | 52.74 | 49.03 |
| July | 26.20 | 22.60 | 443.06 | 158.39 | 191.94 | 68.62 | 20.46 | 10.54 | 59.60 | 58.33 |
| August | 25.38 | 21.90 | 406.90 | 112.21 | 173.15 | 47.75 | 19.84 | 11.16 | 59.06 | 57.18 |
| September | 21.80 | 18.37 | 339.72 | 61.63 | 143.54 | 26.04 | 18.90 | 11.10 | 49.48 | 46.90 |
| October | 16.38 | 12.90 | 265.55 | 25.46 | 116.38 | 11.16 | 19.22 | 11.78 | 35.84 | 32.04 |
| November | 10.03 | 6.81 | 206.39 | 0.86 | 95.44 | 0.40 | 17.10 | 12.90 | 22.45 | 18.01 |
| December | 3.98 | 1.02 | 176.40 | 0.00 | 84.00 | 0.00 | 15.80 | 15.20 | 11.26 | 7.09 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -1.95 | 45.00 | 43.05 | -3.30 | 4.50 | 1.20 | 0.00 | 6.75 | -7.96 | 0.00 |
| February | -1.24 | 45.00 | 43.76 | -3.21 | 4.50 | 1.29 | 0.00 | 7.27 | -8.54 | 0.00 |
| March | 0.19 | 45.00 | 45.19 | -2.15 | 4.50 | 2.35 | 0.00 | 8.57 | -7.04 | 0.00 |
| April | 2.26 | 45.00 | 47.26 | -0.83 | 4.50 | 3.67 | 0.00 | 9.27 | -3.30 | 0.00 |
| May | 3.68 | 45.00 | 48.68 | -0.23 | 4.50 | 4.27 | 0.00 | 10.17 | 0.00 | 0.00 |
| June | 4.10 | 45.00 | 49.10 | 0.67 | 4.50 | 5.17 | 0.00 | 10.48 | 0.00 | 1.90 |
| July | 4.76 | 45.00 | 49.76 | 0.65 | 4.50 | 5.15 | 0.00 | 11.66 | 0.00 | 4.78 |
| August | 4.29 | 45.00 | 49.29 | 0.46 | 4.50 | 4.96 | 0.00 | 11.16 | 0.00 | 4.43 |
| September | 3.01 | 45.00 | 48.01 | -0.01 | 4.50 | 4.49 | 0.00 | 10.26 | 0.00 | 0.75 |
| October | 1.31 | 45.00 | 46.31 | -0.41 | 4.50 | 4.09 | 0.00 | 10.00 | -0.21 | 0.00 |
| November | -0.46 | 45.00 | 44.54 | -1.83 | 4.50 | 2.67 | 0.00 | 8.26 | -4.58 | 0.00 |
| December | -1.92 | 45.00 | 43.08 | -3.00 | 4.50 | 1.50 | 0.00 | 7.14 | -7.63 | 0.00 |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -2.89 | 45.00 | 42.11 | -3.30 | 4.50 | 1.20 | 0.00 | 6.96 | -8.38 | 0.00 |
| February | -2.63 | 45.00 | 42.37 | -3.24 | 4.50 | 1.26 | 0.00 | 5.31 | -6.44 | 0.00 |
| March | -1.56 | 45.00 | 43.44 | -2.38 | 4.50 | 2.12 | 0.00 | 6.19 | -5.31 | 0.00 |
| April | 0.01 | 45.00 | 45.01 | -1.17 | 4.50 | 3.33 | 0.00 | 6.11 | -2.29 | 0.00 |
| May | 1.32 | 45.00 | 46.32 | 0.19 | 4.50 | 4.69 | 0.00 | 6.56 | 0.00 | 0.00 |
| June | 2.04 | 45.00 | 47.04 | 0.33 | 4.50 | 4.83 | 0.00 | 6.13 | 0.00 | 1.16 |
| July | 2.65 | 45.00 | 47.65 | 0.40 | 4.50 | 4.90 | 0.00 | 5.75 | 0.00 | 2.46 |
| August | 2.33 | 45.00 | 47.33 | 0.25 | 4.50 | 4.75 | 0.00 | 6.02 | 0.00 | 2.49 |
| September | 1.37 | 45.00 | 46.37 | -0.21 | 4.50 | 4.29 | 0.00 | 5.81 | 0.00 | 0.44 |
| October | 0.05 | 45.00 | 45.05 | -0.53 | 4.50 | 3.97 | 0.00 | 5.96 | -0.13 | 0.00 |
| November | -1.39 | 45.00 | 43.61 | -1.83 | 4.50 | 2.67 | 0.00 | 6.11 | -3.46 | 0.00 |
| December | -2.70 | 45.00 | 42.30 | -3.00 | 4.50 | 1.50 | 0.00 | 6.75 | -7.34 | 0.00 |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 3.63 | 3.74 | 8.84 | 16.21 |
| February | 0.00 | 0.00 | 0.22 | 3.33 | 3.38 | 7.98 | 14.69 |
| March | 0.00 | 0.00 | 0.22 | 2.74 | 3.74 | 8.84 | 15.32 |
| April | 0.00 | 0.00 | 0.22 | 1.24 | 3.62 | 8.55 | 13.41 |
| May | 0.29 | 4.78 | 0.22 | 0.00 | 3.74 | 8.84 | 17.35 |
| June | 0.29 | 5.62 | 0.22 | 0.00 | 3.62 | 8.55 | 17.79 |
| July | 0.29 | 7.04 | 0.22 | 0.00 | 3.74 | 8.84 | 19.62 |
| August | 0.29 | 6.89 | 0.22 | 0.00 | 3.74 | 8.84 | 19.46 |
| September | 0.29 | 4.93 | 0.22 | 0.00 | 3.62 | 8.55 | 17.10 |
| October | 0.29 | 4.56 | 0.22 | 0.08 | 3.74 | 8.84 | 17.21 |
| November | 0.00 | 0.00 | 0.22 | 1.79 | 3.62 | 8.55 | 13.96 |
| December | 0.00 | 0.00 | 0.22 | 3.33 | 3.74 | 8.84 | 15.90 |
| TOTAL/m2 | | 33.82 | | 16.14 | 44.03 | 104.03 | 198.02 |

BUILDING ENERGY BALANCE CALCULATIONS

## REF. DESIGN FLAT INSULATED NON-PV ROOF

**SITE DATA**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Phoenix | Longitude | 33.43 N | | | | |
| | | Latitude | 112.02 W | Direct Radiation Factor | 1.10 | | |
| Climate | Temperate arid | Altitude | 340.00 m | Diffuse Radiation Factor | 0.90 | | |

**WEATHER DATA**

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 17.80 | 1.80 | 105.00 | 25.00 | 262.00 | 10.84 | 24.18 | 6.82 | 44 | 72 |
| February | 20.10 | 3.80 | 150.00 | 30.00 | 271.00 | 12.41 | 21.84 | 6.16 | 42 | 71 |
| March | 23.90 | 6.10 | 205.00 | 35.00 | 331.00 | 12.56 | 26.35 | 4.65 | 31 | 60 |
| April | 28.80 | 10.20 | 260.00 | 45.00 | 360.00 | 13.48 | 26.70 | 3.30 | 26 | 50 |
| May | 33.80 | 13.90 | 295.00 | 45.00 | 408.00 | 14.00 | 29.14 | 1.86 | 19 | 41 |
| June | 38.70 | 18.60 | 305.00 | 50.00 | 411.00 | 14.57 | 28.20 | 1.80 | 17 | 37 |
| July | 40.30 | 23.90 | 295.00 | 45.00 | 390.00 | 14.30 | 27.28 | 3.72 | 29 | 51 |
| August | 38.70 | 23.00 | 260.00 | 45.00 | 379.00 | 14.22 | 26.66 | 4.34 | 35 | 60 |
| September | 36.80 | 19.60 | 205.00 | 35.00 | 354.00 | 13.11 | 27.00 | 3.00 | 29 | 66 |
| October | 30.40 | 12.60 | 150.00 | 30.00 | 323.00 | 11.98 | 26.97 | 4.03 | 38 | 58 |
| November | 23.20 | 5.80 | 105.00 | 25.00 | 282.00 | 10.93 | 25.80 | 4.20 | 33 | 83 |
| December | 18.90 | 2.80 | 90.00 | 25.00 | 260.00 | 10.75 | 24.18 | 6.82 | 42 | 70 |

**BUILDING DATA**

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

**PV PANEL DATA**

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.00 |
| Thermal Transmittance | W/m2oC | 0.20 |
| PV slope (°) | | 0.00 |

**INTERNAL TEMPERATURES**

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

**HUMIDITY-WINTER**

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

**HUMIDITY-SUMMER**

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

**CALCULATIONS OF MEAN EXTERNAL CONDITIONS**

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 13.80 | 6.94 | 305.66 | 18.24 | 110.75 | 6.61 | 24.18 | 6.82 | 25.94 | 18.43 |
| February | 16.03 | 9.04 | 371.36 | 63.89 | 116.05 | 19.96 | 21.84 | 6.16 | 29.56 | 22.60 |
| March | 19.45 | 11.82 | 491.02 | 89.84 | 133.74 | 24.47 | 26.35 | 4.65 | 31.89 | 26.13 |
| April | 24.15 | 16.18 | 581.17 | 144.59 | 160.20 | 39.86 | 26.70 | 3.30 | 37.82 | 32.46 |
| May | 28.83 | 20.30 | 625.65 | 178.82 | 154.27 | 44.09 | 29.14 | 1.86 | 41.52 | 37.62 |
| June | 33.68 | 25.06 | 626.58 | 204.73 | 164.67 | 53.81 | 28.20 | 1.80 | 47.87 | 45.49 |
| July | 36.20 | 29.17 | 612.75 | 188.04 | 151.09 | 46.36 | 27.28 | 3.72 | 63.15 | 63.82 |
| August | 34.78 | 28.05 | 551.21 | 165.99 | 151.94 | 45.76 | 26.66 | 4.34 | 65.41 | 66.63 |
| September | 32.50 | 25.13 | 470.44 | 104.54 | 128.14 | 28.47 | 27.00 | 3.00 | 55.49 | 61.70 |
| October | 25.95 | 18.32 | 384.76 | 54.31 | 120.24 | 16.97 | 26.97 | 4.03 | 43.31 | 40.03 |
| November | 18.85 | 11.39 | 303.01 | 20.13 | 109.79 | 7.29 | 25.80 | 4.20 | 31.61 | 30.54 |
| December | 14.88 | 7.98 | 271.19 | 14.58 | 111.60 | 6.00 | 24.18 | 6.82 | 27.38 | 20.20 |

**SUNNY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | 1.13 | 45.00 | 46.13 | -1.66 | 4.50 | 2.84 | 0.00 | 12.12 | -4.86 | 0.00 |
| February | 2.12 | 45.00 | 47.12 | -0.86 | 4.50 | 3.64 | 0.00 | 11.41 | -2.88 | 0.00 |
| March | 3.81 | 45.00 | 48.81 | -0.08 | 4.50 | 4.42 | 0.00 | 14.49 | -2.29 | 0.00 |
| April | 5.51 | 45.00 | 50.51 | 0.25 | 4.50 | 4.75 | 0.00 | 15.26 | 0.00 | 0.00 |
| May | 6.82 | 45.00 | 51.82 | 1.36 | 4.50 | 5.86 | 0.00 | 17.49 | 0.00 | 0.00 |
| June | 7.80 | 45.00 | 52.80 | 1.53 | 4.50 | 6.03 | 0.00 | 17.27 | 0.00 | 0.24 |
| July | 8.19 | 45.00 | 53.19 | 2.21 | 4.50 | 6.71 | 0.00 | 17.07 | 0.00 | 8.24 |
| August | 7.39 | 45.00 | 52.39 | 1.80 | 4.50 | 6.30 | 0.00 | 16.32 | 0.00 | 9.21 |
| September | 6.25 | 45.00 | 51.25 | 0.70 | 4.50 | 5.20 | 0.00 | 15.81 | 0.00 | 4.18 |
| October | 4.22 | 45.00 | 49.22 | -0.08 | 4.50 | 4.42 | 0.00 | 14.94 | 0.00 | 0.00 |
| November | 2.12 | 45.00 | 47.12 | -0.75 | 4.50 | 3.75 | 0.00 | 13.51 | -2.38 | 0.00 |
| December | 1.05 | 45.00 | 46.05 | -1.48 | 4.50 | 3.02 | 0.00 | 12.16 | -4.19 | 0.00 |

**CLOUDY DAY HEAT BALANCE**

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -0.51 | 45.00 | 44.49 | -1.76 | 4.50 | 2.74 | 0.00 | 3.30 | -1.37 | 0.00 |
| February | -0.02 | 45.00 | 44.98 | -1.22 | 4.50 | 3.28 | 0.00 | 3.05 | -0.81 | 0.00 |
| March | 0.81 | 45.00 | 45.81 | -0.63 | 4.50 | 3.87 | 0.00 | 2.38 | -0.40 | 0.00 |
| April | 1.98 | 45.00 | 46.98 | -0.13 | 4.50 | 4.37 | 0.00 | 1.75 | 0.00 | 0.00 |
| May | 2.86 | 45.00 | 47.86 | 0.23 | 4.50 | 4.73 | 0.00 | 1.01 | 0.00 | 0.00 |
| June | 3.92 | 45.00 | 48.92 | 0.76 | 4.50 | 5.26 | 0.00 | 1.01 | 0.00 | 0.02 |
| July | 4.31 | 45.00 | 49.31 | 1.02 | 4.50 | 5.52 | 0.00 | 2.12 | 0.00 | 1.12 |
| August | 4.03 | 45.00 | 49.03 | 0.79 | 4.50 | 5.29 | 0.00 | 2.45 | 0.00 | 1.50 |
| September | 3.38 | 45.00 | 48.38 | 0.06 | 4.50 | 4.56 | 0.00 | 1.64 | 0.00 | 0.46 |
| October | 2.00 | 45.00 | 47.00 | -0.39 | 4.50 | 4.11 | 0.00 | 2.13 | 0.00 | 0.00 |
| November | 0.49 | 45.00 | 45.49 | -0.86 | 4.50 | 3.64 | 0.00 | 2.12 | -0.39 | 0.00 |
| December | -0.29 | 45.00 | 44.71 | -1.55 | 4.50 | 2.95 | 0.00 | 3.33 | -1.18 | 0.00 |

**OVERALL ENERGY REQUIREMENTS AND PRODUCTION**

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 1.38 | 4.02 | 8.84 | 14.24 |
| February | 0.29 | 4.13 | 0.22 | 0.82 | 3.63 | 7.98 | 16.56 |
| March | 0.29 | 4.82 | 0.22 | 0.60 | 4.02 | 8.84 | 18.28 |
| April | 0.29 | 4.86 | 0.22 | 0.00 | 3.89 | 8.55 | 17.30 |
| May | 0.29 | 5.29 | 0.22 | 0.00 | 4.02 | 8.84 | 18.14 |
| June | 0.29 | 5.30 | 0.22 | 0.00 | 3.89 | 8.55 | 17.74 |
| July | 0.29 | 8.16 | 0.22 | 0.00 | 4.02 | 8.84 | 21.02 |
| August | 0.29 | 8.42 | 0.22 | 0.00 | 4.02 | 8.84 | 21.28 |
| September | 0.29 | 6.31 | 0.22 | 0.00 | 3.89 | 8.55 | 18.75 |
| October | 0.29 | 4.88 | 0.22 | 0.00 | 4.02 | 8.84 | 17.73 |
| November | 0.29 | 4.47 | 0.22 | 0.61 | 3.89 | 8.55 | 17.52 |
| December | 0.00 | 0.00 | 0.22 | 1.19 | 4.02 | 8.84 | 14.05 |
| TOTAL/m2 | | 56.63 | | 4.61 | 47.35 | 104.03 | 212.62 |

BUILDING ENERGY BALANCE CALCULATIONS

## REF. DESIGN FLAT INSULATED NON-PV ROOF

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Miami | Longitude | 25.80 N | | | | |
| | | Latitude | 80.27 W | Direct Radiation Factor | 0.50 | | |
| Climate | Sub-tropical | Altitude | 2.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 24.30 | 14.40 | 150.00 | 65.00 | 239.00 | 11.51 | 20.77 | 10.23 | 59 | 84 |
| February | 25.00 | 14.90 | 195.00 | 80.00 | 233.00 | 11.72 | 19.88 | 8.12 | 56 | 84 |
| March | 26.60 | 16.20 | 235.00 | 95.00 | 269.00 | 12.22 | 22.01 | 8.99 | 56 | 82 |
| April | 28.10 | 18.80 | 275.00 | 115.00 | 283.00 | 13.10 | 21.60 | 8.40 | 56 | 79 |
| May | 29.70 | 20.90 | 295.00 | 125.00 | 276.00 | 13.49 | 20.46 | 10.54 | 59 | 78 |
| June | 31.10 | 23.10 | 295.00 | 125.00 | 255.00 | 13.93 | 18.30 | 11.70 | 64 | 81 |
| July | 31.60 | 23.70 | 295.00 | 125.00 | 270.00 | 13.82 | 19.53 | 11.47 | 64 | 81 |
| August | 32.10 | 23.80 | 275.00 | 115.00 | 261.00 | 13.16 | 19.84 | 11.16 | 63 | 83 |
| September | 31.10 | 23.70 | 235.00 | 95.00 | 212.00 | 11.98 | 17.70 | 12.30 | 66 | 85 |
| October | 29.30 | 21.60 | 195.00 | 80.00 | 200.00 | 11.73 | 17.05 | 13.95 | 64 | 85 |
| November | 26.80 | 18.10 | 150.00 | 65.00 | 224.00 | 11.31 | 19.80 | 10.20 | 60 | 84 |
| December | 26.10 | 15.10 | 135.00 | 55.00 | 221.00 | 11.14 | 19.84 | 11.16 | 60 | 85 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.00 |
| Thermal Transmittance W/m2oC | | 0.20 |
| PV slope (°) | | 0.00 |

### INTERNAL TEMPERATURES

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 21.83 | 17.58 | 305.55 | 32.89 | 135.57 | 14.59 | 20.77 | 10.23 | 49.08 | 47.57 |
| February | 22.48 | 18.15 | 379.85 | 46.68 | 163.82 | 20.13 | 19.88 | 8.12 | 49.32 | 49.23 |
| March | 24.00 | 19.54 | 435.95 | 69.18 | 186.55 | 29.60 | 22.01 | 8.99 | 53.21 | 52.64 |
| April | 25.78 | 21.79 | 483.60 | 107.15 | 210.66 | 46.67 | 21.60 | 8.40 | 57.88 | 58.21 |
| May | 27.50 | 23.73 | 507.05 | 126.39 | 222.39 | 55.43 | 20.46 | 10.54 | 64.43 | 63.82 |
| June | 29.10 | 25.67 | 490.87 | 137.95 | 215.29 | 60.50 | 18.30 | 11.70 | 72.43 | 71.86 |
| July | 29.63 | 26.24 | 494.76 | 135.17 | 217.00 | 59.29 | 19.53 | 11.47 | 74.06 | 73.80 |
| August | 30.03 | 26.47 | 481.63 | 108.55 | 209.80 | 47.28 | 19.84 | 11.16 | 74.60 | 75.78 |
| September | 29.25 | 26.08 | 444.84 | 62.83 | 190.36 | 26.89 | 17.70 | 12.30 | 74.26 | 75.58 |
| October | 27.38 | 24.08 | 379.53 | 46.91 | 163.68 | 20.23 | 17.05 | 13.95 | 67.19 | 68.60 |
| November | 24.63 | 20.90 | 310.79 | 29.15 | 137.89 | 12.93 | 19.80 | 10.20 | 57.00 | 57.67 |
| December | 23.35 | 18.64 | 275.78 | 22.44 | 118.50 | 9.64 | 19.84 | 11.16 | 53.56 | 51.08 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | 2.73 | 45.00 | 47.73 | -0.21 | 4.50 | 4.29 | 0.00 | 11.16 | 0.00 | 0.66 |
| February | 3.49 | 45.00 | 48.49 | 0.02 | 4.50 | 4.52 | 0.00 | 10.90 | 0.00 | 0.72 |
| March | 4.26 | 45.00 | 49.26 | 0.19 | 4.50 | 4.69 | 0.00 | 12.29 | 0.00 | 2.45 |
| April | 5.02 | 45.00 | 50.02 | 0.56 | 4.50 | 5.06 | 0.00 | 12.33 | 0.00 | 4.34 |
| May | 5.56 | 45.00 | 50.56 | 0.94 | 4.50 | 5.44 | 0.00 | 11.90 | 0.00 | 6.68 |
| June | 5.74 | 45.00 | 50.74 | 1.09 | 4.50 | 5.59 | 0.00 | 10.72 | 0.00 | 8.78 |
| July | 5.88 | 45.00 | 50.88 | 1.18 | 4.50 | 5.68 | 0.00 | 11.49 | 0.00 | 9.99 |
| August | 5.85 | 45.00 | 50.85 | 1.01 | 4.50 | 5.51 | 0.00 | 11.62 | 0.00 | 10.35 |
| September | 5.39 | 45.00 | 50.39 | 0.54 | 4.50 | 5.04 | 0.00 | 10.17 | 0.00 | 9.12 |
| October | 4.46 | 45.00 | 49.46 | 0.34 | 4.50 | 4.84 | 0.00 | 9.59 | 0.00 | 6.47 |
| November | 3.34 | 45.00 | 48.34 | 0.02 | 4.50 | 4.52 | 0.00 | 10.82 | 0.00 | 3.64 |
| December | 2.79 | 45.00 | 47.79 | -0.08 | 4.50 | 4.42 | 0.00 | 10.71 | 0.00 | 2.34 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | 1.30 | 45.00 | 46.30 | -0.06 | 4.50 | 4.44 | 0.00 | 5.37 | 0.00 | 0.33 |
| February | 1.67 | 45.00 | 46.67 | -0.07 | 4.50 | 4.43 | 0.00 | 4.29 | 0.00 | 0.30 |
| March | 2.17 | 45.00 | 47.17 | 0.06 | 4.50 | 4.56 | 0.00 | 4.81 | 0.00 | 1.00 |
| April | 2.72 | 45.00 | 47.72 | 0.22 | 4.50 | 4.72 | 0.00 | 4.56 | 0.00 | 1.69 |
| May | 3.17 | 45.00 | 48.17 | 0.34 | 4.50 | 4.84 | 0.00 | 5.79 | 0.00 | 3.44 |
| June | 3.43 | 45.00 | 48.43 | 0.44 | 4.50 | 4.94 | 0.00 | 6.48 | 0.00 | 5.62 |
| July | 3.55 | 45.00 | 48.55 | 0.55 | 4.50 | 5.05 | 0.00 | 6.38 | 0.00 | 5.86 |
| August | 3.57 | 45.00 | 48.57 | 0.49 | 4.50 | 4.99 | 0.00 | 6.20 | 0.00 | 5.82 |
| September | 3.25 | 45.00 | 48.25 | 0.24 | 4.50 | 4.74 | 0.00 | 6.75 | 0.00 | 6.34 |
| October | 2.65 | 45.00 | 47.65 | 0.12 | 4.50 | 4.62 | 0.00 | 7.55 | 0.00 | 5.29 |
| November | 1.88 | 45.00 | 46.88 | -0.01 | 4.50 | 4.49 | 0.00 | 5.42 | 0.00 | 1.87 |
| December | 1.47 | 45.00 | 46.47 | -0.06 | 4.50 | 4.44 | 0.00 | 5.88 | 0.00 | 1.31 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.29 | 5.01 | 0.22 | 0.00 | 3.86 | 8.84 | 17.71 |
| February | 0.29 | 4.63 | 0.22 | 0.00 | 3.49 | 7.98 | 16.10 |
| March | 0.29 | 5.87 | 0.22 | 0.00 | 3.86 | 8.84 | 18.57 |
| April | 0.29 | 6.55 | 0.22 | 0.00 | 3.74 | 8.55 | 18.84 |
| May | 0.29 | 7.95 | 0.22 | 0.00 | 3.86 | 8.84 | 20.65 |
| June | 0.29 | 9.03 | 0.22 | 0.00 | 3.74 | 8.55 | 21.32 |
| July | 0.29 | 9.63 | 0.22 | 0.00 | 3.86 | 8.84 | 22.33 |
| August | 0.29 | 9.71 | 0.22 | 0.00 | 3.86 | 8.84 | 22.41 |
| September | 0.29 | 9.25 | 0.22 | 0.00 | 3.74 | 8.55 | 21.54 |
| October | 0.29 | 8.26 | 0.22 | 0.00 | 3.86 | 8.84 | 20.96 |
| November | 0.29 | 6.22 | 0.22 | 0.00 | 3.74 | 8.55 | 18.51 |
| December | 0.29 | 5.78 | 0.22 | 0.00 | 3.86 | 8.84 | 18.48 |
| TOTAL/m2 | | 87.88 | | 0.00 | 45.51 | 104.03 | 237.41 |

BUILDING ENERGY BALANCE CALCULATIONS

## REF. DESIGN FLAT INSULATED NON-PV ROOF

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Chicago | Longitude | 41.78 N | | | | |
| | | Latitude | 87.75 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate continental | Altitude | 186.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 0.60 | -7.20 | 85.00 | 40.00 | 125.00 | 10.00 | 12.50 | 18.50 | 70 | 80 |
| February | 1.50 | -6.30 | 130.00 | 55.00 | 141.00 | 10.49 | 13.44 | 14.56 | 67 | 79 |
| March | 6.40 | -1.70 | 190.00 | 75.00 | 206.00 | 12.78 | 16.12 | 14.88 | 61 | 77 |
| April | 14.10 | 4.70 | 250.00 | 100.00 | 206.00 | 12.48 | 16.50 | 13.50 | 56 | 74 |
| May | 20.60 | 10.50 | 290.00 | 120.00 | 275.00 | 14.54 | 18.91 | 12.09 | 55 | 75 |
| June | 26.40 | 15.40 | 305.00 | 125.00 | 307.00 | 15.51 | 19.80 | 10.20 | 56 | 77 |
| July | 28.90 | 19.50 | 290.00 | 120.00 | 310.00 | 13.89 | 22.32 | 8.68 | 53 | 77 |
| August | 28.00 | 18.80 | 250.00 | 100.00 | 285.00 | 13.13 | 21.70 | 9.30 | 56 | 81 |
| September | 23.80 | 14.10 | 190.00 | 75.00 | 246.00 | 12.42 | 19.80 | 10.20 | 53 | 81 |
| October | 17.40 | 8.20 | 130.00 | 55.00 | 214.00 | 11.13 | 19.22 | 11.78 | 54 | 79 |
| November | 8.40 | 0.30 | 85.00 | 40.00 | 135.00 | 10.00 | 13.50 | 16.50 | 62 | 78 |
| December | 2.10 | -5.30 | 70.00 | 35.00 | 115.00 | 10.00 | 11.50 | 19.50 | 69 | 80 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | |
|---|---|---|
| Conversion Efficiency | % | 10.00 |
| Direct Transmittance | % | 0.00 |
| Thermal Transmittance | W/m2oC | 0.20 |
| PV slope | (°) | 0.00 |

### INTERNAL TEMPERATURES

| | | |
|---|---|---|
| Occupied Period Set Point | oC | 21.00 |
| Unoccupied Period Offset | oC | 5.00 |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | -1.35 | -4.69 | 207.60 | 0.00 | 96.00 | 0.00 | 12.50 | 18.50 | 3.63 | -0.55 |
| February | -0.45 | -3.79 | 287.10 | 10.07 | 125.82 | 4.41 | 13.44 | 14.56 | 4.78 | 0.64 |
| March | 4.38 | 0.90 | 333.36 | 66.17 | 140.85 | 27.96 | 16.12 | 14.88 | 12.07 | 7.80 |
| April | 11.75 | 7.72 | 451.75 | 80.18 | 192.23 | 34.12 | 16.50 | 13.50 | 25.03 | 20.36 |
| May | 18.08 | 13.75 | 457.14 | 148.33 | 198.04 | 64.26 | 18.91 | 12.09 | 38.34 | 34.37 |
| June | 23.65 | 18.94 | 448.89 | 176.51 | 193.49 | 76.08 | 19.80 | 10.20 | 52.31 | 48.88 |
| July | 26.55 | 22.52 | 478.66 | 132.96 | 207.36 | 57.60 | 22.32 | 8.68 | 58.17 | 59.53 |
| August | 25.70 | 21.76 | 429.43 | 96.12 | 182.74 | 40.90 | 21.70 | 9.30 | 57.68 | 59.03 |
| September | 21.38 | 17.22 | 342.88 | 59.37 | 144.88 | 25.09 | 19.80 | 10.20 | 45.23 | 45.46 |
| October | 15.10 | 11.16 | 270.52 | 21.92 | 118.55 | 9.60 | 19.22 | 11.78 | 31.44 | 29.05 |
| November | 6.38 | 2.90 | 207.60 | 0.00 | 96.00 | 0.00 | 13.50 | 16.50 | 15.78 | 11.43 |
| December | 0.25 | -2.92 | 176.40 | 0.00 | 84.00 | 0.00 | 11.50 | 19.50 | 6.03 | 1.95 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -2.73 | 45.00 | 42.27 | -4.14 | 4.50 | 0.36 | 0.00 | 5.35 | -7.87 | 0.00 |
| February | -1.88 | 45.00 | 43.12 | -3.87 | 4.50 | 0.63 | 0.00 | 5.91 | -8.16 | 0.00 |
| March | -0.52 | 45.00 | 44.48 | -2.46 | 4.50 | 2.04 | 0.00 | 7.53 | -7.54 | 0.00 |
| April | 1.94 | 45.00 | 46.94 | -0.98 | 4.50 | 3.52 | 0.00 | 8.56 | -3.61 | 0.00 |
| May | 3.25 | 45.00 | 48.25 | 0.30 | 4.50 | 4.80 | 0.00 | 10.39 | 0.00 | 0.00 |
| June | 4.30 | 45.00 | 49.30 | 0.74 | 4.50 | 5.24 | 0.00 | 11.21 | 0.00 | 1.86 |
| July | 5.13 | 45.00 | 50.13 | 0.75 | 4.50 | 5.25 | 0.00 | 12.83 | 0.00 | 4.61 |
| August | 4.55 | 45.00 | 49.55 | 0.46 | 4.50 | 4.96 | 0.00 | 12.26 | 0.00 | 4.27 |
| September | 2.96 | 45.00 | 47.96 | 0.24 | 4.50 | 4.74 | 0.00 | 10.81 | 0.00 | 0.00 |
| October | 1.09 | 45.00 | 46.09 | -0.78 | 4.50 | 3.72 | 0.00 | 9.86 | -1.84 | 0.00 |
| November | -1.18 | 45.00 | 43.82 | -2.62 | 4.50 | 1.88 | 0.00 | 6.27 | -5.35 | 0.00 |
| December | -2.67 | 45.00 | 42.33 | -3.78 | 4.50 | 0.72 | 0.00 | 4.98 | -6.71 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -3.66 | 45.00 | 41.34 | -4.14 | 4.50 | 0.36 | 0.00 | 7.74 | -11.64 | 0.00 |
| February | -3.23 | 45.00 | 41.77 | -3.92 | 4.50 | 0.58 | 0.00 | 6.20 | -8.84 | 0.00 |
| March | -2.14 | 45.00 | 42.86 | -2.78 | 4.50 | 1.72 | 0.00 | 6.73 | -6.96 | 0.00 |
| April | -0.24 | 45.00 | 44.76 | -1.37 | 4.50 | 3.13 | 0.00 | 6.63 | -2.95 | 0.00 |
| May | 1.08 | 45.00 | 46.08 | 0.09 | 4.50 | 4.59 | 0.00 | 6.35 | 0.00 | 0.00 |
| June | 2.16 | 45.00 | 47.16 | 0.33 | 4.50 | 4.83 | 0.00 | 5.50 | 0.00 | 0.96 |
| July | 2.85 | 45.00 | 47.85 | 0.29 | 4.50 | 4.79 | 0.00 | 4.74 | 0.00 | 1.79 |
| August | 2.47 | 45.00 | 47.47 | 0.16 | 4.50 | 4.66 | 0.00 | 5.02 | 0.00 | 1.83 |
| September | 1.29 | 45.00 | 46.29 | -0.05 | 4.50 | 4.45 | 0.00 | 5.36 | 0.00 | 0.00 |
| October | -0.18 | 45.00 | 44.82 | -0.89 | 4.50 | 3.61 | 0.00 | 5.88 | -1.13 | 0.00 |
| November | -2.12 | 45.00 | 42.88 | -2.62 | 4.50 | 1.88 | 0.00 | 7.51 | -6.54 | 0.00 |
| December | -3.44 | 45.00 | 41.56 | -3.78 | 4.50 | 0.72 | 0.00 | 8.30 | -11.38 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 4.34 | 3.76 | 8.84 | 16.93 |
| February | 0.00 | 0.00 | 0.22 | 3.78 | 3.39 | 7.98 | 15.15 |
| March | 0.00 | 0.00 | 0.22 | 3.22 | 3.76 | 8.84 | 15.81 |
| April | 0.00 | 0.00 | 0.22 | 1.46 | 3.63 | 8.55 | 13.64 |
| May | 0.29 | 4.78 | 0.22 | 0.00 | 3.76 | 8.84 | 17.37 |
| June | 0.29 | 5.58 | 0.22 | 0.00 | 3.63 | 8.55 | 17.76 |
| July | 0.29 | 6.85 | 0.22 | 0.00 | 3.76 | 8.84 | 19.44 |
| August | 0.29 | 6.68 | 0.22 | 0.00 | 3.76 | 8.84 | 19.27 |
| September | 0.29 | 4.62 | 0.22 | 0.00 | 3.63 | 8.55 | 16.80 |
| October | 0.29 | 4.50 | 0.22 | 0.66 | 3.76 | 8.84 | 17.74 |
| November | 0.00 | 0.00 | 0.22 | 2.64 | 3.63 | 8.55 | 14.82 |
| December | 0.00 | 0.00 | 0.22 | 4.02 | 3.76 | 8.84 | 16.61 |
| TOTAL/m2 | | 33.00 | | 20.11 | 44.21 | 104.03 | 201.35 |

BUILDING ENERGY BALANCE CALCULATIONS

## REF. DESIGN FLAT INSULATED NON-PV ROOF

### SITE DATA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| City | Cincinnati | Longitude | 39.15 N | | | | |
| | | Latitude | 84.52 W | Direct Radiation Factor | 0.50 | | |
| Climate | Temperate continental | Altitude | 232.00 m | Diffuse Radiation Factor | 1.10 | | |

### WEATHER DATA

| Month | Typical Daily Temperatures | | Radiation 24hr averages | | Hours of Sunshine | | Equivalent Days | | Average Humidity % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max oC | Min oC | Direct W/m2 | Diffuse W/m2 | Total hours | Max per day | Sunny | Cloudy | Day | Night |
| January | 6.20 | -3.30 | 85.00 | 40.00 | 108.00 | 10.00 | 10.80 | 20.20 | 68 | 83 |
| February | 6.30 | -2.90 | 130.00 | 55.00 | 129.00 | 10.24 | 12.60 | 15.40 | 64 | 81 |
| March | 11.10 | 0.70 | 190.00 | 75.00 | 173.00 | 11.16 | 15.50 | 15.50 | 57 | 79 |
| April | 18.00 | 6.60 | 250.00 | 100.00 | 201.00 | 11.96 | 16.80 | 13.20 | 53 | 76 |
| May | 23.80 | 11.90 | 290.00 | 120.00 | 241.00 | 12.74 | 18.91 | 12.09 | 53 | 78 |
| June | 28.80 | 17.20 | 305.00 | 125.00 | 305.00 | 14.73 | 20.70 | 9.30 | 55 | 80 |
| July | 30.80 | 19.10 | 290.00 | 120.00 | 322.00 | 14.43 | 22.32 | 8.68 | 52 | 82 |
| August | 30.20 | 18.30 | 250.00 | 100.00 | 291.00 | 13.41 | 21.70 | 9.30 | 52 | 86 |
| September | 26.80 | 14.20 | 190.00 | 75.00 | 254.00 | 12.45 | 20.40 | 9.60 | 50 | 86 |
| October | 20.50 | 8.20 | 130.00 | 55.00 | 213.00 | 11.26 | 18.91 | 12.09 | 61 | 85 |
| November | 11.80 | 2.20 | 85.00 | 40.00 | 145.00 | 10.51 | 13.80 | 16.20 | 60 | 81 |
| December | 5.90 | -2.30 | 70.00 | 35.00 | 126.00 | 10.16 | 12.40 | 18.60 | 68 | 82 |

### BUILDING DATA

| | |
|---|---|
| Area of PV panel per m2 of floor | 1.00 |
| Area of North light per m2 of floor | 0.00 |
| Heat Gain from Lights W/m2 | 20.00 |
| Heat Gain from Equipment W/m2 | 5.00 |
| Heat Gain from People W/m2 | 20.00 |
| Occupancy Start Time | 9.00 |
| Occupancy Finish Time | 19.00 |

### PV PANEL DATA

| | | | |
|---|---|---|---|
| Conversion Efficiency | % | 10.00 | %RH |
| Direct Transmittance | % | 0.00 | Enthalpy |
| Thermal Transmittance W/m2oC | | 0.20 | |
| PV slope (°) | | 0.00 | |

### INTERNAL TEMPERATURES

| | | | |
|---|---|---|---|
| Occupied Period Set Point | oC | 21.00 | %RH |
| Unoccupied Period Offset | oC | 5.00 | Enthalpy |

### HUMIDITY-WINTER

| | |
|---|---|
| %RH | 35 |
| Enthalpy | 36.41 |

### HUMIDITY-SUMMER

| | |
|---|---|
| %RH | 60 |
| Enthalpy | 47.425 |

### CALCULATIONS OF MEAN EXTERNAL CONDITIONS

| Month | Temperature oC | | Sunny Day Radiation W/m2 | | Cloudy Day Radiation W/m2 | | Equivalent Days | | Ext Enthalpy kJ/kg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occupied | Unoccupied | Occupied | Unoccupied | Occupied | Unoccupied | Sunny | Cloudy | Occupied | Unoccupied |
| January | 3.83 | -0.25 | 207.50 | 0.00 | 96.00 | 0.00 | 10.80 | 20.20 | 11.96 | 6.36 |
| February | 4.00 | 0.06 | 294.20 | 5.00 | 128.93 | 2.19 | 12.60 | 15.40 | 11.79 | 6.71 |
| March | 8.50 | 4.04 | 381.58 | 31.66 | 161.27 | 13.38 | 15.50 | 15.50 | 18.91 | 13.69 |
| April | 15.15 | 10.26 | 471.40 | 66.14 | 200.60 | 28.14 | 16.80 | 13.20 | 31.24 | 26.31 |
| May | 20.83 | 15.73 | 521.63 | 102.26 | 225.88 | 44.30 | 18.91 | 12.09 | 43.93 | 40.35 |
| June | 25.90 | 20.93 | 472.37 | 159.74 | 203.61 | 68.85 | 20.70 | 9.30 | 57.64 | 56.01 |
| July | 27.88 | 22.86 | 460.82 | 145.70 | 199.63 | 63.12 | 22.32 | 8.68 | 61.04 | 63.03 |
| August | 27.23 | 22.13 | 420.58 | 102.44 | 178.97 | 43.59 | 21.70 | 9.30 | 59.33 | 62.55 |
| September | 23.65 | 18.25 | 342.14 | 59.90 | 144.57 | 25.31 | 20.40 | 9.60 | 49.24 | 50.29 |
| October | 17.43 | 12.15 | 267.40 | 24.14 | 117.19 | 10.58 | 18.91 | 12.09 | 38.98 | 32.94 |
| November | 9.40 | 5.29 | 197.58 | 7.16 | 91.37 | 3.31 | 13.80 | 16.20 | 21.21 | 16.41 |
| December | 3.85 | 0.34 | 173.50 | 2.00 | 82.67 | 0.85 | 12.40 | 18.60 | 12.00 | 7.27 |

### SUNNY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -1.69 | 45.00 | 43.31 | -3.25 | 4.50 | 1.25 | 0.00 | 4.87 | -5.07 | 0.00 |
| February | -0.93 | 45.00 | 44.07 | -3.15 | 4.50 | 1.35 | 0.00 | 5.79 | -5.96 | 0.00 |
| March | 0.71 | 45.00 | 45.71 | -2.13 | 4.50 | 2.37 | 0.00 | 7.60 | -5.21 | 0.00 |
| April | 2.79 | 45.00 | 47.79 | -0.59 | 4.50 | 3.91 | 0.00 | 8.95 | -1.57 | 0.00 |
| May | 4.35 | 45.00 | 49.35 | 0.30 | 4.50 | 4.80 | 0.00 | 10.60 | 0.00 | 0.00 |
| June | 4.95 | 45.00 | 49.95 | 0.66 | 4.50 | 5.16 | 0.00 | 11.83 | 0.00 | 4.06 |
| July | 5.25 | 45.00 | 50.25 | 0.60 | 4.50 | 5.10 | 0.00 | 12.81 | 0.00 | 5.83 |
| August | 4.78 | 45.00 | 49.78 | 0.42 | 4.50 | 4.92 | 0.00 | 12.30 | 0.00 | 4.96 |
| September | 3.40 | 45.00 | 48.40 | 0.15 | 4.50 | 4.65 | 0.00 | 11.20 | 0.00 | 0.71 |
| October | 1.53 | 45.00 | 46.53 | -0.57 | 4.50 | 3.93 | 0.00 | 9.84 | 0.00 | 0.00 |
| November | -0.66 | 45.00 | 44.34 | -2.08 | 4.50 | 2.42 | 0.00 | 6.59 | -4.03 | 0.00 |
| December | -1.97 | 45.00 | 43.03 | -3.12 | 4.50 | 1.38 | 0.00 | 5.58 | -5.81 | 0.00 |

### CLOUDY DAY HEAT BALANCE

| Month | Occupied Period W/m2 | | | Unoccupied Period W/m2 | | | Monthly Requirement kWh | | Fresh Air Load kWh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PV net gain | Internals | Overall | PV net gain | Internals | Overall | Heating | Cooling | Heating | Cooling |
| January | -2.63 | 45.00 | 42.37 | -3.25 | 4.50 | 1.25 | 0.00 | 8.91 | -9.48 | 0.00 |
| February | -2.32 | 45.00 | 42.68 | -3.17 | 4.50 | 1.33 | 0.00 | 6.86 | -7.28 | 0.00 |
| March | -1.15 | 45.00 | 43.85 | -2.28 | 4.50 | 2.22 | 0.00 | 7.28 | -5.21 | 0.00 |
| April | 0.52 | 45.00 | 45.52 | -0.91 | 4.50 | 3.59 | 0.00 | 6.67 | -1.31 | 0.00 |
| May | 1.86 | 45.00 | 46.86 | -0.18 | 4.50 | 4.32 | 0.00 | 6.40 | 0.00 | 0.00 |
| June | 2.69 | 45.00 | 47.69 | 0.36 | 4.50 | 4.86 | 0.00 | 5.07 | 0.00 | 1.82 |
| July | 3.05 | 45.00 | 48.05 | 0.40 | 4.50 | 4.90 | 0.00 | 4.77 | 0.00 | 2.27 |
| August | 2.75 | 45.00 | 47.75 | 0.26 | 4.50 | 4.76 | 0.00 | 5.06 | 0.00 | 2.13 |
| September | 1.74 | 45.00 | 46.74 | -0.14 | 4.50 | 4.36 | 0.00 | 5.07 | 0.00 | 0.33 |
| October | 0.27 | 45.00 | 45.27 | -0.68 | 4.50 | 3.82 | 0.00 | 6.12 | 0.00 | 0.00 |
| November | -1.55 | 45.00 | 43.45 | -2.12 | 4.50 | 2.38 | 0.00 | 7.58 | -4.73 | 0.00 |
| December | -2.74 | 45.00 | 42.26 | -3.12 | 4.50 | 1.38 | 0.00 | 8.22 | -8.72 | 0.00 |

### OVERALL ENERGY REQUIREMENTS AND PRODUCTION

| Month | Cooling Consumption | | Heating Consumption | | Fans | Lighting and | Total kWh |
|---|---|---|---|---|---|---|---|
| | 1/cop | kWh Electric | 1/cop | kWh Electric | kWh | Power kWh | Consumed |
| January | 0.00 | 0.00 | 0.22 | 3.23 | 3.80 | 8.84 | 15.87 |
| February | 0.00 | 0.00 | 0.22 | 2.94 | 3.44 | 7.98 | 14.36 |
| March | 0.00 | 0.00 | 0.22 | 2.32 | 3.80 | 8.84 | 14.95 |
| April | 0.29 | 4.46 | 0.22 | 0.66 | 3.68 | 8.55 | 17.36 |
| May | 0.29 | 4.86 | 0.22 | 0.00 | 3.80 | 8.84 | 17.50 |
| June | 0.29 | 6.51 | 0.22 | 0.00 | 3.68 | 8.55 | 18.74 |
| July | 0.29 | 7.34 | 0.22 | 0.00 | 3.80 | 8.84 | 19.98 |
| August | 0.29 | 6.98 | 0.22 | 0.00 | 3.80 | 8.84 | 19.62 |
| September | 0.29 | 4.95 | 0.22 | 0.00 | 3.68 | 8.55 | 17.18 |
| October | 0.29 | 4.56 | 0.22 | 0.00 | 3.80 | 8.84 | 17.20 |
| November | 0.00 | 0.00 | 0.22 | 1.95 | 3.68 | 8.55 | 14.18 |
| December | 0.00 | 0.00 | 0.22 | 3.23 | 3.80 | 8.84 | 15.87 |
| TOTAL/m2 | | 39.66 | | 14.33 | 44.79 | 104.03 | 202.81 |

# D PV HOURLY PERFORMANCE & UTILITY RATE ANALYSIS

| UTILITY RATES | OAKLAND | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pacific Gas & Electric | | | | | | | | | | | | |
| Rate A6 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 5-6 | 0.0608 | 0.0608 | 0.0608 | 0.0608 | 0.0789 | 0.0789 | 0.0789 | 0.0789 | 0.0789 | 0.0789 | 0.0608 | 0.0608 |
| 6-7 | 0.0608 | 0.0608 | 0.0608 | 0.0608 | 0.0789 | 0.0789 | 0.0789 | 0.0789 | 0.0789 | 0.0789 | 0.0608 | 0.0608 |
| 7-8 | 0.0608 | 0.0608 | 0.0608 | 0.0608 | 0.0789 | 0.0789 | 0.0789 | 0.0789 | 0.0789 | 0.0789 | 0.0608 | 0.0608 |
| 8-9 | 0.0809 | 0.0809 | 0.0809 | 0.0809 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.0809 | 0.0809 |
| 9-10 | 0.0809 | 0.0809 | 0.0809 | 0.0809 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.0809 | 0.0809 |
| 10-11 | 0.0809 | 0.0809 | 0.0809 | 0.0809 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.0809 | 0.0809 |
| 11-12 | 0.0809 | 0.0809 | 0.0809 | 0.0809 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.0809 | 0.0809 |
| 12-13 | 0.0809 | 0.0809 | 0.0809 | 0.0809 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.0809 | 0.0809 |
| 13-14 | 0.0809 | 0.0809 | 0.0809 | 0.0809 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.0809 | 0.0809 |
| 14-15 | 0.0809 | 0.0809 | 0.0809 | 0.0809 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.0809 | 0.0809 |
| 15-16 | 0.0809 | 0.0809 | 0.0809 | 0.0809 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.0809 | 0.0809 |
| 16-17 | 0.0809 | 0.0809 | 0.0809 | 0.0809 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.0809 | 0.0809 |
| 17-18 | 0.0809 | 0.0809 | 0.0809 | 0.0809 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.3029 | 0.0809 | 0.0809 |
| 18-19 | 0.0809 | 0.0809 | 0.0809 | 0.0809 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.1516 | 0.0809 | 0.0809 |
| | | | | | | | | | | | | |
| PV OUTPUT (Option 1, PV1) | | | | | | | | | | | | |
| PER HOUR | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| Oak/15°/45°az | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 5-6 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1034 | 0.1396 | 0.1233 | 0.0376 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 6-7 | 0.0000 | 0.0000 | 0.0861 | 0.1974 | 0.3254 | 0.3722 | 0.3521 | 0.2442 | 0.1238 | 0.0000 | 0.0000 | 0.0000 |
| 7-8 | 0.0675 | 0.1616 | 0.3813 | 0.6092 | 0.8528 | 0.9171 | 0.9047 | 0.7096 | 0.4542 | 0.2271 | 0.0899 | 0.0421 |
| 8-9 | 0.3702 | 0.5462 | 0.9620 | 1.2720 | 1.5388 | 1.5679 | 1.5945 | 1.3964 | 1.0706 | 0.7239 | 0.4211 | 0.3208 |
| 9-10 | 0.8188 | 1.0422 | 1.5841 | 1.9220 | 2.1583 | 2.1555 | 2.2165 | 2.0410 | 1.7135 | 1.3365 | 0.9024 | 0.7493 |
| 10-11 | 1.2338 | 1.4677 | 2.0936 | 2.4264 | 2.6425 | 2.6110 | 2.7007 | 2.5434 | 2.2307 | 1.8457 | 1.3397 | 1.1541 |
| 11-12 | 1.5031 | 1.7364 | 2.4118 | 2.7408 | 2.9397 | 2.8890 | 2.9972 | 2.8544 | 2.5517 | 2.1677 | 1.6248 | 1.4141 |
| 12-13 | 1.5753 | 1.8122 | 2.5007 | 2.8301 | 3.0243 | 2.9698 | 3.0831 | 2.9425 | 2.6418 | 2.2580 | 1.7003 | 1.4898 |
| 13-14 | 1.4423 | 1.6810 | 2.3510 | 2.6874 | 2.8902 | 2.8455 | 2.9511 | 2.8018 | 2.4955 | 2.1072 | 1.5648 | 1.3577 |
| 14-15 | 1.1272 | 1.3693 | 1.9871 | 2.3341 | 2.5563 | 2.5342 | 2.6201 | 2.4525 | 2.1341 | 1.7396 | 1.2422 | 1.0477 |
| 15-16 | 0.6993 | 0.9314 | 1.4654 | 1.8138 | 2.0618 | 2.0707 | 2.1281 | 1.9382 | 1.6095 | 1.2180 | 0.7979 | 0.6289 |
| 16-17 | 0.2483 | 0.4483 | 0.8618 | 1.1937 | 1.4599 | 1.5049 | 1.5276 | 1.3157 | 0.9962 | 0.6303 | 0.3185 | 0.1960 |
| 17-18 | 0.0000 | 0.0000 | 0.2764 | 0.5629 | 0.8149 | 0.8858 | 0.8765 | 0.6692 | 0.3841 | 0.0000 | 0.0000 | 0.0000 |
| 18-19 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2416 | 0.3167 | 0.2872 | 0.1234 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 9.0858 | 11.1963 | 16.9613 | 20.5898 | 23.6099 | 23.7799 | 24.3627 | 22.0699 | 18.4057 | 14.2540 | 10.0016 | 8.4005 |
| | | | | | | | | | | | | |
| Peak kW | 0.0508 | 0.0647 | 0.0807 | 0.0943 | 0.0976 | 0.0990 | 0.0995 | 0.0949 | 0.0881 | 0.0728 | 0.0567 | 0.0481 |
| demand credit @ | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 |
| 0% | | | | | | | | | | | | |
| Total energy charges/yr | $35.3447 | | | | | | | | | | | |
| Total demand charges/yr | $0.0000 | | | | | | | | | | | |
| Total kWh/m2/yr | 202.72 | | | | | | | | | | | |
| Av. $/kWh | $0.1744 | | | | | | | | | | | |
| | | | | | | | | | | | | |

| UTILITY RATES | NEW YORK 1 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LILCO | | | | | | | | | | | | |
| Rates SC 2-MRP Rate 1 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 5-6 | 0.1003 | 0.1003 | 0.1003 | 0.1003 | 0.1003 | 0.1038 | 0.1038 | 0.1038 | 0.1038 | 0.1003 | 0.1003 | 0.1003 |
| 6-7 | 0.1003 | 0.1003 | 0.1003 | 0.1003 | 0.1003 | 0.1038 | 0.1038 | 0.1038 | 0.1038 | 0.1003 | 0.1003 | 0.1003 |
| 7-8 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1230 | 0.1230 | 0.1230 | 0.1230 | 0.1195 | 0.1195 | 0.1195 |
| 8-9 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1230 | 0.1230 | 0.1230 | 0.1230 | 0.1195 | 0.1195 | 0.1195 |
| 9-10 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1230 | 0.1230 | 0.1230 | 0.1230 | 0.1195 | 0.1195 | 0.1195 |
| 10-11 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1375 | 0.1375 | 0.1375 | 0.1375 | 0.1195 | 0.1195 | 0.1195 |
| 11-12 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1375 | 0.1375 | 0.1375 | 0.1375 | 0.1195 | 0.1195 | 0.1195 |
| 12-13 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1375 | 0.1375 | 0.1375 | 0.1375 | 0.1195 | 0.1195 | 0.1195 |
| 13-14 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1375 | 0.1375 | 0.1375 | 0.1375 | 0.1195 | 0.1195 | 0.1195 |
| 14-15 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1375 | 0.1375 | 0.1375 | 0.1375 | 0.1195 | 0.1195 | 0.1195 |
| 15-16 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1375 | 0.1375 | 0.1375 | 0.1375 | 0.1195 | 0.1195 | 0.1195 |
| 16-17 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1375 | 0.1375 | 0.1375 | 0.1375 | 0.1195 | 0.1195 | 0.1195 |
| 17-18 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1375 | 0.1375 | 0.1375 | 0.1375 | 0.1195 | 0.1195 | 0.1195 |
| 18-19 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1195 | 0.1375 | 0.1375 | 0.1375 | 0.1375 | 0.1195 | 0.1195 | 0.1195 |
| | | | | | | | | | | | | |
| PV OUTPUT (Option 1, PV1) | | | | | | | | | | | | |
| PER HOUR | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| NY/15°/45°az | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 5-6 | 0.0000 | 0.0000 | 0.0000 | 0.0044 | 0.1157 | 0.1508 | 0.1333 | 0.0475 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 6-7 | 0.0000 | 0.0000 | 0.0766 | 0.1940 | 0.3220 | 0.3593 | 0.3396 | 0.2361 | 0.1143 | 0.0000 | 0.0000 | 0.0000 |
| 7-8 | 0.0371 | 0.1304 | 0.3201 | 0.5042 | 0.7075 | 0.7385 | 0.7235 | 0.5718 | 0.3712 | 0.1859 | 0.0582 | 0.0109 |
| 8-9 | 0.2692 | 0.4135 | 0.7349 | 0.9543 | 1.1785 | 1.1662 | 1.1739 | 1.0269 | 0.7913 | 0.5481 | 0.2863 | 0.2071 |
| 9-10 | 0.6050 | 0.7764 | 1.1775 | 1.3961 | 1.6059 | 1.5543 | 1.5818 | 1.4562 | 1.2283 | 0.9983 | 0.6027 | 0.4854 |
| 10-11 | 0.9200 | 1.0946 | 1.5433 | 1.7426 | 1.9396 | 1.8545 | 1.8983 | 1.7903 | 1.5822 | 1.3826 | 0.8950 | 0.7499 |
| 11-12 | 1.1238 | 1.2971 | 1.7709 | 1.9551 | 2.1421 | 2.0353 | 2.0896 | 1.9945 | 1.8003 | 1.6246 | 1.0818 | 0.9243 |
| 12-13 | 1.1787 | 1.3479 | 1.8282 | 2.0089 | 2.1938 | 2.0816 | 2.1384 | 2.0462 | 1.8565 | 1.6904 | 1.1295 | 0.9665 |
| 13-14 | 1.0666 | 1.2407 | 1.7088 | 1.8993 | 2.0914 | 1.9897 | 2.0417 | 1.9419 | 1.7455 | 1.5676 | 1.0271 | 0.8669 |
| 14-15 | 0.8145 | 0.9973 | 1.4336 | 1.6424 | 1.8482 | 1.7717 | 1.8118 | 1.6956 | 1.4835 | 1.2802 | 0.7934 | 0.6491 |
| 15-16 | 0.4767 | 0.6588 | 1.0438 | 1.2712 | 1.4929 | 1.4517 | 1.4749 | 1.3380 | 1.1097 | 0.8780 | 0.4814 | 0.3589 |
| 16-17 | 0.1333 | 0.2947 | 0.5991 | 0.8350 | 1.0656 | 1.0652 | 1.0688 | 0.9114 | 0.6789 | 0.4340 | 0.1581 | 0.0712 |
| 17-18 | 0.0000 | 0.0000 | 0.1803 | 0.3973 | 0.6125 | 0.6485 | 0.6330 | 0.4733 | 0.2562 | 0.0000 | 0.0000 | 0.0000 |
| 18-19 | 0.0000 | 0.0000 | 0.0000 | 0.0371 | 0.2060 | 0.2618 | 0.2350 | 0.1002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| $0.1304 | 6.6249 | 8.2514 | 12.4171 | 14.8419 | 17.5217 | 17.1291 | 17.3436 | 15.6299 | 13.0179 | 10.5897 | 6.5135 | 5.2902 |
| | | | | | | | | | | | | |
| Peak kW | 0.0380 | 0.0481 | 0.0590 | 0.0670 | 0.0708 | 0.0694 | 0.0690 | 0.0660 | 0.0619 | 0.0545 | 0.0377 | 0.0312 |
| demand credit @ | $0.0390 | $0.0494 | $0.0605 | $0.0687 | $0.0726 | $0.0712 | $0.0708 | $0.0677 | $0.0635 | $0.0559 | $0.0386 | $0.0320 |
| 20% | | | | | | | | | | | | |
| Total energy charges/yr | $18.2465 | | | | | | | | | | | |
| Total demand charges/yr | $0.6900 | | | | | | | | | | | |
| Total kWh/m2/yr | 145.17 | | | | | | | | | | | |
| Av. $/kWh | $0.1304 | | | | | | | | | | | |
| | | | | | | | | | | | | |

| UTILITY RATES | NEW YORK 2 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LILCO | | | | | | | | | | | | |
| Rate SC 2-VMRP, Rate 2 (≤7kW) | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 5-6 | 0.1432 | 0.1432 | 0.1432 | 0.1432 | 0.1432 | 0.1484 | 0.1484 | 0.1484 | 0.1484 | 0.1432 | 0.1432 | 0.1432 |
| 6-7 | 0.1432 | 0.1432 | 0.1432 | 0.1432 | 0.1432 | 0.1484 | 0.1484 | 0.1484 | 0.1484 | 0.1432 | 0.1432 | 0.1432 |
| 7-8 | 0.1432 | 0.1432 | 0.1432 | 0.1432 | 0.1432 | 0.1484 | 0.1484 | 0.1484 | 0.1484 | 0.1432 | 0.1432 | 0.1432 |
| 8-9 | 0.1432 | 0.1432 | 0.1432 | 0.1432 | 0.1432 | 0.1484 | 0.1484 | 0.1484 | 0.1484 | 0.1432 | 0.1432 | 0.1432 |
| 9-10 | 0.1432 | 0.1432 | 0.1432 | 0.1432 | 0.1432 | 0.1484 | 0.1484 | 0.1484 | 0.1484 | 0.1432 | 0.1432 | 0.1432 |
| 10-11 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.4368 | 0.4368 | 0.4368 | 0.4368 | 0.2035 | 0.2035 | 0.2035 |
| 11-12 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.4368 | 0.4368 | 0.4368 | 0.4368 | 0.2035 | 0.2035 | 0.2035 |
| 12-13 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.4368 | 0.4368 | 0.4368 | 0.4368 | 0.2035 | 0.2035 | 0.2035 |
| 13-14 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.4368 | 0.4368 | 0.4368 | 0.4368 | 0.2035 | 0.2035 | 0.2035 |
| 14-15 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.4368 | 0.4368 | 0.4368 | 0.4368 | 0.2035 | 0.2035 | 0.2035 |
| 15-16 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.4368 | 0.4368 | 0.4368 | 0.4368 | 0.2035 | 0.2035 | 0.2035 |
| 16-17 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.4368 | 0.4368 | 0.4368 | 0.4368 | 0.2035 | 0.2035 | 0.2035 |
| 17-18 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.4368 | 0.4368 | 0.4368 | 0.4368 | 0.2035 | 0.2035 | 0.2035 |
| 18-19 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.2035 | 0.4368 | 0.4368 | 0.4368 | 0.4368 | 0.2035 | 0.2035 | 0.2035 |
| | | | | | | | | | | | | |
| PV OUTPUT (Option 1, PV1) | | | | | | | | | | | | |
| PER HOUR | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| NY/15°/45°az | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 5-6 | 0.0000 | 0.0000 | 0.0000 | 0.0044 | 0.1157 | 0.1508 | 0.1333 | 0.0475 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 6-7 | 0.0000 | 0.0000 | 0.0766 | 0.1940 | 0.3220 | 0.3593 | 0.3396 | 0.2361 | 0.1143 | 0.0000 | 0.0000 | 0.0000 |
| 7-8 | 0.0371 | 0.1304 | 0.3201 | 0.5042 | 0.7075 | 0.7385 | 0.7235 | 0.5718 | 0.3712 | 0.1859 | 0.0582 | 0.0109 |
| 8-9 | 0.2692 | 0.4135 | 0.7349 | 0.9543 | 1.1785 | 1.1662 | 1.1739 | 1.0269 | 0.7913 | 0.5481 | 0.2863 | 0.2071 |
| 9-10 | 0.6050 | 0.7764 | 1.1775 | 1.3961 | 1.6059 | 1.5543 | 1.5818 | 1.4562 | 1.2283 | 0.9983 | 0.6027 | 0.4854 |
| 10-11 | 0.9200 | 1.0946 | 1.5433 | 1.7426 | 1.9396 | 1.8545 | 1.8983 | 1.7903 | 1.5822 | 1.3826 | 0.8950 | 0.7499 |
| 11-12 | 1.1238 | 1.2971 | 1.7709 | 1.9551 | 2.1421 | 2.0353 | 2.0896 | 1.9945 | 1.8003 | 1.6246 | 1.0818 | 0.9243 |
| 12-13 | 1.1787 | 1.3479 | 1.8282 | 2.0089 | 2.1938 | 2.0816 | 2.1384 | 2.0462 | 1.8565 | 1.6904 | 1.1295 | 0.9665 |
| 13-14 | 1.0666 | 1.2407 | 1.7088 | 1.8993 | 2.0914 | 1.9897 | 2.0417 | 1.9419 | 1.7455 | 1.5676 | 1.0271 | 0.8669 |
| 14-15 | 0.8145 | 0.9973 | 1.4336 | 1.6424 | 1.8482 | 1.7717 | 1.8118 | 1.6956 | 1.4835 | 1.2802 | 0.7934 | 0.6491 |
| 15-16 | 0.4767 | 0.6588 | 1.0438 | 1.2712 | 1.4929 | 1.4517 | 1.4749 | 1.3380 | 1.1097 | 0.8780 | 0.4814 | 0.3589 |
| 16-17 | 0.1333 | 0.2947 | 0.5991 | 0.8350 | 1.0656 | 1.0652 | 1.0688 | 0.9114 | 0.6789 | 0.4340 | 0.1581 | 0.0712 |
| 17-18 | 0.0000 | 0.0000 | 0.1803 | 0.3973 | 0.6125 | 0.6485 | 0.6330 | 0.4733 | 0.2562 | 0.0000 | 0.0000 | 0.0000 |
| 18-19 | 0.0000 | 0.0000 | 0.0000 | 0.0371 | 0.2060 | 0.2618 | 0.2350 | 0.1002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 6.6249 | 8.2514 | 12.4171 | 14.8419 | 17.5217 | 17.1291 | 17.3436 | 15.6299 | 13.0179 | 10.5897 | 6.5135 | 5.2902 |
| | | | | | | | | | | | | |
| Peak kW | 0.0380 | 0.0481 | 0.0590 | 0.0670 | 0.0708 | 0.0694 | 0.0690 | 0.0660 | 0.0619 | 0.0545 | 0.0377 | 0.0312 |
| demand credit @ | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 | $0.0000 |
| 0% | | | | | | | | | | | | |
| Total energy charges/yr | $39.3964 | | | | | | | | | | | |
| Total demand charges/yr | $0.0000 | | | | | | | | | | | |
| Total kWh/m2/yr | 145.17 | | | | | | | | | | | |
| Av. $/kWh | $0.2714 | | | | | | | | | | | |
| | | | | | | | | | | | | |

| UTILITY RATES | PHOENIX | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arizona Public Service Company | | | | | | | | | | | | |
| Rate E-32 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 5-6 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 |
| 6-7 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 |
| 7-8 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 |
| 8-9 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 |
| 9-10 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 |
| 10-11 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 |
| 11-12 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 |
| 12-13 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 |
| 13-14 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 |
| 14-15 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 |
| 15-16 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 |
| 16-17 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 |
| 17-18 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 |
| 18-19 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 | 0.0878 |
| | | | | | | | | | | | | |
| PV OUTPUT (Option 1, PV1) | | | | | | | | | | | | |
| PER HOUR | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| AZ/15°/45°az | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 5-6 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0735 | 0.1037 | 0.0898 | 0.0170 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 6-7 | 0.0000 | 0.0000 | 0.0938 | 0.1831 | 0.2793 | 0.3123 | 0.2985 | 0.2176 | 0.1210 | 0.0121 | 0.0000 | 0.0000 |
| 7-8 | 0.1132 | 0.2102 | 0.4407 | 0.6531 | 0.8758 | 0.9032 | 0.8407 | 0.6950 | 0.4834 | 0.2770 | 0.1342 | 0.0867 |
| 8-9 | 0.5486 | 0.7396 | 1.1595 | 1.4663 | 1.7135 | 1.6639 | 1.5567 | 1.4319 | 1.1888 | 0.9268 | 0.5999 | 0.4824 |
| 9-10 | 1.1723 | 1.3931 | 1.9254 | 2.2583 | 2.4680 | 2.3466 | 2.1984 | 2.1187 | 1.9171 | 1.6743 | 1.2477 | 1.0696 |
| 10-11 | 1.7279 | 1.9355 | 2.5460 | 2.8754 | 3.0602 | 2.8773 | 2.6969 | 2.6530 | 2.4932 | 2.2977 | 1.8148 | 1.6027 |
| 11-12 | 2.0874 | 2.2820 | 2.9326 | 3.2630 | 3.4267 | 3.2034 | 3.0006 | 2.9827 | 2.8509 | 2.6942 | 2.1788 | 1.9509 |
| 12-13 | 2.1877 | 2.3785 | 3.0418 | 3.3787 | 3.5390 | 3.3031 | 3.0887 | 3.0760 | 2.9542 | 2.8093 | 2.2849 | 2.0451 |
| 13-14 | 2.0203 | 2.2195 | 2.8668 | 3.2129 | 3.3844 | 3.1644 | 2.9514 | 2.9271 | 2.7933 | 2.6315 | 2.1172 | 1.8831 |
| 14-15 | 1.6220 | 1.8303 | 2.4333 | 2.7906 | 2.9868 | 2.8089 | 2.6099 | 2.5573 | 2.3939 | 2.1943 | 1.7139 | 1.4944 |
| 15-16 | 1.0594 | 1.2770 | 1.8064 | 2.1661 | 2.3943 | 2.2771 | 2.1029 | 2.0129 | 1.8100 | 1.5653 | 1.1426 | 0.9576 |
| 16-17 | 0.4525 | 0.6531 | 1.0795 | 1.4162 | 1.6683 | 1.6234 | 1.4821 | 1.3508 | 1.1232 | 0.8436 | 0.5186 | 0.3781 |
| 17-18 | 0.0000 | 0.0000 | 0.3585 | 0.6519 | 0.8922 | 0.9122 | 0.8137 | 0.6638 | 0.4332 | 0.1828 | 0.0000 | 0.0000 |
| 18-19 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2190 | 0.2747 | 0.2236 | 0.0904 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 12.9913 | 14.9188 | 20.6843 | 24.3156 | 26.9810 | 25.7742 | 23.9539 | 22.7942 | 20.5622 | 18.1089 | 13.7526 | 11.9506 |
| | | | | | | | | | | | | |
| Peak kW | 0.0706 | 0.0849 | 0.0981 | 0.1126 | 0.1142 | 0.1101 | 0.0996 | 0.0992 | 0.0985 | 0.0906 | 0.0762 | 0.0660 |
| demand credit @ | $0.0265 | $0.0318 | $0.0368 | $0.0422 | $0.0428 | $0.0455 | $0.0412 | $0.0410 | $0.0407 | $0.0374 | $0.0286 | $0.0247 |
| 20% | | | | | | | | | | | | |
| Total energy charges/yr | $20.7956 | | | | | | | | | | | |
| Total demand charges/yr | $0.4392 | | | | | | | | | | | |
| Total kWh/m2/yr | 236.79 | | | | | | | | | | | |
| Av. $/kWh | $0.0897 | | | | | | | | | | | |
| | | | | | | | | | | | | |

| UTILITY RATES | MIAMI | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Florida Power & Light | | | | | | | | | | | | |
| Rate GSDT-1 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 5-6 | 0.0470 | 0.0470 | 0.0470 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0470 | 0.0470 |
| 6-7 | 0.0747 | 0.0747 | 0.0747 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0747 | 0.0747 |
| 7-8 | 0.0747 | 0.0747 | 0.0747 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0747 | 0.0747 |
| 8-9 | 0.0747 | 0.0747 | 0.0747 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0747 | 0.0747 |
| 9-10 | 0.0747 | 0.0747 | 0.0747 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0747 | 0.0747 |
| 10-11 | 0.0470 | 0.0470 | 0.0470 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0470 | 0.0470 |
| 11-12 | 0.0470 | 0.0470 | 0.0470 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0309 | 0.0470 | 0.0470 |
| 12-13 | 0.0470 | 0.0470 | 0.0470 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0470 | 0.0470 |
| 13-14 | 0.0470 | 0.0470 | 0.0470 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0470 | 0.0470 |
| 14-15 | 0.0470 | 0.0470 | 0.0470 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0470 | 0.0470 |
| 15-16 | 0.0470 | 0.0470 | 0.0470 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0470 | 0.0470 |
| 16-17 | 0.0470 | 0.0470 | 0.0470 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0470 | 0.0470 |
| 17-18 | 0.0470 | 0.0470 | 0.0470 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0470 | 0.0470 |
| 18-19 | 0.0747 | 0.0747 | 0.0747 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0585 | 0.0747 | 0.0747 |
| | | | | | | | | | | | | |
| PV OUTPUT | | | | | | | | | | | | |
| PER HOUR | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| MI/15°/45°az | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 5-6 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0290 | 0.0550 | 0.0429 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 6-7 | 0.0000 | 0.0152 | 0.1027 | 0.1757 | 0.2443 | 0.2559 | 0.2528 | 0.1995 | 0.1215 | 0.0392 | 0.0000 | 0.0000 |
| 7-8 | 0.1924 | 0.2685 | 0.4432 | 0.5585 | 0.6463 | 0.6162 | 0.6356 | 0.5540 | 0.4287 | 0.3197 | 0.2082 | 0.1688 |
| 8-9 | 0.6437 | 0.7549 | 1.0392 | 1.1704 | 1.2108 | 1.0934 | 1.1560 | 1.0692 | 0.9166 | 0.8251 | 0.6624 | 0.6054 |
| 9-10 | 1.1803 | 1.2816 | 1.6522 | 1.7589 | 1.7291 | 1.5268 | 1.6306 | 1.5548 | 1.4047 | 1.3618 | 1.1844 | 1.1407 |
| 10-11 | 1.6240 | 1.7134 | 2.1327 | 2.2159 | 2.1322 | 1.8640 | 2.0003 | 1.9325 | 1.7842 | 1.7968 | 1.6163 | 1.5892 |
| 11-12 | 1.9009 | 1.9786 | 2.4258 | 2.4930 | 2.3740 | 2.0653 | 2.2212 | 2.1587 | 2.0140 | 2.0615 | 1.8847 | 1.8657 |
| 12-13 | 1.9669 | 2.0440 | 2.4978 | 2.5620 | 2.4326 | 2.1117 | 2.2731 | 2.2111 | 2.0662 | 2.1233 | 1.9492 | 1.9350 |
| 13-14 | 1.8180 | 1.9035 | 2.3429 | 2.4172 | 2.3026 | 1.9997 | 2.1519 | 2.0842 | 1.9370 | 1.9787 | 1.8049 | 1.7862 |
| 14-15 | 1.4771 | 1.5787 | 1.9838 | 2.0801 | 2.0025 | 1.7443 | 1.8737 | 1.7967 | 1.6450 | 1.6484 | 1.4752 | 1.4433 |
| 15-16 | 1.0020 | 1.1217 | 1.4686 | 1.5927 | 1.5686 | 1.3761 | 1.4732 | 1.3844 | 1.2276 | 1.1827 | 1.0135 | 0.9675 |
| 16-17 | 0.4769 | 0.5985 | 0.8727 | 1.0138 | 1.0477 | 0.9345 | 0.9922 | 0.8955 | 0.7441 | 0.6509 | 0.4984 | 0.4456 |
| 17-18 | 0.0000 | 0.1173 | 0.2866 | 0.4340 | 0.5136 | 0.4799 | 0.4980 | 0.4042 | 0.2688 | 0.1503 | 0.0000 | 0.0000 |
| 18-19 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0678 | 0.0938 | 0.0816 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 12.2822 | 13.3759 | 17.2482 | 18.4722 | 18.3011 | 16.2166 | 17.2831 | 16.2448 | 14.5584 | 14.1384 | 12.2972 | 11.9474 |
| | | | | | | | | | | | | |
| Peak kW | 0.0634 | 0.0730 | 0.0806 | 0.0854 | 0.0785 | 0.0704 | 0.0733 | 0.0713 | 0.0689 | 0.0685 | 0.0650 | 0.0624 |
| demand credit @ | $0.0883 | $0.1016 | $0.1122 | $0.1189 | $0.1093 | $0.0980 | $0.1021 | $0.0993 | $0.0959 | $0.0954 | $0.0905 | $0.0869 |
| 20% | | | | | | | | | | | | |
| Total energy charges/yr | $19.9043 | | | | | | | | | | | |
| Total demand charges/yr | $1.1983 | | | | | | | | | | | |
| Total kWh/m2/yr | 182.37 | | | | | | | | | | | |
| Av. $/kWh | $0.1157 | | | | | | | | | | | |

| UTILITY RATES | CHICAGO | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Commonwealth Edison | (Includes ECA) | | | | | | | | | | | |
| Rate Sched 6 TOU | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 5-6 | 0.0296 | 0.0296 | 0.0296 | 0.0296 | 0.0296 | 0.0284 | 0.0284 | 0.0284 | 0.0284 | 0.0296 | 0.0296 | 0.0296 |
| 6-7 | 0.0296 | 0.0296 | 0.0296 | 0.0296 | 0.0296 | 0.0284 | 0.0284 | 0.0284 | 0.0284 | 0.0296 | 0.0296 | 0.0296 |
| 7-8 | 0.0296 | 0.0296 | 0.0296 | 0.0296 | 0.0296 | 0.0284 | 0.0284 | 0.0284 | 0.0284 | 0.0296 | 0.0296 | 0.0296 |
| 8-9 | 0.0296 | 0.0296 | 0.0296 | 0.0296 | 0.0296 | 0.0284 | 0.0284 | 0.0284 | 0.0284 | 0.0296 | 0.0296 | 0.0296 |
| 9-10 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0631 | 0.0631 | 0.0631 | 0.0631 | 0.0644 | 0.0644 | 0.0644 |
| 10-11 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0631 | 0.0631 | 0.0631 | 0.0631 | 0.0644 | 0.0644 | 0.0644 |
| 11-12 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0631 | 0.0631 | 0.0631 | 0.0631 | 0.0644 | 0.0644 | 0.0644 |
| 12-13 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0631 | 0.0631 | 0.0631 | 0.0631 | 0.0644 | 0.0644 | 0.0644 |
| 13-14 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0631 | 0.0631 | 0.0631 | 0.0631 | 0.0644 | 0.0644 | 0.0644 |
| 14-15 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0631 | 0.0631 | 0.0631 | 0.0631 | 0.0644 | 0.0644 | 0.0644 |
| 15-16 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0631 | 0.0631 | 0.0631 | 0.0631 | 0.0644 | 0.0644 | 0.0644 |
| 16-17 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0631 | 0.0631 | 0.0631 | 0.0631 | 0.0644 | 0.0644 | 0.0644 |
| 17-18 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0631 | 0.0631 | 0.0631 | 0.0631 | 0.0644 | 0.0644 | 0.0644 |
| 18-19 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0644 | 0.0631 | 0.0631 | 0.0631 | 0.0631 | 0.0644 | 0.0644 | 0.0644 |
| | | | | | | | | | | | | |
| PV OUTPUT (Option 1, PV1) | | | | | | | | | | | | |
| PER HOUR | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| Chl/15°/45°az | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 5-6 | 0.0000 | 0.0000 | 0.0000 | 0.0079 | 0.1244 | 0.1616 | 0.1435 | 0.0538 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 6-7 | 0.0000 | 0.0000 | 0.0773 | 0.1990 | 0.3370 | 0.3874 | 0.3620 | 0.2457 | 0.1173 | 0.0000 | 0.0000 | 0.0000 |
| 7-8 | 0.0291 | 0.1276 | 0.3280 | 0.5280 | 0.7615 | 0.8392 | 0.8098 | 0.6315 | 0.3913 | 0.1840 | 0.0527 | 0.0022 |
| 8-9 | 0.2639 | 0.4271 | 0.7799 | 1.0164 | 1.2835 | 1.3494 | 1.3382 | 1.1713 | 0.8705 | 0.5770 | 0.2933 | 0.1982 |
| 9-10 | 0.6201 | 0.8246 | 1.2665 | 1.4970 | 1.7559 | 1.8117 | 1.8154 | 1.6809 | 1.3729 | 1.0821 | 0.6453 | 0.4842 |
| 10-11 | 0.9574 | 1.1772 | 1.6706 | 1.8751 | 2.1247 | 2.1689 | 2.1856 | 2.0766 | 1.7811 | 1.5177 | 0.9760 | 0.7624 |
| 11-12 | 1.1810 | 1.4041 | 1.9238 | 2.1079 | 2.3500 | 2.3862 | 2.4114 | 2.3208 | 2.0350 | 1.7952 | 1.1879 | 0.9488 |
| 12-13 | 1.2424 | 1.4634 | 1.9905 | 2.1694 | 2.4107 | 2.4464 | 2.4733 | 2.3879 | 2.1053 | 1.8745 | 1.2479 | 0.9947 |
| 13-14 | 1.1255 | 1.3498 | 1.8644 | 2.0550 | 2.3030 | 2.3457 | 2.3681 | 2.2733 | 1.9849 | 1.7426 | 1.1365 | 0.8923 |
| 14-15 | 0.8588 | 1.0868 | 1.5674 | 1.7813 | 2.0413 | 2.0971 | 2.1094 | 1.9931 | 1.6923 | 1.4268 | 0.8784 | 0.6663 |
| 15-16 | 0.4984 | 0.7178 | 1.1442 | 1.3834 | 1.6560 | 1.7281 | 1.7263 | 1.5814 | 1.2715 | 0.9803 | 0.5314 | 0.3634 |
| 16-17 | 0.1338 | 0.3205 | 0.6589 | 0.9138 | 1.1896 | 1.2780 | 1.2609 | 1.0860 | 0.7836 | 0.4860 | 0.1724 | 0.0651 |
| 17-18 | 0.0000 | 0.0000 | 0.2012 | 0.4400 | 0.6914 | 0.7870 | 0.7550 | 0.5715 | 0.3007 | 0.0000 | 0.0000 | 0.0000 |
| 18-19 | 0.0000 | 0.0000 | 0.0000 | 0.0489 | 0.2402 | 0.3241 | 0.2874 | 0.1303 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 6.9104 | 8.8989 | 13.4727 | 16.0231 | 19.2692 | 20.1108 | 20.0463 | 18.2041 | 14.7064 | 11.6662 | 7.1218 | 5.3776 |
| | | | | | | | | | | | | |
| Peak kW | 0.0401 | 0.0523 | 0.0642 | 0.0723 | 0.0778 | 0.0815 | 0.0798 | 0.0770 | 0.0702 | 0.0605 | 0.0416 | 0.0321 |
| demand credit @ | $0.0951 | $0.1241 | $0.1524 | $0.1717 | $0.1846 | $0.2476 | $0.2422 | $0.2338 | $0.2130 | $0.1435 | $0.0987 | $0.0762 |
| 20% | | | | | | | | | | | | |
| Total energy charges/yr | $9.7554 | | | | | | | | | | | |
| Total demand charges/yr | $1.9831 | | | | | | | | | | | |
| Total kWh/m2/yr | 161.81 | | | | | | | | | | | |
| Av. $/kWh | $0.0725 | | | | | | | | | | | |
| | | | | | | | | | | | | |

| UTILITY RATES | CINCINNATI | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cincinnati Gas & Electric | | | | | | | | | | | | |
| Rate Comm. Gen. Service Schedule DS | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 5-6 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0469284 | 0.0469284 | 0.0469284 |
| 6-7 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0469284 | 0.0469284 | 0.0469284 |
| 7-8 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0469284 | 0.0469284 | 0.0469284 |
| 8-9 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0469284 | 0.0469284 | 0.0469284 |
| 9-10 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0469284 | 0.0469284 | 0.0469284 |
| 10-11 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0469284 | 0.0469284 | 0.0469284 |
| 11-12 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0469284 | 0.0469284 | 0.0469284 |
| 12-13 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0469284 | 0.0469284 | 0.0469284 |
| 13-14 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0469284 | 0.0469284 | 0.0469284 |
| 14-15 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0469284 | 0.0469284 | 0.0469284 |
| 15-16 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0469284 | 0.0469284 | 0.0469284 |
| 16-17 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0469284 | 0.0469284 | 0.0469284 |
| 17-18 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0469284 | 0.0469284 | 0.0469284 |
| 18-19 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0469284 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0470654 | 0.0469284 | 0.0469284 | 0.0469284 |
| | | | | | | | | | | | | |
| PV OUTPUT (Option 1, PV1) | | | | | | | | | | | | |
| PER HOUR | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| Cin/15°/45°az | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 5-6 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1063 | 0.1423 | 0.1249 | 0.0414 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 6-7 | 0.0000 | 0.0000 | 0.0788 | 0.1925 | 0.3146 | 0.3556 | 0.3350 | 0.2372 | 0.1176 | 0.0000 | 0.0000 | 0.0000 |
| 7-8 | 0.0512 | 0.1425 | 0.3260 | 0.5098 | 0.7085 | 0.7654 | 0.7403 | 0.6054 | 0.3923 | 0.2055 | 0.0735 | 0.0260 |
| 8-9 | 0.2866 | 0.4337 | 0.7340 | 0.9722 | 1.1958 | 1.2371 | 1.2243 | 1.1174 | 0.8503 | 0.6104 | 0.3255 | 0.2360 |
| 9-10 | 0.6094 | 0.7967 | 1.1658 | 1.4252 | 1.6380 | 1.6644 | 1.6621 | 1.5988 | 1.3251 | 1.1073 | 0.6700 | 0.5261 |
| 10-11 | 0.9077 | 1.1104 | 1.5209 | 1.7785 | 1.9831 | 1.9948 | 2.0019 | 1.9734 | 1.7079 | 1.5263 | 0.9836 | 0.7954 |
| 11-12 | 1.0976 | 1.3079 | 1.7402 | 1.9952 | 2.1923 | 2.1938 | 2.2071 | 2.2025 | 1.9433 | 1.7881 | 1.1857 | 0.9689 |
| 12-13 | 1.1448 | 1.3569 | 1.7940 | 2.0495 | 2.2451 | 2.2458 | 2.2599 | 2.2619 | 2.0039 | 1.8589 | 1.2339 | 1.0112 |
| 13-14 | 1.0367 | 1.2487 | 1.6748 | 1.9366 | 2.1384 | 2.1461 | 2.1564 | 2.1475 | 1.8850 | 1.7277 | 1.1247 | 0.9087 |
| 14-15 | 0.7939 | 1.0051 | 1.4034 | 1.6731 | 1.8861 | 1.9083 | 1.9105 | 1.8752 | 1.6038 | 1.4163 | 0.8769 | 0.6854 |
| 15-16 | 0.4721 | 0.6684 | 1.0211 | 1.2922 | 1.5181 | 1.5588 | 1.5500 | 1.4786 | 1.2012 | 0.9795 | 0.5433 | 0.3895 |
| 16-17 | 0.1420 | 0.3048 | 0.5867 | 0.8451 | 1.0755 | 1.1364 | 1.1150 | 1.0034 | 0.7359 | 0.4936 | 0.1932 | 0.0926 |
| 17-18 | 0.0000 | 0.0000 | 0.1760 | 0.3968 | 0.6077 | 0.6793 | 0.6489 | 0.5141 | 0.2777 | 0.0000 | 0.0000 | 0.0000 |
| 18-19 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1916 | 0.2586 | 0.2267 | 0.0997 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 6.5420 | 8.3751 | 12.2217 | 15.0667 | 17.8011 | 18.2867 | 18.1630 | 17.1565 | 14.0440 | 11.7136 | 7.2103 | 5.6398 |
| | | | | | | | | | | | | |
| Peak kW | 0.0369 | 0.0485 | 0.0579 | 0.0683 | 0.0724 | 0.0749 | 0.0729 | 0.0730 | 0.0668 | 0.0600 | 0.0411 | 0.0326 |
| demand credit @ | $0.0717 | $0.0941 | $0.1124 | $0.1327 | $0.1406 | $0.1454 | $0.1416 | $0.1417 | $0.1297 | $0.1165 | $0.0799 | $0.0633 |
| 20% | | | | | | | | | | | | |
| Total energy charges/yr | $7.1527 | | | | | | | | | | | |
| Total demand charges/yr | $1.3696 | | | | | | | | | | | |
| Total kWh/m2/yr | 152.22 | | | | | | | | | | | |
| Av. $/kWh | $0.0560 | | | | | | | | | | | |
| | | | | | | | | | | | | |

# REPORT DOCUMENTATION PAGE

*Form Approved*
*ORB NO. 0704-0188*



| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | March 1995 | Subcontract Report |

**4. TITLE AND SUBTITLE**

Building Integrated Photovoltaics: A Case Study

**5. FUNDING NUMBERS**

(C) AAE-5-14456-01
(TA) BE 51.2101

**6. AUTHOR(S)**

Gregory Kiss, Jennifer Kinkead, Mahadev Raman

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

Kiss Cathcart Anders Architects, P.C.
150 Nassau St.
New York, NY 10038

**8. PERFORMING ORGANIZATION REPORT NUMBER**

NA

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401-3393

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

NREL/TP-472-7574

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

**12b. DISTRIBUTION CODE**

UC-1600

**13. ABSTRACT** *(Maximum 200 words)*

In 1992, Kiss Cathcart Anders Architects performed a study for NREL on building integrated photovoltaic (BIPV) issues as seen from the perspective of the building community. That study included a broad overview of potential BIPV applications in commercial /institutional buildings. In general, the purpose of the study was to list major issues and potential applications; by its nature it asked more questions than it answered.

The second phase of the studyreported on here–was commissioned by NREL in 1994 to produce quantitative data on the performance of specific BIPV systems. High value-added applications for BIPV are targeted in medium to high-end commercial/institutional buildings. These building types should offer a good initial market for BIPV products. The study did not attempt to identify the best possible application for BIPV. The study reached the following conclusions: (1) Payback periods range from 14.5 years and up. (2) Systems with payback periods of approximately 20 years can be cost effective today. (3) No single PV technology is most cost effective in all cases. (4) No single BIPV roof system is most cost effective in all cases.

**14. SUBJECT TERMS**

Building-integrated photovoltaics, roof-integrated photovoltaics

**15. NUMBER OF PAGES**

136

**16. PRICE CODE**

A07

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| | | | |