RESIDENTIAL USE OF BUILDING INTEGRATED PHOTO VOLTAICS

A Thesis

by

ASWINI KUMAR BALABADHRAPATRUNI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Construction Management

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Approved by:

Chair of Committee,	Iftekharuddin Choudhury
Committee Members,	Sarel Lavy
	Samiran Sinha
Head of Department,	Joe Horlen

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ABSTRACT

Residential Use of Building Integrated Photo Voltaics. (May 2011)

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Chair of Advisory Committee: Dr. Iftekharuddin Choudhury

Building Integrated Photo Voltaics (BIPVs) are devices which are manufactured to replace building components exposed to sufficient sunlight to generate energy. Photo Voltaic Roof tiles are Building Integrated components which can be used instead of traditional roofing materials. The following thesis is focused on comparing traditional, cheaper asphalt roof tiles with Photo Voltaic (PV) roofing tiles in terms of energy cost savings during their respective Net Present Values. The method used for achieving this is computer simulation made possible by software named “Solar Advisory Model” (SAM), developed by National Renewable Energy Laboratories (NREL), to simulate energy output and resultant energy costs saved. The simulations have been run on a prototype example of a model of a dwelling unit’s roof area. The simulations have been repeated for 35 cities all over the U.S.A. for 5 different climatic zones on the same prototype example of the dwelling unit. Similarly, the roof area being laid with an array of PV roof tiles has been estimated for coverage by traditional asphalt roof shingles by using data from the RS Means construction costs data. The estimated costs associated with the asphalt roof area have been adjusted to a different set of 35 locations from the 5 climatic zones by using the location factor from RS Means.

A statistical analysis was done to analyze the data, net present value of roofing materials being the dependent variable versus climatic zones and roofing material as the independent variables. The statistical model also included CDD (Cooling Degree Days) and HDD (Heating Degree Days) as co-variates. The results indicate that NPV (Net Present Value) of BIPV roof is significantly different from that of asphalt roof.

Another statistical analysis was done to determine the effect of climatic zones on energy savings due to the use of BIPV roofing. Energy savings (in US$) was used as a dependent variable, and climatic zone as the independent variable. HDD AND CDD were also included in this model as co-variates. The results of this test indicate that both climatic zone and HDD have an effect on total energy savings.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Choudhury, and my committee members, Dr. Lavy and Dr. Sinha for their guidance and support throughout the course of this research.

Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience. I also want to extend my gratitude to the National Education Foundation, which provided the survey instrument, and to all the Texas elementary teachers and students who were willing to participate in the study.

Finally, thanks to my mother and father for their encouragement.

NOMENCLATURE

BIPV	Building Integrated Photo Voltaics
CDD	Cooling Degree Days
E costs	Energy costs
E savings	Energy savings
HDD	Heating Degree Days
NREL	National Renewable Energy Laboratories
NREL	National Renewable Energy Laboratories
NPV:	Net present value in US$ (Financial function from Microsoft excel)
OMR	Operation, Maintenance and Repair costs
PV	Photo Voltaic
SAM	Solar Advisory Model

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1. INTRODUCTION

This study addresses the importance of BIPV (Building Integrated Photo Voltaic) modules connected to a utility grid in a single family dwelling unit in the United States. PV cells are known to have significant advantages as electric generators in spite of their high initial installation costs (Fanney *et al.*, 2002).

"Solar roof tiles" are designed specifically to function on rooftops. A roof of a single prototype residential dwelling unit has been estimated to be installed with asphalt shingle roofs with the help of a quantity take off and estimation of costs involved in a case study example for 35 locations from 5 climatic zones of USA. The Net Present Value costs involved have been recorded in a data table for comparison with the Net Present Value costs involved with installation of BIPV roof tiles in place of the asphalt shingle roof for 35 different locations from the same 5 climatic zones. The BIPV roof's costs and energy output have been estimated with the help of NREL's simulation software SAM to obtain initial installation and Net Present Value operation costs along with annual energy savings and total energy saving costs

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This thesis follows the style of *International Journal of Construction Education and Research.*

The PV roof tile system hooked up to a residential utility grid has been analyzed through a simulation of the dwelling unit example in different locations. This BIPV-Grid interconnection system allows the excess electricity produced by the PV system to be supplied for utility. The grid acts as the backup when the PV system's output cannot entirely meet the required electricity load, or in the unlikely event the array fails to operate. As the installation of BIPVs on-site has been known to have significant costs associated with it, it is therefore important to determine whether the costs incurred can be returned with some energy savings.

The National Renewable Energy Laboratory (NREL) provides its website users with calculative simulation models for optimized use of BIPVs. One of the models which will be used for simulating the PV module performance is NREL's SAM (Solar Advisory Model). The PV WATTS calculator works by providing monthly and annual performance simulations providing the user with estimated monthly energy production throughout the year in Kilowatts and energy value based on of state average cost per Kilowatt hour. The weather data for the year long sun radiation averages is factored in SAM by choosing a particular weather station in a location to determine the solar radiation incident of the PV grid connected array and PV cell temperature for each hour throughout the year based on the location input. Other software which have been used are AutoCad for drawing a plan of the roof area covered by PV grid on the prototype dwelling unit's roof and Microsoft excel to calculate various costs associated with the BIPV roof and asphalt roof installation and maintenance.

2. OBJECTIVES, HYPOTHESIS AND ASSUMPTIONS

2.1. OBJECTIVES

- To determine the energy savings from the BIPV roof for every year for 25 years of its entire life period.
- To determine the orientation- Direction of BIPV roof tiles on roof. (N, S, E or W).
- To determine the estimate costs for installing the required roof area of the dwelling unit with BIPV roof tiles.
- To determine the estimated costs for installing the same area with asphalt shingles.

2.2. HYPOTHESIS

- Net present value of a BIPV roof is significantly differently than that of an asphalt roof for a single family dwelling unit in USA.
- Energy savings for a single family dwelling unit due to the use of BIPV roof are affected by Heating Degree Days and Cooling Degree Days.

2.3. ASSUMPTIONS

- To determine the effective direction of facing of PV grid by using SAM, factors other than DC nameplate rating, Array type, Azimuth and average utility electricity cost are assumed to be constant. Solar radiation and other meteorological data is factored in by default in PV WATTS.
- To determine the rooftop area usable for array of the PV panels, variables other than rooftop area under shadow, area insufficient for array of panels, area facing away from the required azimuth is not considered.
- To estimate the energy savings cost from BIPV roof, the average annual utility prices per state for residential sector are used provided by U.S Energy Information and Administration.
- The initial installation costs for BIPV roof (which include costs for inverters and engineering and installation costs) were based on NREL‘s National PV Cost Values report (Blair *et al*., 2008).
- Market price variations are not factored in w hen using NREL’s Solar Advisory Model and when estimating cost for Asphalt shingle roof.
- The estimation costs for asphalt roofing shingles were obtained from RS cost data, 2011 and were adjusted to a particular location’s price by using the location factor provided.

- This study was made on the assumption that both the roofs have an equal life time of 25 years and any replacement costs occurring would only occur at the end of 25 years which would not have any bearing on this equation. The residual costs or salvage value was also assumed to be zero as it was assumed that both the roofs would reach the end of their useful life periods and would be disposed off therefore diminishing their salvage value to zero.

2.4. DEFINITIONS

- Array: The grid arrangement of PV roof tiles one beside the other connected in series or parallel.
- Azimuth: A horizontal angular distance used to locate an object, measured clockwise around the horizon from the North.
- DC nameplate rating: The power rating of a PV roof tile on its nameplate providing the users with the maximum power wattage capacity.
- DC to AC Derate Factor: The efficiency of conversion of the DC current produced by the PV roof tiles into AC current is never 100% and is usually assumed to be between 90% to99%.
- Inverter: The Inverter converts the DC current to AC current and helps the grid to supply current for the dwelling unit’s utility.

3. LITERATURE REVIEW

3.1 PV MODULES: DEFINITION, ADVANTAGES, COSTS AND TRADEOFFS

PV modules are Photo Voltaic panels manufactured by closely arranging solar cells to produce energy from solar radiation. The first generation of PV modules were bulky and of lower energy productivity which made them feasible to be used only in large scale grid arrays. New innovations in silicon cell technology and crystalline silicone photo voltaics have reduced the size of PV modules for use in commercial market but their costs of installation were still seen as additional costs to the building's own. Even more recent upgrades in PV modules are the BIPVs (Building Integrated Photo Volataics) which were manufactured as components for building envelopes to be used as replacements for glass facades, skylights etc. The BIPV panels which are even more widely being experimented with to promote them in residential markets are the BIPV roof tiles. Manufactured to be light weight and to be used as roofing material to compete with membrane roofing and metal roofing, these BIPV roof tiles can be even used on smaller dwelling units roofs. To evaluate the trade offs and challenges that these BIPV modules have been facing in the market, it is imperative to look at them in comparison with conventional building materials. The comparison of BIPVs with traditional materials in construction reveals that there is currently a significantly noticeable trade-off between the environmental and economic implications of Photo Voltaics. Although, there are considerable environmental benefits to be gained from using PVs to produce energy, the cost of doing so is significantly higher than conventional sources of energy conservation and utilization (Oliver and Jackson, 2000). BIPVs are newer thinner developments in PV technology for Building Integration as their name suggests. The focus of some researchers in this technology have been to determine the sensitivity of BIPV output along with energy costs generation which would make them cost effective to be promoted in residential and commercial markets. Initially PV technology was developed to be used in space to generate electricity for satellites in the form of solar cells. However, the development of the technology in the past few years has shown observations of a trend in lowering of costs leading to wider market penetration, which in turn leads to lower costs as the industry explores this technology on a learning curve (Oliver, 2000). Gusdorf (1992) has shown that there has been a considerable progress in decreasing energy payback times for PVs in the last two decades. Authors in the 1970s suggested that solar energy might be found unviable in energy terms, presenting arguments that required energy for production of PV systems was greater than the energy the system would produce over its lifetime (Georgescu-Roegen, 1979) . Oliver and Jackson (1999) have highlighted some of the vital factors that have made it possible to cost reductions of PVs in economic and energy terms. In UK, for example it was observed that there were '*many hundreds of small systems providing power for monitoring and control devices, for the gas, electricity and water industries, for meteorological stations, for small lights on buoys in estuaries and at sea and of course millions of calculators*' (Hill *et al.,* 1995, p. 141).

3.2 BIPV INSTALLATION OPTIMIZATION FOR EFFICIENT ENERGY PRODUCTION

Such trends when noticed would have to have given way to analysis of efficient and optimized use of PV technology in construction. More recently a study conducted by the National Renewable Energy Laboratory [NREL] was aimed at examining the performance of BIPV roof tiles in two kinds of mountings on a roof (Muller *et al*., 2009). The first kind was of a normal inclined Solar panel manner of mounting on furring strips (wooden) in an inclined position allowing air to pass between the roof and the solar panels, both of them therefore existing as separate components and the second kind were PV panels directly integrated as roofing units along with concrete roofing tiles. Fig. 1 shows the two types of mounts used for the experiment.

Fig. 1 The 2 kinds of mounted PV roofs. (Source: Muller *et al*., 2009)

It was concluded in this study that mounted PV roof produced more wattage when exposed to irradiances of more than 31.69 btu’s/sq.ft (100 W/ Sq. m) but also resulted in more heating up of attic space below the roof. Fig. 2 shows the performance comparison of the two plots. The study was limited to installation of panels in a side by side arrangement over a single attic space. It also showed that there is a clear contrast in installation methods of BIPVs in terms of output. The specific results from the study analyzed that the mounted BIPV roof system produced 3.4% more watts in DC current for all irradiances greater than 100 W/ sq. m (31.69 btu’s/sq.ft).

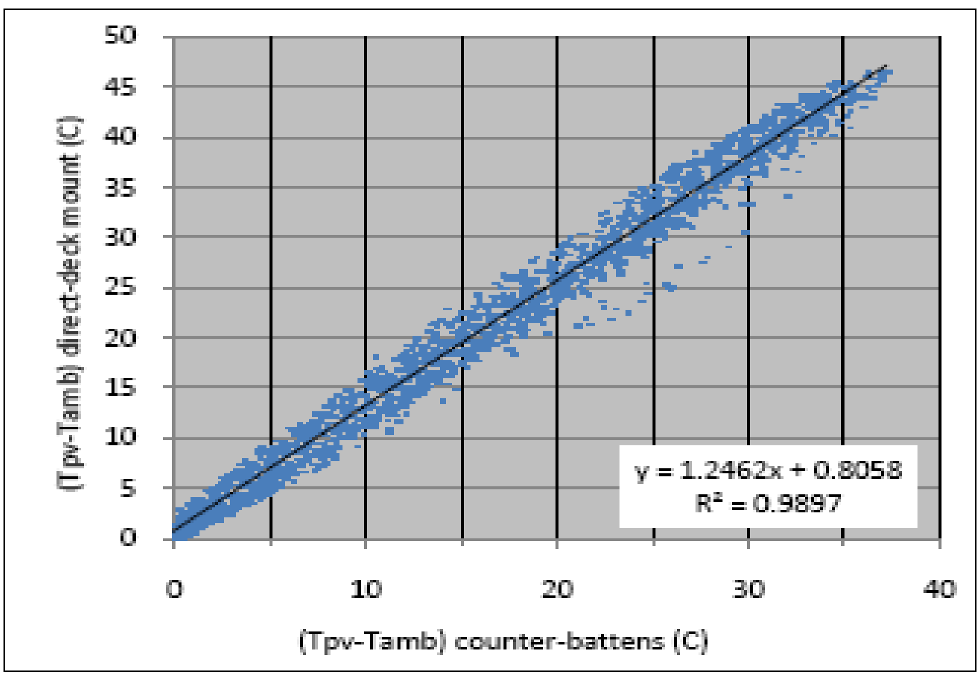

Fig. 2 Performance comparison plot of the two mounts. (Source: Muller *et al*., 2009)

This helped to know the limitations of direct PV roof tile installations when compared to mounted PV panels. But mounting PV panels to increase output may also lead to even bigger initial installation costs for this thesis.

Since the objective of this thesis also involves the optimization of PV panel grid array for efficiency, more studies on the same lines were reviewed. A case study example study carried out in Putrajaya, Malaysia focused more on the configuration of tilt angle and orientation of the PV grid arrangement. The use of simulation model for predicting the energy output of the PV grid arrays was notable which showed clearly contrasting outputs for various angles of PV panel tilt and direction combinations. The best combination of tilt angle and direction were chosen by plotting a graph of the simulation output results and tilt angle-direction combinations which was an azimuth of South with a tilt angle of 0degrees. Their simulation even allowed them to plot a graph of monthly distribution of energy output from the BIPV panels over an entire year. The calculated the payback periods of the 2.72 kw PV system with the resultant annual energy output was determined to be at 75 years which was three times the life period of the PV panels (Muhida *et al*., 2010).

3.3 AREAS OF PREDICTING BIPV PERFORMANCE WITH SIMULATION MODELS

Other research eventually led to prediction techniques of BIPV performances which allowed for cheaper analyses than actual experimental studies. However, these predictive simulation techniques used by software models were compared with actual performance testing of BIPVs. The study carried out in Northern Italy addressed the comparative analysis of BIPV panels integrated into the facade of a building in Bolzano, Italy (Maturi *et al*., 2008). The study was done through an actual experimental case study and a single day's output was also modeled through a simulation process which had the local weather data factored into it. This was done to predict the accuracy between a simulation model and an actual real time case study example's output. Another objective to be tested in this study was the role ventilation of the PV panels in decreasing the external PV cell temperature which in turn gives a better energy output. The most interesting results in this study came from the comparison of a single day's simulation modeling which only differed in predicted the actual PV module temperature by -2% and +2 %. But the simulation modeling did differ considerably from actual energy output the PV modules produced by -20%. Another significant study carried along the same lines of comparison by Sandia Laboratories (Cameron e*t al*., 2008)aimed at examining the accuracy of performance model calculations within NREL's SAM simulation software to actual measured PV performance. This was done by feeding meteorological and solar irradiance data as an input to SAM and then comparing the results obtained from the model to actual measured PV performances which were located in the same locations whose data was fed into SAM. The results from the study showed that when measured weather data was factored in to the Systems performance model of SAM ,the resultant output was within reasonable agreement with measured results. These have been summarized as follows:

- The radiation models were in agreement with a variation of 2%.
- All the module performance models used within SAM have exhibited the following agreements when compared with measured PV performances. These results even took into consideration radiation errors and system derate factor errors.
    - Sandia , PV module performance model, within 5% absolute and ±3% relative.
    - PVMod - within 4% absolute, ±1% relative.
    - PVWATTS - within 11% absolute, ±1% relative.
    - Inverter model – within 1%.

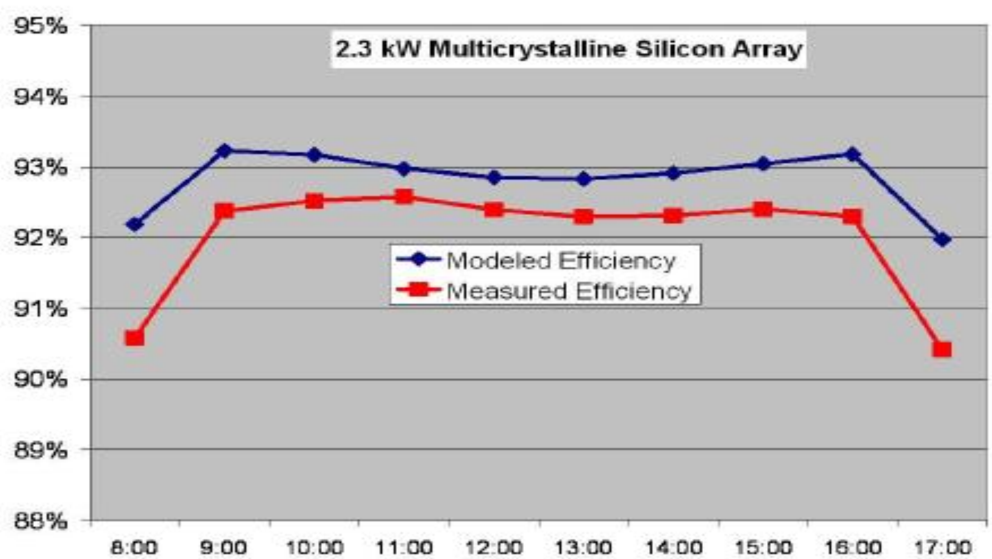

Fig. 3 Comparison of modeled to measured inverter performance. (Source: Cameron *et al*., 2008).

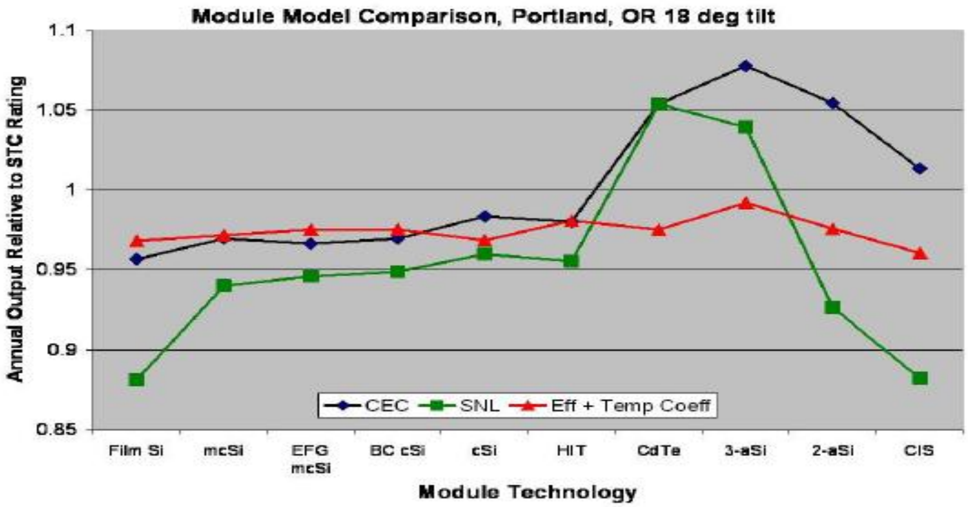

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Fig. 4 Comparison of modeled PV module performance for different PV technologies (polycrystalline, silicon film based etc.). (Source: Cameron *et al*., 2008)

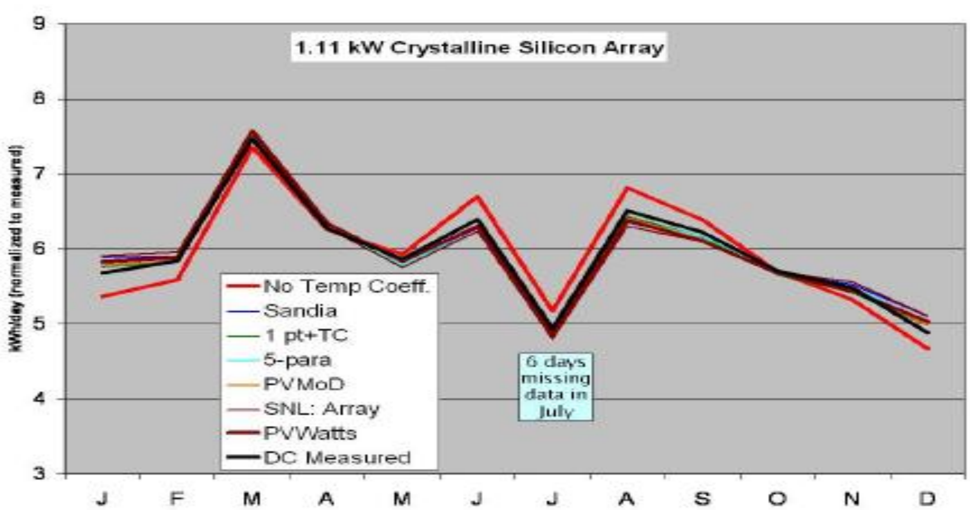

Fig. 5 Comparison of modeled to measured PV module performance. .(Source: Cameron *et al*., 2008)

The study provided inputs about SAM's modeling accuracies when compared to measured performances of PV arrays. PV watts and PV Sol were simulation soft wares which are used as modeling components in SAM. Their accuracies to simulate PV array performances were also notable. SAM's array modeling algorithm also provides the user with value of energy savings per year in US$. Figures 3, 4 and 5 show the results obtained in this experiment.

3.4 CONCLUSIONS OF LITERATURE STUDY

The factors modeled for consideration in using simulation model prediction techniques in SAM developed by NREL can be assumed to be reliable and can be adjusted from their default values when required. However, since this thesis aims to study the impact of climatic zone's significance on BIPV performance, assumptions can be allowed to leave inflation rate and degrading factors of BIPV performances at their default values given by SAM without affecting the outcome of the overall analysis.

4. METHODOLOGY

4.1 DATA COLLECTION PROCEDURE AND SELECTION OF OBSERVATIONAL UNITS

The study required observational units for consideration, these include locations from the 5 different climatic zones of USA which were zone 1(Cool zone), zone 2(Temperate zone), zone 3(Moderately temperate zone), zone 4(Hot and arid zone) and zone 5(Hot and humid zone) each categorized based on HDD ranges as shown in Fig. 6.

The simulation software SAM (Solar Advisory Model) requires a PV module selection from its database of PV modules whose performance factors were factored into SAM by default. Of all the PV modules in its database, a few PV modules which function as PV roof tiles were looked at and one of these modules – The Uni-solar PVL 68 Solar roof tile was chosen as it was one of the modules presently available in the market today and whose performance factors were modeled into SAM. This formed the PV module observational unit for the study. Similarly, a Class A multilayered asphalt shingle available in the market was chosen to be the asphalt shingle observational unit.

The dwelling unit used for calculation of roof area and calculated for BIPV roof tile installation as well as asphalt shingle roof installation was chosen by obtaining the roof plan and area from a randomly from a Homebuilder (Cheldan Homes online website, 2010) firm since the parameter being considered in this study was only the roof area.

The PV roof tile observational unit and the dwelling unit's roof area being used as a observational unit have been shown in Figures 6 and 7.

Furthermore, SAM requires specific locations to be selected for factoring in weather and solar irradiance data from its database for which 35 locations (7from each climatic zone) were selected for the simulation runs for BIPV roof output. To balance this analysis, another 35 locations (7from each climatic zone) were selected from the same 5 climatic zones mentioned before for asphalt roof installation for the comparative analysis. Fig. 8 shows the typical connection of a BIPV grid in a residential dwelling unit to the utility grid. The selected locations from the climatic zones (for BIPV) were based on availability of locations listed in SAM's database which was due to presence of weather stations in these areas. Although, weather data will not be factored into asphalt roof estimations, the locations for asphalt roof were also chosen from the same list of locations available in SAM's database.

4.2 LOCATION

A Selection of locations and number of locations from the 5 climatic zones for BIPV roofs and asphalt roofs as well are considered as the variable indicating the climatic zone of a location classified as zone 1(Cool zone), zone 2(Temperate zone), zone 3(Moderately temperate zone), zone 4(Hot and arid zone) and zone 5(Hot and humid zone). Table 1 and Table 2 have been summarized below showing the locations and the zones they belong to.

Table 1 The selected locations from the 5 climatic zones for BIPV roof installation.

Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Bismarck_ND	Burns_OR	Baltimore_MD	Amarillo TX	Abilene_TX
Cheyenne WY	Chicago_IL	Covington_KY	Asheville_NC	Brownsville_TX
Fargo_ND	Colorado springs_CO	Eugene_OR	Birmingham_AL	Fortworth_TX
Kalispell_MT	Grand island NE	Knoxville_TN	El paso TX	Lake charles_LA
Mason city_IA	Omaha NE	Lousville_KY	Fresno_CA	Lufkin_TX
North platte NE	Pueblo_CO	North bend_OR	Huntsville_AL	Midlands
Rapid city_SD	Reno_NV	Tucson_AZ	Memphis_TN	New orleans_LA

Table 2 The selected locations from the 5 climatic zones for asphalt roof installation.

Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Casper WY	Cedar city_UT	Bristol_TN	Arcata_CA	Baton Rouge_LA
Eagle_CO	Cleveland_OH	Dodge city_KS	Athens_GA	Corpus christi_TX
Grand junction_CO	Goodlands KA	Evansville_IN	Charlotte_NC	Keywest_FL
Lander TX	Las vegas_NV	Lexington_KY	Fort smith_AR	Lubbock_TX
Minneapolis_MN	Pittsburg_PA	Lynchburg_VA	Greensboro_NC	Miami_FL
Pierre_SD	Redmond_OR	Roanoke_VA	Long Beach_CA	Mobile_AL
Saint cloud_MN	Seattle_WA	Wichita_KS	Tulsa_OK	Savannah_GA

- The simulation procedures for determining the optimum azimuth for the PV array have determined that an azimuth of 0^0 (i.e. facing south) gives better energy savings. Therefore, this azimuth has been used as a constant when SAM was being used to simulate energy savings for the prototype dwelling unit's BIPV roof which meant that only those faces of the roof which faced south were integrated with BIPV roof tiles. For figures to determine optimum azimuth, see section 4.
- Estimated initial costs for BIPV roofs were estimated by SAM which was US$ 25,611.99. This value was the same for all the locations as SAM estimates this value based on the PV module selected with a constant procurement and installation cost and it does not vary with change in location. The OMR costs for BIPV roofs were generated for the 25 years by SAM along with the annual energy savings for 25 years in every location and these values have been reduced to their NPV taking into account even the NPV of energy savings from the BIPV roof. See Section 6.
- Estimated initial costs for asphalt shingle roofs were estimated from RS Means cost data and their OMR (Operation, Maintenance and Repair costs) were estimated to be a recurring cost of US $37.50 for the life cycle of 25 years. These costs over the life cycle of 25 years have been added up and reduced to their NPV based on the initial estimated cost by using the NPV function in Microsoft excel. See Section 6.
- The tables summarizing the NPV for BIPV roof in all the locations for the 5 climatic zones are in tables in the appendix numbered A.13 TO A.17. The tables summarizing the NPV costs for asphalt shingle roofs are summarized in Table A.18 in the Appendix.

4.3 VARIABLES FROM DATA COLLECTION

The variables obtained for analysis of data from the data collection are as follows

Climatic zone: This is an independent categorical variable subject determining the climatic zone of each and every location (from section 4).

- **Roof type**: This is an independent categorical variable with two levels, 1) BIPV and 2) asphalt, for each and every location.
- **NPV**: This is the net present value (shown in section 5), measured in US dollars. It was used as the dependent variable.
- **Energy savings**: These are the cumulative energy savings of the dwelling unit's roof in each location for a lifecycle of 25 years, measured US$. It was used as the dependent variable.
- **Climate**: The climatic zone of the respective locations for which the data(NPV and energy savings) of dwelling unit's roof classified into 5 zones as summarized in Figures 6 and 7.
- **HDD :** These are heating degree days for a particular location measured in number of degrees for a year (in ^{0}F). One HDD corresponds to a difference of 1^{0}F between minimum mean outdoor temperature and balance point temperature.
- **CDD:** These are heating degree days for a particular location measured in number of degrees for a year (in ^{0}F). One HDD corresponds to a difference of 1^{0}F between maximum mean outdoor temperature and balance point temperature.

4.4 OBSERVATIONAL UNITS

- BIPV roof Tiles: Uni-solar PVL 68 Solar roof tile as shown in Fig. 6.
- Certainteed Class A multilayered Asphalt shingle.
- Prototype Dwelling Unit Roof area as shown in plan in Fig. 7.
- 70 locations of cities with weather stations from the 5 types of climatic regions of U.S.A. (14 locations from each climatic region, 7 for BIPV roof, a different 7 for asphalt shingle roof as shown in Fig. 8.
- 3 azimuth faces possible for arranging the array of PV roof tiles over the dwelling unit's roof. 0 Degrees- Facing the Equator- Facing South, 90 degrees- facing west and -90 degrees facing east.

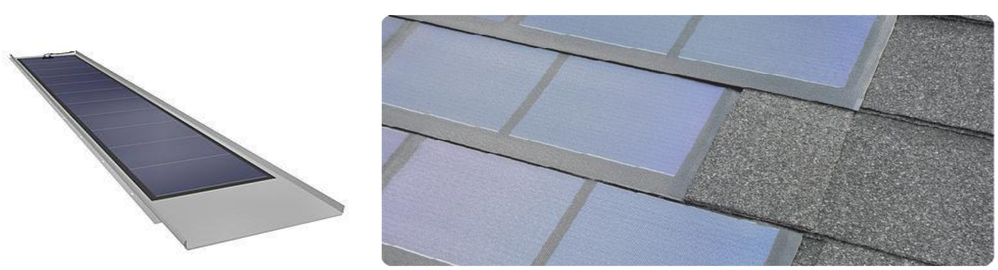

Fig. 6 A single unit of Uni-Solar PVL 68 solar roof tile.(source: Uni-Solar Residential products online content, 2011)

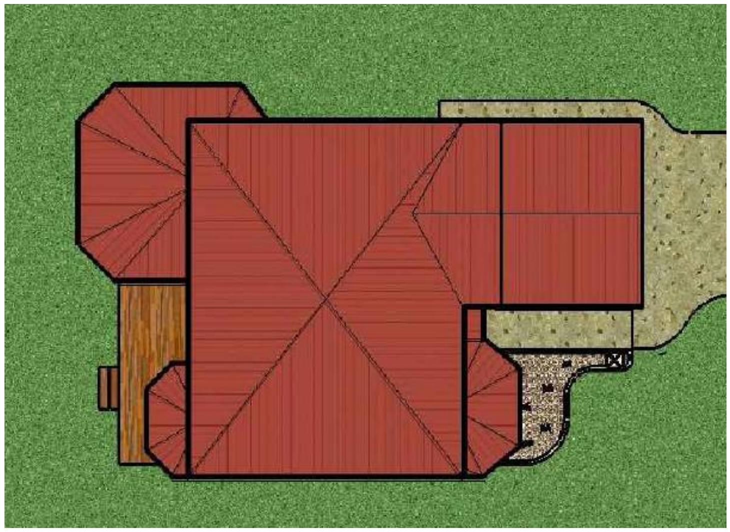

Fig. 7 The roof area (plan) of the prototype dwelling unit used for simulating the PV roof tile array.

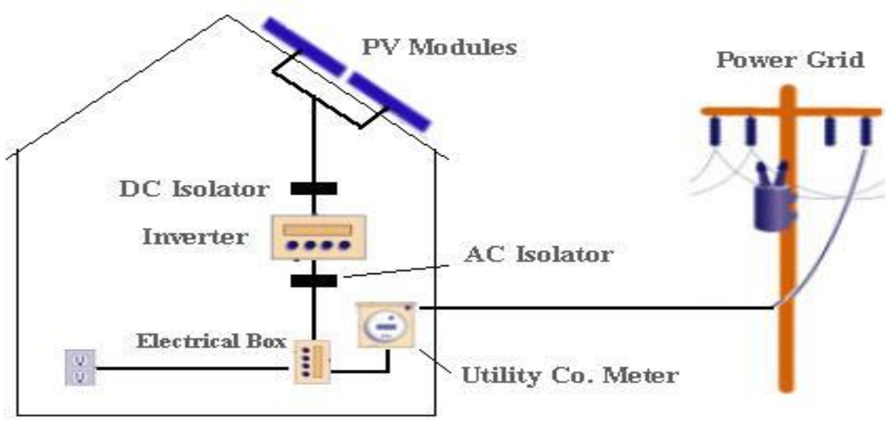

Fig. 8 The connection diagram between The PV grid, the Inverter and the Dwelling Unit utility. (source: Midwest Green Energy online, 2011)

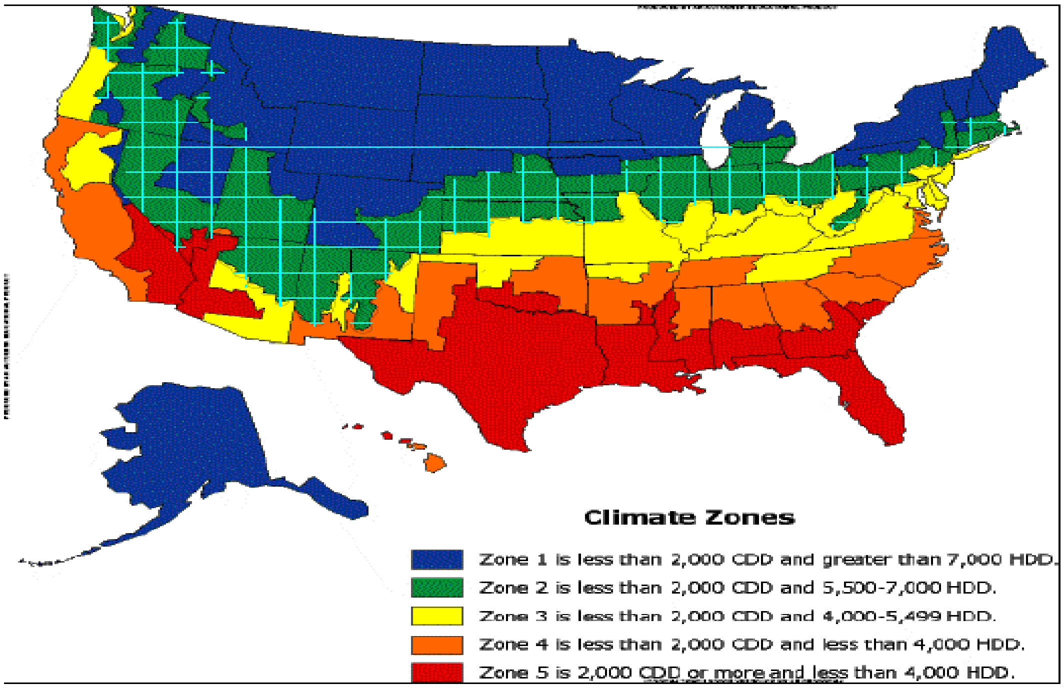

Fig. 9 Climatic regions of USA (source: US DOE's Building energy data book online, 2010)

4.5 SIMULATION PROCEDURE FOR DETERMINING THE OPTIMUM AZIMUTH FOR INSTALLATION OF PV ROOF TILES

SAM is a Non Renewable Energy technology simulation model which uses performance modeling developed by NREL for modeling output. In this study SAM was used to run models based on the roof area of a prototype dwelling unit in 35 different locations in 5 different climatic zones of U.S.A to test for the significance of the variable.- location's climatic zone. Fig. 9 shows the map of the climatic regions of the USA used to select the

35 locations. The prototype dwelling unit was chosen at random from Cheldan Homes, TX to represent a typical dwelling unit's roof area and a typical connection diagram of BIPV roof to the utility grid is show in Fig. 8 of the previous section 4. The roof area of the chosen dwelling unit was 1682 sq. feet (inclined roof area).

Since, the PV module selected was "Uni-Solar PVL 68" which is a roof tile which does not get installed with a tilt angle but rather is directly installed on the roof of the dwelling unit, the only variable that mattered in determining for placement of PV array on the roof is the azimuth-direction. For this, a simulation was run for an array of 40 Uni-Solar PVL 68 modules array arranged in two strings in the 35 different locations chosen from 5 different climatic zones all over USA. This was possible with the help of radiation performance models present in SAM. The following inputs as constants were used for running the simulations in all the locations SAM for three different azimuths- 0^0 (Array Facing the Equator i.e. Facing South), 90^0 (Facing West) and -90^0 (Facing East). Table 3 lists the simulation parameters and the values used in the simulations showing the parameter values which were set by default by SAM and with exception to only the values of a few parameters which were obtained from calculation of dwelling units roof area and roof tilt angle.

Table 3 Inputs used for running first stage of simulations for testing azimuths (Blair *et al*., 2008).

Inputs used for Running SAM.	***Values***	***Default or Calculated values***
Uni-Solar PVL 68 PV Modules per string	20	Calculated
Strings in Parallel	2	Calculated
Number of inverters	1	Default SAM values
Total modules	40	Calculated
Total area	482.65 sq. feet(44.84 M^2)	Default SAM values
Array power (at reference conditions)	2.70625 kwdc	Default SAM values
Total Inverter capacity	4kwac	Default SAM values
Radiation model chosen with SAM	Total and Beam.	Default SAM values
Tilt angle	Fixed to slope of roof 6/12 -26.6^0	Calculated
Module characteristics at reference conditions	Total irradiation=316.99 btu's/sq. feet (1000w/m^2), Cell temp.= 77^0F.	Default SAM values
PV performance model used from with SAM	Sandia PV array performance model	Default SAM values
Single unit Module area	12.066 sq. feet	Default SAM values
Inverter performance model used from within SAM	Sandia Performance model for grid connected PV array.	Default SAM values
Inverter used	SMA America: SB4000US 240 V [cec 2007 model]	Default SAM values
PV performance model used from with SAM	Sandia PV array performance model	Default SAM values

The above inputs from data table 3 have been kept as constant for running the simulations in 35 different locations. After running the simulations, the first year's annual energy output in kilowatt hours (kwh) for the first annual year has been collected as shown below in Figures 10-14 for the 35 locations in five climatic zones for the three possible azimuths. Since the concern here at this stage was about the first years annual energy output (which will ultimately give us an idea about the efficiency of the PV grid for different array), other factors such as electricity utility rates, energy costs or installation costs remain constant and haven't been taken into consideration.

The results obtained included the energy output of the PV grid array for every year after it has been put into operation for the lifetime of the PV grid which was 25 years. But all that was required to measure the efficiency of the PV array in different azimuths is the first years annual energy output in kilowatt hours (kwhs) compared for the three different azimuths as well as the different locations chosen Figures 10—14 detail the plots of the results from stage 1 of simulations showing that an azimuth of 0^0 (i.e. facing south) produces more energy in the first annual year after their operation begins.

The resultant plots of energy output values for the initial year after beginning of operation of the tested PV array showed that the PV panels produce energy at an efficient level when the array is facing the equator (Azimuth 0^0, Facing South) for all the locations in the climatic zones.

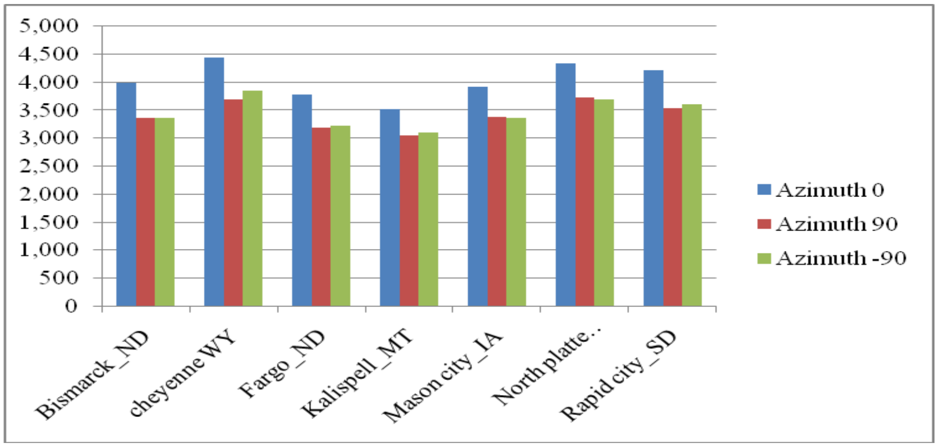

Fig. 10 Showing the plotted first year energy output for the different azimuths in different locations. Y axis- Energy output in Kwhs. X axis- locations in Climatic Zone 1

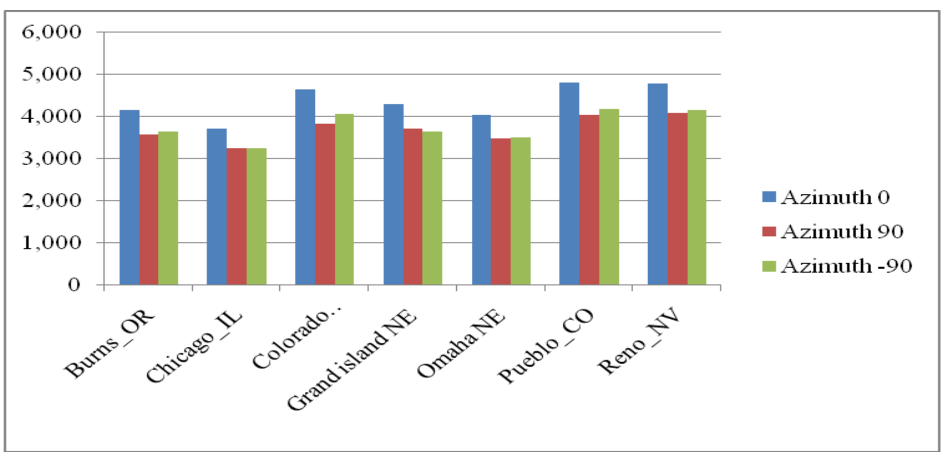

Fig. 11 Showing the plotted first year energy output for the different azimuths in different locations. Y axis-Energy output in Kwhs. X axis- locations in Climatic Zone 2.

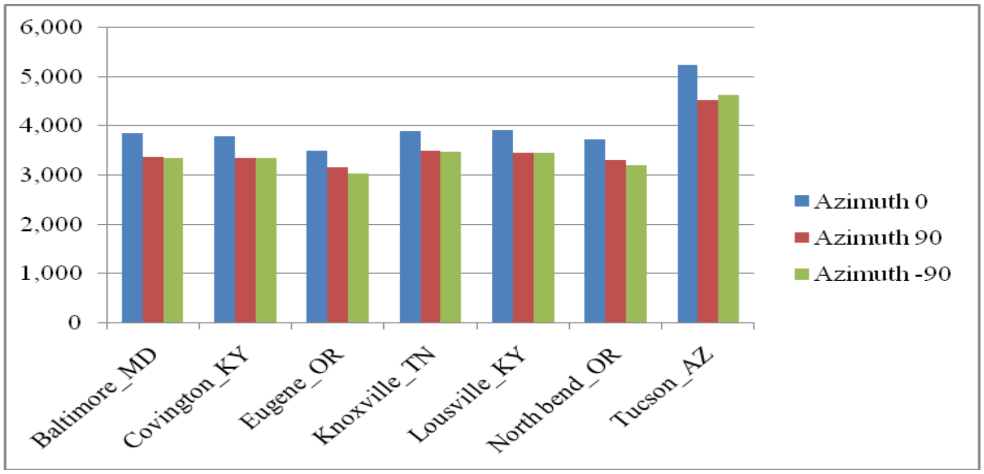

Fig. 12 Showing the plotted first year energy output for the different azimuths in different locations. Y axis-Energy output in Kwhs. X axis- locations in Climatic Zone 3.

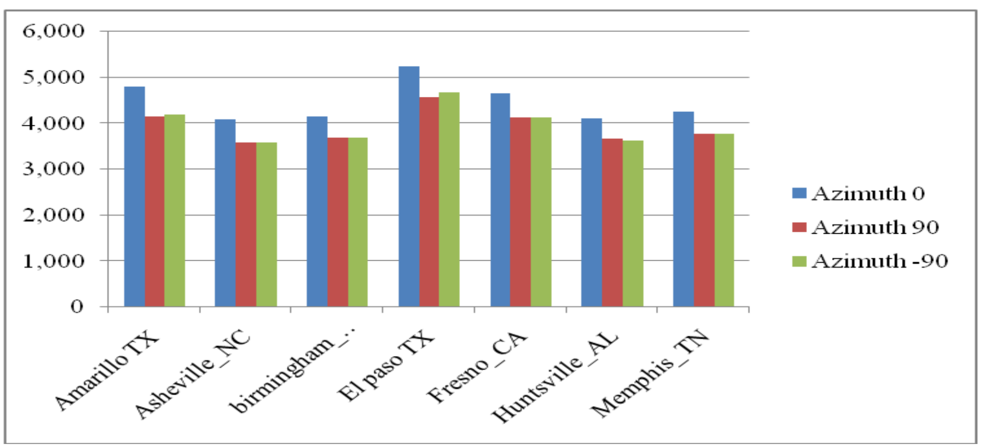

Fig. 13 Showing the plotted first year energy output for the different azimuths in different locations. Y axis-Energy output in Kwhs. X axis-locations in Climatic Zone 4.

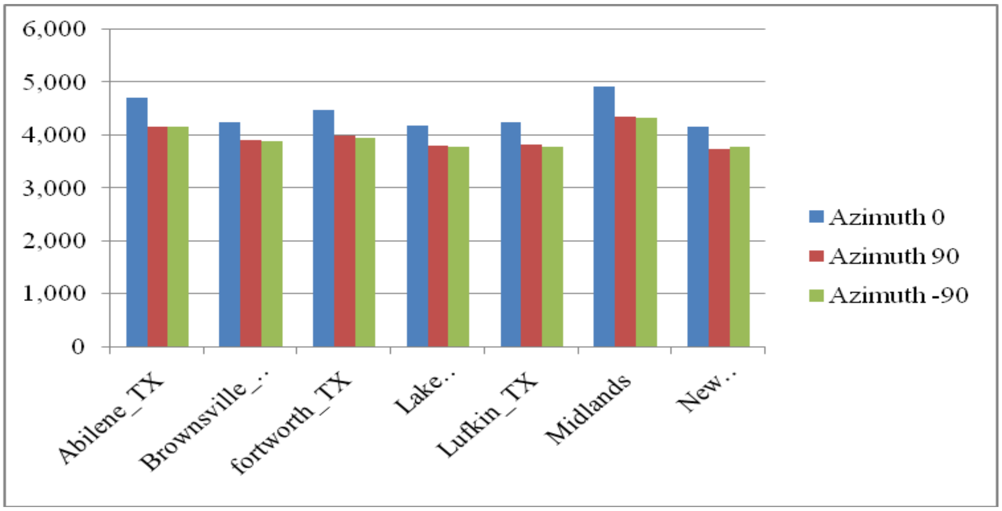

Fig. 14 Showing the plotted first year energy output for the different azimuths in different locations. Y axis-Energy output in Kwhs. X axis-locations in Climatic Zone 5.

4.6 SIMULATION PROCEDURE FOR DETERMINING BIPV PERFORMANCE AND COSTS ASSOCIATED WITH BOTH THE ROOF TYPES

The next step of the study was to identify South facing portions of the roof area of the prototype dwelling unit for installation of the PV roof tiles. The roof top faces which exposed the array towards south only were integrated with PV roof tiles. Integrating roof tiles on the other faces results in larger Initial costs and greater pay back costs thus reducing cost efficiency. This was calculated by detailing a plan in Autodesk Autocad software by detailing the placement of PV roof tiles on portions of the dwelling units roof area. The dwelling unit’s roof plan has already been shown in Fig.7 in Section 4.

SAM 's interface allowed to select the required PV roof tile from its databank of available PV panels and the relevant information of Uni-solar PVL 68 roof tile simultaneously. This information showed the area occupied by a single Uni-solar PVL 68 roof tile was 12.06sq. feet (1.121 m^2). The dimensions have been obtained as Length: 2849 mm (112.1"), Width: 394 mm (15.5"), Depth: 4 mm (0.2"). The areas facing south were integrated with the arrangement of Uni-solar PVL 68 roof tiles in a drawing of the Roof plan. And the area estimated to be covered was derived as 863.265 ft^2 in total. Figure 15 shows the roof plan with hatched area indicating the area to be integrated with BIPV roof tiles.

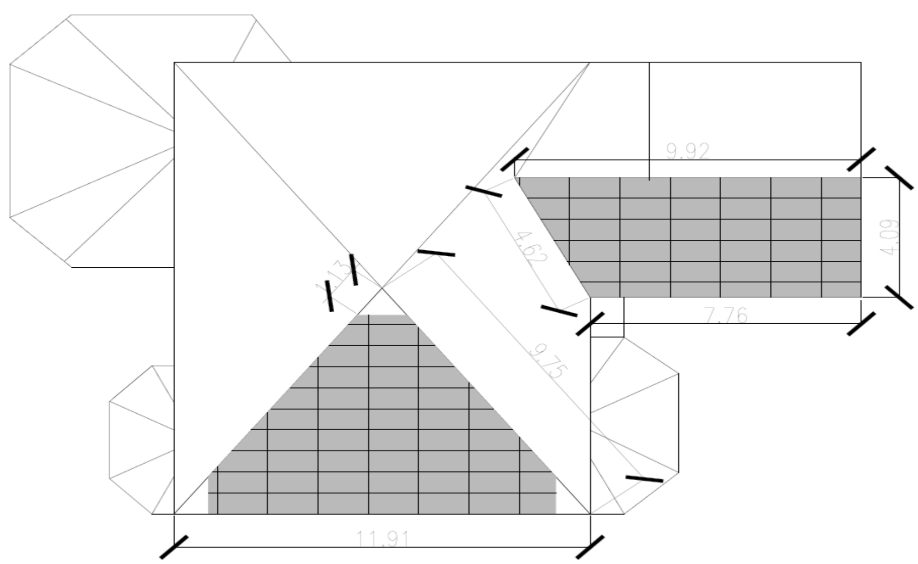

Fig. 15 The roof plan of the example dwelling unit integrated with BIPV roof tiles facing South.

The hatched area marked in the roof plan above on the roof pitch faces facing south were calculated for area of BIPV arrangement which was 82.26 m^2.The number of PV roof tile modules which were arranged on the roof area was counted to be 72 .

4.7 SIMULATION PROCEDURE TO DERIVE COSTS INVOLVED IN LIFECYCLE, PAYBACK PERIOD AND ENERGY SAVINGS IN ALL THE 35 LOCATIONS FROM 5 CLIMATIC ZONES FOR BIPV ROOF

The simulation of the PV array arrangement shown in Fig.15 in Subsection 4.6 was broken down into 9 rows of PV roof tiles connected in a series of 4 strings which gave us the arrangement of (9 x 4) + (9 x 4) modules in total i.e. 72 modules. This determines the PV array capacity and size. An analysis period of 25 years was set as the lifetime and analysis period for the BIPV roof which would leave the panels at the end of their Net Present Value period. Some inputs were related to the PV system regarding their performance, deterioration rate etc. were taken as constant for all the locations and are detailed as follows in table 4. The state averages for Energy utility prices were derived from U.S Energy information and administration (Electric Power Monthly Back Issues Historical Excel Tables, 2011).

Table 4 Inputs which remained constant for all locations for simulation procedure stage 2 of the study (Blair *et al*., 2008).

Inputs	***Values or Specifics.***	***Default, fixed or Calculated values***
Analysis period	25 years.	Fixed value
Inflation rate(Annual rate of change of prices)	2.50 %	(Energy price indices and discount factors for life cycle cost analysis, 2010)
Real discount rate (A time value measure of money to calculate present values of future costs/savings)	10.8%	(Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis, 2010)
One time federal taxes	28%/year	default
One time state taxes	7%/year	default
Annual System Degradation	0.5%	default
Annual system Availability	100%	default
Capacity of single PV module(unit)	0.1 kwdc/unit	default
Total capacity for 72 Modules (units)	4.871 kwdc	default(calculated by SAM)
Capital costs for module in $/Wdc	$3.39/Wdc	default(Blair,2008)
Inverter	1	default
Inverter capacity(rate)	2.1kwac/unit	default
Total Inverter capacity	2.1 kwac	default
Modules per string	9	calculated
No. of strings	4 + 4	calculated
Total area covered by PV array	868.77sq. feet(80.712 m^2)	calculated
Derate factor for inverter, wiring and diode connections	90%	default
Tilt angle	Fixed to slope of roof 6/12 -26.6^0	calculated
Azimuth	0^0, facing equator, facing south.	calculated
PV Module name	Uni Solar PVL 68	
Nameplate capacity	68 watts	default
Array power (at reference conditions)	2.70625 kwdc	default
Radiation model chosen with SAM	Total and Beam.	default
Module characteristics at reference conditions	Total irradiation=316.99btu's/ sq. feet (1000w/m^2), Cell temp.=25^{0}c.	default
PV performance model used from within SAM	Sandia PV array performance model	default
Single unit Module area	12.06sq. feet(1.121 $m^{2.}$)	default
Inverter performance model used from within SAM	Sandia Performance model for grid connected PV array.	default
Inverter used	SMA America: SWR2100U 208 V [cec 2006]	default

4.8 PV SYSTEM ASSOCIATED COSTS USED IN THE SIMULATION RUNS

The initial installation costs for the PV roof were kept at a constant of US$ 25,611.99 (Value estimated by SAM) (Blair *et al*., 2008) and the first year annual operation and maintenance costs were fixed at $ 200 (SAM Default value). The Operation and maintenance costs will escalate at a rate simulated by SAM simulation model for the lifecycle of 25 years. The annual energy savings for the 25 years of the PV roof for the 35 locations will be generated by the SAM model as well with an input of average Utility prices of energy obtained for each of the 35 locations from the following Utility Prices table obtained from the "U.S Energy Information and Administration" online database. These rates have been detailed in data table A.1 in the Appendix.

The annual utility prices for the 35 locations were obtained with reference to the residential sector use and by the state they were located in.

4.9 ENERGY SAVINGS AND MAINTENANCE COSTS FROM SIMULATIONS

The simulation runs yielded annual energy savings from the PV roof in the 35 locations from the 5 climatic zones. These values in US $ along with the PV system Installation costs detailed in Section 5.3 have been used to derive the Net Present Value costs (25 years) for the PV roof in all the locations selected from the zones. The values have been collected in data tables A.2—A.6 in the Appendix. Similarly, the Operation Maintenance and Repair costs (OMR) have been collected to be later reduced to their Net Present Values (NPV) in data table A.7 in the Appendix.

4.10 ESTIMATION OF ASPHALT SHINGLE ROOF IN US DOLLARS FROM 35 LOCATIONS IN THE 5 CLIMATIC ZONES

The area of the example dwelling unit roof which was computed for BIPV roof integration was estimated for installation of Asphalt shingles. The cost of Asphalt shingles per Sq. foot is much lower than PV roof which was determined from the RS means Cost data. For comparison with a PV roof, the same amount of roof area was taken into consideration as was taken for PV integration. Asphalt shingles of type A , multilayered shingles were selected to be installed and the related cost per sq. foot were recorded. These costs were multiplied by the selected sq. foot area of the roof to give the total estimated cost including “over head costs” for the asphalt shingle roof area. The roof area estimated for installation of asphalt shingles remains constant for the 35 locations but asphalt shingle roof cost was adapted to the 35 locations from the 5 climatic zones by a multiplication with the location factor available from the RS means cost data. It is to be noted that the 35 locations selected for the asphalt shingle area were different from the 35 locations (although selected from the same 5 climatic zones) the PV roofs. This was to avoid repeated categorical variables for deriving the General linear model. The asphalt shingle roof costs and the PV roof costs have a wide contrasting difference in their installation costs. The objective is to avoid comparing these Installation costs directly but to compare the overall Net Present Value costs of both the roofs. Fig. 16 shows the area of the roof to be used for asphalt shingle roofing. A summary of the estimated costs for asphalt shingle roofs for the chosen 35 locations is summarized in Table 5. The estimation tables for asphalt shingle roofs for the hatched area for zones 1,2,3,4 and 5 have been collected and detailed in tables A.8 TO A.12 in the Appendix.

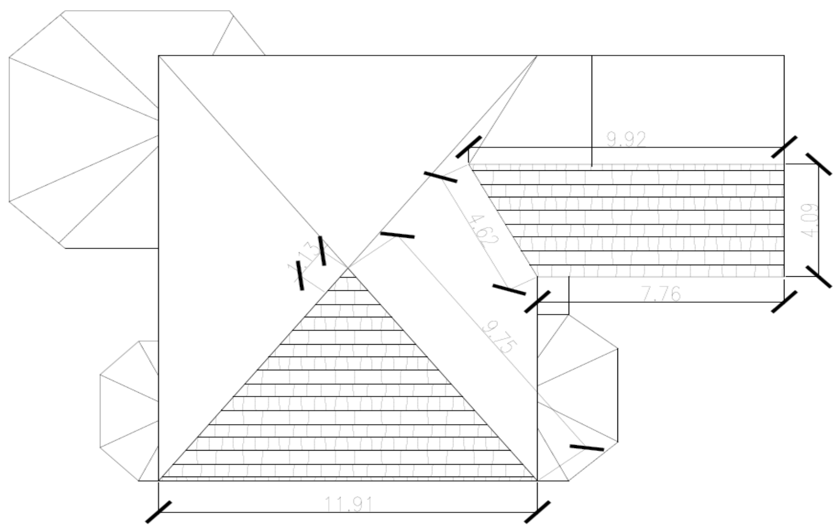

Fig. 16 Roof area of the dwelling unit which was estimated for installation of asphalt shingles

Table 5 Summary of estimated costs of asphalt roof for the prototype dwelling unit.

Location	**Estimated costs**	**Location**	**Estimated costs**
Zone 1		**Zone 3**	
Casper WY	$2,173.00	Bristol_TN	$2,170.32
Eagle_CO	$2,435.26	Dodge city_KS	$2,306.80
Grand junction_CO	$2,448.64	Evansville_IN	$2,448.64
Lander TX	$2,162.29	Lexington_KY	$2,325.54
Minneapolis_MN	$3,010.62	Lynchburg_VA	$2,237.22
Pierre_SD	$2,127.50	Roanoke_VA	$2,215.82
Saint Cloud_MN	$2,914.28	Wichita_KS	$2,231.87

Table 5 Continued			
Location	**Estimated costs**	**Location**	**Estimated costs**
Zone 2		**Zone 4**	
Cedar city_UT	$2,676.11	Arcata_CA	$2,839.35
Cleveland_OH	$2,676.11	Athens_GA	$2,181.03
Goodlands KA	$2,676.11	Charlotte_NC	$2,047.22
Las vegas_NV	$2,676.11	Fort smith_AR	$2,194.41
Pittsburg_PA	$2,676.11	Greensboro_NC	$2,039.19
Redmond_OR	$2,676.11	Long Beach_CA	$2,796.53
Seattle_WA	$2,676.11	Tulsa_OK	$2,090.04
Zone 5			
Baton Rouge_LA	$2,261.31		
Corpus christi_TX	$2,076.66		
Keywest_FL	$2,360.33		
Lubbock_TX	$2,162.29		
Miami_FL	$2,400.47		
Mobile_AL	$2,245.25		
Savannah_GA	$2,079.33		

4.11 CALCULATING NET PRESENT VALUE COSTS FOR BOTH THE ROOFS

Based on the estimated costs for BIPV and asphalt roof, the NPV for both the roofs was determined by the equation (Levander *et al*., 2003)

NPV for the dwelling unit roof = E costs – E savings + OMR.

E costs = NPV of energy costs.

E savings = NPV Value of energy savings.

The OMR costs for BIPV roofs are summarized in Table A7 in the appendix and the OMR costs for the asphalt roofs are summarized in Tables A.18 in the Appendix along with the derived NPV costs.

As this study was made on the assumption that both the roofs have an equal life time of 25 years and any replacement costs occurring would only occur at the end of 25 years which would not have any bearing on this equation. The residual costs or salvage value was also assumed to be zero as it was assumed that both the roofs would reach the end of their useful life periods and would be disposed off therefore diminishing their salvage value to zero.

Net present value costs for BIPV roof: The operation & maintenance costs (OMR) for BIPV roofs have been tabulated in Table A6 of the Appendix.. These values remain constant for the BIPV roof in all the 35 locations. The Initial installation or Initial Investment costs of us $ 25,611.99 also remain constant for the BIPV roof in all the 35 locations.Since the "Operation and maintenance costs" and "Energy savings" occur as cash outflows during the future i.e the Net Present Value of the BIPV roof at the end of each year, they have been diminished to their Net Present Value using the "NPV" function in Microsoft excel. The underlying formula for which is documented as

$$\mathrm{NPV} = \sum_{i=1}^{n} \frac{values_i}{(1+rate)^i}$$ ....Equation (1)

"n" is the number of cash flows in the list of values.

The total Net Present Value costs for the BIPV roofs for all the locations in zone 1,2,3,4 and 5 have been collected and detailed in data table A.13—a.17 in the Appendix.

Net present value costs for asphalt roofs: The Net Present Value costs for asphalt roofs have been calculated from the same equation that was used to calculate for the BIPV roofs. The net present value of the Operation and maintenance costs was a constant at US$ -25276.77 for all the locations where asphalt roof was estimated. There are no energy costs or energy savings associated with asphalt roof as it's assumed that no other costs other than directly generated energy savings or energy costs were considered for this study.

The data table for the Net Present Value costs obtained for asphalt roofs in climatic zones 1,2,3,4 and 5 have been collected and placed in Table A.18 in the Appendix. The OMR costs have been entered in Net present value.

5. ANALYSIS OF DATA, RESULTS AND INTERPRETATION

5.1 STATISTICAL ANALYSIS I FOR TESTING HYPOTHESIS 1

Hypothesis 1: Net present value of a BIPV roof is significantly differently than that of an asphalt roof for a single family dwelling unit in USA.

A general linear model was used in statistical software SPSS to analyze the Net Present Value cost percentages for all the locations for both the roofs as predicted values of independent variables location's climatic zone(categorical variable), Heating Degree days and Cooling degree days. heating degree days and cooling degree days (HDD and CDD's) were included as covariates in the model. This model was used to test the significance of any relationship between any of the independent variables and the dependent variable- Net Present Value costs percentages. The annual HDD and CDD data were available from NREL'S Solar Radiation Data Manual (NREL, 2009). Table 6 shows the results of this statistical analysis.

The model is:

$NPV = \beta_0 + \beta_1(HDD) + \beta_2(CDD) + \beta_3(\text{Roof type}) + \beta_4(\text{Climate}) + \beta_5(\text{Roof type* Climate}) + e.$

Table 6 General Linear Model of NPV using climatic zone , Roof type as independent variables. HDD and CDD as co-variates.

Variable	Intercept	Regression Coefficient	T value	P value
Intercept	-13746.017		-31.599	.000
HDD		-.145	-1.916	.060
CDD		.082	.748	.458
Roof type = Asphalt		11133.370	32.366	.0001
Roof type = BIPV $_{(a)}$		0^b	.	.
[climate=zone 1]		-658.285	-1.215	.229
[climate=zone 2]		554.895	1.146	.256
[climate=zone 3]		-660.473	-1.683	.098
[climate=zone 4]		244.627	.670	.506
[climate=zone 5 $_{(b)}$]		0^b	.	.
[Roof type=Asphalt] * [climate=zone 1]		1344.934	2.645	.010
[Roof type=Asphalt] * [climate=zone 2]		-248.383	-.507	.614
[Roof type=Asphalt] * [climate=zone 3]		1225.98	2.517	.01
[Roof type=Asphalt] * [climate=zone 4]		29.367	.060	.95

a. Model R Squared = .990 (Adjusted R Squared = .988)

b. Computed using alpha = .05

C, Model F = 536.256

d. P value of Model = 0.0001

(a), (b) BIPV and zone 5 parameters have been set to zero because they are redundant.

Interpretation: The F value of the model used was found to be statistically significant at 0.0001 level. Therefore, there is evidence that the independent variables do exhibit a relationship with the NPV dependent variable. A widely used consideration to examine the model's efficiency in predicting the dependent variable is it's coefficient of determination R^2. If there is a perfectly direct relationship between the independent variables and the dependent variable, R^2 is 1. If there is no evidence of a relationship, R^2 is 0. The predictive efficiency of this model was found to be high with R^2 of 0.990 and adjusted R^2 of 0.998. The result indicated that NPV is positively correlated with roof type at the level of significance of 0.0001. It provides evidence in support of the hypothesis that there is a statistically significant difference between net present values of BIPV and asphalt roofs.

5.2 STATISTICAL ANALYSIS II FOR TESTING HYPOTHESIS 2

Hypothesis 2: Energy savings for a single family dwelling unit due to the use of BIPV roof are affected by Heating Degree Days and Cooling Degree Days.

A general linear model was plotted for energy savings from BIPV roof as the dependent variable and locations climatic zone, HDD and CDD as independent variables. A general linear model was used in statistical software SPSS to analyze the energy saving costs for all the locations for both the roofs as predicted values of independent variables location's climatic zone(categorical variable), Heating Degree days and Cooling degree days. Heating degree days and cooling degree days (HDD and CDD's) were included as covariates in the model. Table 7 shows the results of this statistical analysis. The model is: Energy Savings = $\beta_0 + \beta_1$(HDD) + β_2(CDD) + β_3(Roof type) + β_4(Climate) + β_5(Roof type* Climate) + e.

Table 7 General Linear Model of energy savings using climatic zone as independent variables, HDD and CDD as co-variates.

Variable	Intercept	Regression Coefficient	T value	P value
Intercept	-11037.015		-16.934	.000
HDD		-.503	-3.222	.003
CDD		.115	.697	.492
[climate=zone 1]		1506.982	1.551	.132
[climate=zone 2]		1001.758	1.241	.225
[climate=zone 3]		217.617	.397	.694
[climate=zone 4]		817.105	1.736	.094
[climate=zone 5*]		0[a]	-16.934	.0001

a. R Squared = .614 (Adjusted R Squared = .531)
b. Computed using alpha = .05
c. Model F = 7.419
d. P value of model = 0.0001
*This parameter has been set to zero because it is redundant.

Interpretation: The F value of the model used was found to be statistically significant at 0.0001 level showing evidence that the independent variables do exhibit a relationship with the Energy savings dependent variable. The predictive efficiency of this model was found to be moderately high with R^2 of 0.614 and adjusted R^2 of 0.531. The result indicated that energy savings are positively correlated with HDD at the level of significance of 0.003. It provides evidence in support of the hypothesis that there is a statistically significant relationship between energy savings from a BIPV roof and heating degree days of the location.

6. CONCLUSIONS

Renewable energy sources are being hailed as one of the prominent technologies in development of sustainable energy strategy (Hill *et al*., 1995). Authors such as Hill (1996) and EPIA (1995) do share a vision of significant growth in PV technology industry as making their markets economic. However, we can only say the present market for PV technology is inelastic due the presence of only few niches in the market which can bear the high initial costs of BIPVs and producing energy savings as viable returns. A further study of sensitivity of the results can be made in the future for supporting hypothesis 2 of this study by including variables which can be investigated to the extent of energy savings dependency on climatic factors. BIPV technology is being promoted in commercial and industrial markets successfully producing acceptable outcomes but the high initial costs of BIPVs do not make them close competitors to conventional building materials yet. A further inclusion of federal and state tax benefits guaranteed to home owners when they integrate BIPVs in their homes might bridge this gap in costs between BIPVs and conventional materials in the Residential market.

The BIPV industry market can be expected to continue growing showing significant reduction in costs. If economic viability can be achieved to a greater extent even in the commercial market, a large scale production and deployment of PVs can be expected to be triggered.

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APPENDIX

Table A.1 AVERAGE RETAIL PRICE OF ELECTRICITY TO ULTIMATE CUSTOMERS BY RESIDENTIAL SECTOR, BY STATE, YEAR-TO-DATE THROUGH NOVEMBER 2010 AND 2009 (U.S Energy Information and Administration, Report February 14th, 2011)

Census Division and State	**Residential (U.S cents) 2010**	**Residential(U.S cents) 2009**
Connecticut	19.35	20.39
Maine	15.73	15.66
Massachusetts	15.18	17.23
New Hampshire	16.31	16.41
Rhode Island	15.94	15.64
Vermont	15.56	14.91
New Jersey	16.61	16.51
New York	18.66	17.77
Pennsylvania	12.84	11.7
Illinois	11.6	11.35[R]
Indiana	9.61	9.37
Michigan	12.51	11.83
Ohio	11.34	10.65
Wisconsin	12.57	11.97
Iowa	10.46	9.94
Kansas	9.97	9.68
Minnesota	10.46	10.01
Missouri	9.22	8.51
Nebraska	9.02	8.58
North Dakota	8.15	7.67
South Dakota	8.94	8.53
Delaware	13.84	14.16
District of Columbia	13.74	13.5
Florida	11.5	12.33
Georgia	10.26	10.13
Maryland	14.54	15.12
North Carolina	10.28	9.99

Table A1 Continued		
Census Division	**Residential (U.S cents)**	**Residential(U.S cents)**
and State	**2010**	**2009**
South Carolina	10.56	10.23
Virginia	10.55	10.66
West Virginia	8.78	7.87
Alabama	10.87	10.61
Kentucky	8.59	8.35
Mississippi	9.98	10.2
Tennessee	9.29	9.38
Arkansas	8.82	9.37
Louisiana	8.97	8.28
Oklahoma	9.17	8.71
Texas	11.61	12.78
Arizona	11.05	10.81
Colorado	11.12	9.99
Idaho	7.98	7.67
Montana	9.18	8.91
Nevada	12.42	12.84
New Mexico	10.63	10.17
Utah	8.77	8.54
Wyoming	8.79	8.59
California	15.23	15.05
Oregon	8.86	8.76
Washington	7.97	7.75
Alaska	16.44	17.3
Hawaii	28	24.01

Table A.2 THE ENERGY SAVINGS IN US$ FROM THE SIMULATIONS OF THE PV ROOF FOR THE LOCATIONS IN CLIMATIC ZONE 1 FOR A NET PRESENT VALUE OF 25 YEARS

	Bismarck _ND	**Cheyenne WY**	**Fargo_ND**	**Kalispell_ MT**	**Mason city_IA**	**North platte NE**	**Rapid city_SD**
Year 1	1,139.16	1,269.24	1,106.44	1,090.30	1,236.66	1,269.41	1,205.12
Year 2	1,161.80	1,294.47	1,128.43	1,111.97	1,261.24	1,294.64	1,229.07
Year 3	1,184.90	1,320.19	1,150.86	1,134.07	1,286.30	1,320.37	1,253.50
Year 4	1,208.44	1,346.43	1,173.74	1,156.61	1,311.87	1,346.62	1,278.41
Year 5	1,232.46	1,373.19	1,197.06	1,179.60	1,337.94	1,373.38	1,303.82
Year 6	1,256.96	1,400.49	1,220.86	1,203.04	1,364.53	1,400.68	1,329.73
Year 7	1,281.94	1,428.32	1,245.12	1,226.96	1,391.65	1,428.52	1,356.16
Year 8	1,307.42	1,456.71	1,269.87	1,251.34	1,419.31	1,456.91	1,383.11
Year 9	1,333.40	1,485.66	1,295.11	1,276.21	1,447.52	1,485.86	1,410.60
Year 10	1,359.90	1,515.19	1,320.85	1,301.58	1,476.29	1,515.39	1,438.64
Year 11	1,386.93	1,545.30	1,347.10	1,327.45	1,505.63	1,545.51	1,467.23
Year 12	1,414.50	1,576.02	1,373.87	1,353.83	1,535.56	1,576.23	1,496.39
Year 13	1,442.61	1,607.34	1,401.18	1,380.74	1,566.08	1,607.56	1,526.13
Year 14	1,471.28	1,639.28	1,429.03	1,408.18	1,597.20	1,639.51	1,556.47
Year 15	1,500.53	1,671.87	1,457.43	1,436.17	1,628.95	1,672.09	1,587.40
Year 16	1,530.35	1,705.09	1,486.39	1,464.71	1,661.32	1,705.33	1,618.95
Year 17	1,560.76	1,738.98	1,515.94	1,493.82	1,694.34	1,739.22	1,651.13
Year 18	1,591.78	1,773.55	1,546.06	1,523.51	1,728.01	1,773.79	1,683.94
Year 19	1,623.42	1,808.79	1,576.79	1,553.79	1,762.36	1,809.04	1,717.41
Year 20	1,655.69	1,844.74	1,608.13	1,584.67	1,797.39	1,844.99	1,751.55
Year 21	1,688.59	1,881.41	1,640.09	1,616.17	1,833.11	1,881.66	1,786.36
Year 22	1,722.15	1,918.80	1,672.69	1,648.29	1,869.54	1,919.06	1,821.86
Year 23	1,756.38	1,956.94	1,705.93	1,681.05	1,906.70	1,957.20	1,858.07
Year 24	1,791.29	1,995.83	1,739.84	1,714.46	1,944.59	1,996.10	1,895
Year 25	1,826.89	2,035.50	1,774.42	1,748.53	1,983.24	2,035.78	1,932.66

Table A.3 THE ENERGY SAVINGS IN US$ FROM THE SIMULATIONS OF THE PV ROOF FOR THE LOCATIONS IN CLIMATIC ZONE 2 FOR A NET PRESENT VALUE OF 25 YEARS

	Burns_OR	**Chicago_IL**	**Colorado springs_CO**	**Grand island NE**	**Omaha NE**	**Pueblo_CO**	**Reno_NV**
Year 1	1,277.28	1,178.03	1,389.53	1,311.96	1,248.70	1,415.85	1,402.73
Year 2	1,302.67	1,201.44	1,417.14	1,338.03	1,273.52	1,443.99	1,430.61
Year 3	1,328.56	1,225.32	1,445.31	1,364.62	1,298.83	1,472.69	1,459.04
Year 4	1,354.97	1,249.67	1,474.04	1,391.75	1,324.64	1,501.96	1,488.04
Year 5	1,381.90	1,274.51	1,503.33	1,419.41	1,350.97	1,531.81	1,517.62
Year 6	1,409.36	1,299.84	1,533.21	1,447.62	1,377.82	1,562.25	1,547.78
Year 7	1,437.37	1,325.68	1,563.68	1,476.39	1,405.21	1,593.30	1,578.54
Year 8	1,465.94	1,352.02	1,594.76	1,505.73	1,433.13	1,624.97	1,609.92
Year 9	1,495.08	1,378.90	1,626.46	1,535.66	1,461.62	1,657.27	1,641.91
Year 10	1,524.79	1,406.30	1,658.78	1,566.18	1,490.67	1,690.21	1,674.55
Year 11	1,555.10	1,434.25	1,691.75	1,597.31	1,520.29	1,723.80	1,707.83
Year 12	1,586	1,462.76	1,725.37	1,629.05	1,550.51	1,758.06	1,741.77
Year 13	1,617.52	1,491.83	1,759.67	1,661.43	1,581.33	1,793	1,776.39
Year 14	1,649.67	1,521.48	1,794.64	1,694.45	1,612.75	1,828.64	1,811.69
Year 15	1,682.46	1,551.72	1,830.31	1,728.13	1,644.81	1,864.98	1,847.70
Year 16	1,715.90	1,582.56	1,866.69	1,762.48	1,677.50	1,902.05	1,884.42
Year 17	1,750	1,614.01	1,903.79	1,797.51	1,710.84	1,939.85	1,921.88
Year 18	1,784.78	1,646.09	1,941.62	1,833.23	1,744.84	1,978.41	1,960.07
Year 19	1,820.26	1,678.81	1,980.21	1,869.67	1,779.52	2,017.73	1,999.03
Year 20	1,856.43	1,712.17	2,019.57	1,906.83	1,814.89	2,057.83	2,038.76
Year 21	1,893.33	1,746.20	2,059.71	1,944.72	1,850.96	2,098.73	2,079.28
Year 22	1,930.96	1,780.91	2,100.65	1,983.38	1,887.75	2,140.44	2,120.61
Year 23	1,969.34	1,816.31	2,142.40	2,022.80	1,925.27	2,182.98	2,162.75
Year 24	2,008.48	1,852.40	2,184.98	2,063	1,963.53	2,226.37	2,205.74
Year 25	2,048.40	1,889.22	2,228.40	2,104	2,002.56	2,270.62	2,249.58

Table A.4 THE ENERGY SAVINGS IN US$ FROM THE SIMULATIONS OF THE PV ROOF FOR THE LOCATIONS IN CLIMATIC ZONE 3 FOR A NET PRESENT VALUE OF 25 YEARS

	Baltimore _MD	**Covingto n_KY**	**Eugene_OR**	**Knoxville _TN**	**Lousville _KY**	**North bend_OR**	**Tucson_ AZ**
Year 1	1,210.28	1,197.15	1,111.49	1,240.13	1,238.40	1,171.91	1,490.43
Year 2	1,234.34	1,220.94	1,133.59	1,264.78	1,263.02	1,195.20	1,520.05
Year 3	1,258.87	1,245.21	1,156.12	1,289.91	1,288.12	1,218.96	1,550.26
Year 4	1,283.89	1,269.96	1,179.09	1,315.55	1,313.72	1,243.19	1,581.07
Year 5	1,309.41	1,295.20	1,202.53	1,341.70	1,339.83	1,267.89	1,612.49
Year 6	1,335.43	1,320.94	1,226.43	1,368.36	1,366.46	1,293.09	1,644.54
Year 7	1,361.97	1,347.20	1,250.80	1,395.56	1,393.62	1,318.79	1,677.23
Year 8	1,389.04	1,373.97	1,275.66	1,423.30	1,421.32	1,345	1,710.56
Year 9	1,416.65	1,401.28	1,301.02	1,451.58	1,449.56	1,371.74	1,744.56
Year 10	1,444.81	1,429.13	1,326.87	1,480.43	1,478.37	1,399	1,779.23
Year 11	1,473.52	1,457.53	1,353.25	1,509.86	1,507.76	1,426.81	1,814.60
Year 12	1,502.81	1,486.50	1,380.14	1,539.87	1,537.72	1,455.16	1,850.66
Year 13	1,532.68	1,516.05	1,407.57	1,570.47	1,568.29	1,484.08	1,887.44
Year 14	1,563.14	1,546.18	1,435.55	1,601.68	1,599.46	1,513.58	1,924.96
Year 15	1,594.21	1,576.91	1,464.08	1,633.52	1,631.24	1,543.66	1,963.21
Year 16	1,625.89	1,608.25	1,493.18	1,665.98	1,663.67	1,574.34	2,002.23
Year 17	1,658.21	1,640.21	1,522.85	1,699.10	1,696.73	1,605.63	2,042.03
Year 18	1,691.16	1,672.81	1,553.12	1,732.86	1,730.45	1,637.55	2,082.61
Year 19	1,724.77	1,706.06	1,583.99	1,767.31	1,764.85	1,670.09	2,124
Year 20	1,759.05	1,739.97	1,615.47	1,802.43	1,799.92	1,703.28	2,166.22
Year 21	1,794.02	1,774.55	1,647.58	1,838.25	1,835.70	1,737.14	2,209.27
Year 22	1,829.67	1,809.82	1,680.32	1,874.79	1,872.18	1,771.66	2,253.18
Year 23	1,866.04	1,845.79	1,713.72	1,912.05	1,909.39	1,806.87	2,297.96
Year 24	1,903.12	1,882.47	1,747.78	1,950.05	1,947.34	1,842.79	2,343.64
Year 25	1,940.95	1,919.89	1,782.52	1,988.81	1,986.04	1,879.41	2,390.22

Table A.5 THE ENERGY SAVINGS IN US$ FROM THE SIMULATIONS OF THE PV ROOF FOR THE LOCATIONS IN CLIMATIC ZONE 4 FOR A NET PRESENT VALUE OF 25 YEARS

	Amarillo TX	**Asheville _NC**	**birmingham _AL**	**El paso TX**	**Fresno_C A**	**huntsville _AL**	**memphis _TN**
Year 1	1,408.38	1,262	1,293.01	1,474.88	1,363.50	1,276.01	1,301.41
Year 2	1,436.37	1,287.08	1,318.70	1,504.19	1,390.60	1,301.37	1,327.28
Year 3	1,464.92	1,312.66	1,344.91	1,534.09	1,418.24	1,327.23	1,353.65
Year 4	1,494.03	1,338.75	1,371.64	1,564.58	1,446.42	1,353.61	1,380.56
Year 5	1,523.73	1,365.36	1,398.91	1,595.67	1,475.17	1,380.52	1,408
Year 6	1,554.01	1,392.49	1,426.71	1,627.39	1,504.49	1,407.95	1,435.98
Year 7	1,584.90	1,420.17	1,455.06	1,659.73	1,534.39	1,435.94	1,464.52
Year 8	1,616.40	1,448.40	1,483.98	1,692.72	1,564.89	1,464.48	1,493.63
Year 9	1,648.52	1,477.18	1,513.48	1,726.36	1,595.99	1,493.58	1,523.31
Year 10	1,681.29	1,506.54	1,543.56	1,760.67	1,627.71	1,523.27	1,553.59
Year 11	1,714.70	1,536.48	1,574.24	1,795.67	1,660.06	1,553.54	1,584.47
Year 12	1,748.78	1,567.02	1,605.52	1,831.35	1,693.05	1,584.42	1,615.96
Year 13	1,783.54	1,598.17	1,637.43	1,867.75	1,726.70	1,615.91	1,648.08
Year 14	1,818.99	1,629.93	1,669.98	1,904.87	1,761.02	1,648.03	1,680.83
Year 15	1,855.14	1,662.32	1,703.17	1,942.73	1,796.02	1,680.78	1,714.24
Year 16	1,892.01	1,695.36	1,737.02	1,981.35	1,831.72	1,714.19	1,748.31
Year 17	1,929.61	1,729.06	1,771.54	2,020.73	1,868.12	1,748.25	1,783.06
Year 18	1,967.96	1,763.42	1,806.75	2,060.89	1,905.25	1,783	1,818.50
Year 19	2,007.08	1,798.47	1,842.66	2,101.85	1,943.12	1,818.44	1,854.64
Year 20	2,046.97	1,834.22	1,879.28	2,143.62	1,981.74	1,854.58	1,891.50
Year 21	2,087.65	1,870.67	1,916.64	2,186.23	2,021.13	1,891.44	1,929.09
Year 22	2,129.14	1,907.85	1,954.73	2,229.68	2,061.30	1,929.03	1,967.43
Year 23	2,171.46	1,945.77	1,713.72	2,273.99	2,102.26	1,967.37	2,006.54
Year 24	2,214.62	1,984.44	1,747.78	2,319.19	2,144.05	2,006.47	2,046.42
Year 25	2,258.63	2,023.88	1,782.52	2,365.28	2,186.66	2,046.35	2,087.09

Table A.6 THE ENERGY SAVINGS IN US$ FROM THE SIMULATIONS OF THE PV ROOF FOR THE LOCATIONS IN CLIMATIC ZONE 5 FOR A NET PRESENT VALUE OF 25 YEARS

	Abilene_ TX	**Brownsvi lle_TX**	**Fortworth_T X**	**Lake charles_L A**	**Lufkin_T X**	**Midland TX**	**New orleans_L A**
Year 1	1,398.50	1,318.42	1,345.71	1,301.53	1,318.80	1,426.07	1,300.36
Year 2	1,426.29	1,344.62	1,372.45	1,327.40	1,345.01	1,454.42	1,326.21
Year 3	1,454.64	1,371.35	1,399.73	1,353.78	1,371.74	1,483.32	1,352.57
Year 4	1,483.55	1,398.60	1,427.55	1,380.68	1,399.01	1,512.80	1,379.45
Year 5	1,513.04	1,426.40	1,455.92	1,408.13	1,426.81	1,542.87	1,406.87
Year 6	1,543.11	1,454.75	1,484.86	1,436.11	1,455.17	1,573.54	1,434.83
Year 7	1,573.78	1,483.66	1,514.37	1,464.65	1,484.09	1,604.81	1,463.34
Year 8	1,605.06	1,513.15	1,544.47	1,493.76	1,513.59	1,636.71	1,492.43
Year 9	1,636.96	1,543.22	1,575.17	1,523.45	1,543.67	1,669.24	1,522.09
Year 10	1,669.49	1,573.90	1,606.47	1,553.73	1,574.35	1,702.41	1,552.34
Year 11	1,702.67	1,605.18	1,638.40	1,584.61	1,605.64	1,736.25	1,583.19
Year 12	1,736.51	1,637.08	1,670.96	1,616.11	1,637.55	1,770.75	1,614.66
Year 13	1,771.03	1,669.62	1,704.17	1,648.23	1,670.10	1,805.95	1,646.75
Year 14	1,806.23	1,702.80	1,738.04	1,680.99	1,703.29	1,841.84	1,679.48
Year 15	1,842.13	1,736.64	1,772.59	1,714.39	1,737.15	1,878.45	1,712.86
Year 16	1,878.74	1,771.16	1,807.82	1,748.47	1,771.67	1,915.78	1,746.90
Year 17	1,916.08	1,806.36	1,843.75	1,783.22	1,806.88	1,953.86	1,781.62
Year 18	1,954.16	1,842.26	1,880.39	1,818.66	1,842.80	1,992.69	1,817.03
Year 19	1,993	1,878.88	1,917.77	1,854.81	1,879.42	2,032.30	1,853.15
Year 20	2,032.61	1,916.22	1,955.88	1,891.67	1,916.78	2,072.69	1,889.98
Year 21	2,073.01	1,954.31	1,994.76	1,929.27	1,954.87	2,113.88	1,927.54
Year 22	2,114.21	1,993.15	2,034.40	1,967.61	1,993.72	2,155.90	1,965.85
Year 23	2,156.23	2,032.76	2,074.83	2,006.72	2,033.35	2,198.74	2,004.92
Year 24	2,199.08	2,073.16	2,116.07	2,046.60	2,073.76	2,242.44	2,044.77
Year 25	2,242.79	2,114.37	2,158.13	2,087.28	2,114.98	2,287.01	2,085.41

Table A.7 THE MAINTENANCE COSTS IN US$ FROM THE SIMULATIONS.

(SAME FOR ALL CLIMATIC ZONES)

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5
Year 1	200	200	200	200	200
Year 2	205	205	205	205	205
Year 3	210.12	210.12	210.12	210.12	210.12
Year 4	215.38	215.38	215.38	215.38	215.38
Year 5	220.76	220.76	220.76	220.76	220.76
Year 6	226.28	226.28	226.28	226.28	226.28
Year 7	231.94	231.94	231.94	231.94	231.94
Year 8	237.74	237.74	237.74	237.74	237.74
Year 9	243.68	243.68	243.68	243.68	243.68
Year 10	249.77	249.77	249.77	249.77	249.77
Year 11	256.02	256.02	256.02	256.02	256.02
Year 12	262.42	262.42	262.42	262.42	262.42
Year 13	268.98	268.98	268.98	268.98	268.98
Year 14	275.7	275.7	275.7	275.7	275.7
Year 15	282.59	282.59	282.59	282.59	282.59
Year 16	289.66	289.66	289.66	289.66	289.66
Year 17	296.9	296.9	296.9	296.9	296.9
Year 18	304.32	304.32	304.32	304.32	304.32
Year 19	311.93	311.93	311.93	311.93	311.93
Year 20	319.73	319.73	319.73	319.73	319.73
Year 21	327.72	327.72	327.72	327.72	327.72
Year 22	335.92	335.92	335.92	335.92	335.92
Year 23	344.31	344.31	344.31	344.31	344.31
Year 24	352.92	352.92	352.92	352.92	352.92
Year 25	361.75	361.75	361.75	361.75	361.75

Table A.8 THE ESTIMATION OF THE ASPHALT SHINGLES FOR HATCHED ROOF AREA FOR ZONE 1

Zone 1	**Area(sq.ft)**	**Material costs-$/sq.ft**	**Labor costs-$/sq.ft**	**Bare costs with overhead(/sq.ft)**	**Total cost**	**Location factor**	**Final cost**
Casper WY	863.26	1.57	0.83	$3.10	$2,676.11	81.2	$2,173.00
Eagle_CO	863.26	1.57	0.83	$3.10	$2,676.11	91	$2,435.26
Grand junction_CO	863.26	1.57	0.83	$3.10	$2,676.11	91.5	$2,448.64
Lander TX	863.26	1.57	0.83	$3.10	$2,676.11	80.8	$2,162.29
Minneapolis_MN	863.26	1.57	0.83	$3.10	$2,676.11	112.5	$3,010.62
Pierre_SD	863.26	1.57	0.83	$3.10	$2,676.11	79.5	$2,127.50
Saint cloud_MN	863.26	1.57	0.83	$3.10	$2,676.11	108.9	$2,914.28

Table A.9 THE ESTIMATION OF THE ASPHALT SHINGLES FOR HATCHED ROOF AREA FOR ZONE 2

Zone 1	**Area(sq.ft)**	**Material costs-$/sq.ft**	**Labor costs-$/sq.ft**	**Bare costs with overhead(/sq.ft)**	**Total cost**	**Location factor**	**Final cost**
Cedar city_UT	863.26	1.57	0.83	$3.10	$2,676.11	87.3	$2,336.24
Cleveland_OH	863.26	1.57	0.83	$3.10	$2,676.11	99.7	$2,668.08
Goodlands KA	863.26	1.57	0.83	$3.10	$2,676.11	86.4	$2,312.16
Las vegas_NV	863.26	1.57	0.83	$3.10	$2,676.11	105.9	$2,834.00
Pittsburg_PA	863.26	1.57	0.83	$3.10	$2,676.11	100.9	$2,700.19
Redmond_OR	863.26	1.57	0.83	$3.10	$2,676.11	99.3	$2,657.37
Seattle_WA	863.26	1.57	0.83	$3.10	$2,676.11	105	$2,809.91

Table A.10 THE ESTIMATION OF THE ASPHALT SHINGLES FOR HATCHED ROOF AREA FOR ZONE 3

Zone 1	Area(sq.ft)	Material costs-$/sq.ft	Labor costs-$/sq.ft	Bare costs with overhead(/sq.ft)	Total cost	Location factor	Final cost
Bristol_TN	863.26	1.57	0.83	$3.10	$2,676.11	81.1	$2,170.32
Dodge city_KS	863.26	1.57	0.83	$3.10	$2,676.11	86.2	$2,306.80
Evansville_IN	863.26	1.57	0.83	$3.10	$2,676.11	91.5	$2,448.64
Lexington_KY	863.26	1.57	0.83	$3.10	$2,676.11	86.9	$2,325.54
Lynchburg_VA	863.26	1.57	0.83	$3.10	$2,676.11	83.6	$2,237.22
Roanoke_VA	863.26	1.57	0.83	$3.10	$2,676.11	82.8	$2,215.82
Wichita_KS	863.26	1.57	0.83	$3.10	$2,676.11	83.4	$2,231.87

Table A.11 THE ESTIMATION OF THE ASPHALT SHINGLES FOR HATCHED ROOF AREA FOR ZONE 4

Zone 1	Area(sq.ft)	Material costs-$/sq.ft	Labor costs-$/sq.ft	Bare costs with overhead(/sq.ft)	Total cost	Location factor	Final cost
Arcata_CA	863.26	1.57	0.83	$3.10	$2,676.11	106.1	$2,839.35
Athens_GA	863.26	1.57	0.83	$3.10	$2,676.11	81.5	$2,181.03
Charlotte_NC	863.26	1.57	0.83	$3.10	$2,676.11	76.5	$2,047.22
Fort smith_AR	863.26	1.57	0.83	$3.10	$2,676.11	82	$2,194.41
Greensboro_NC	863.26	1.57	0.83	$3.10	$2,676.11	76.2	$2,039.19
Long beach_ca	863.26	1.57	0.83	$3.10	$2,676.11	104.5	$2,796.53
Tulsa_OK	863.26	1.57	0.83	$3.10	$2,676.11	78.1	$2,090.04

Table A.12 THE ESTIMATION OF THE ASPHALT SHINGLES FOR HATCHED ROOF AREA FOR ZONE 5

Zone 1	**Area(sq.ft)**	**Material costs-$/sq.ft**	**Labor costs-$/sq.ft**	**Bare costs with overhead(/sq.ft)**	**Total cost**	**Location factor**	**Final cost**
Baton Rouge_LA	863.26	1.57	0.83	$3.10	$2,676.11	84.5	$2,261.31
Corpus christi_TX	863.26	1.57	0.83	$3.10	$2,676.11	77.6	$2,076.66
Keywest_FL	863.26	1.57	0.83	$3.10	$2,676.11	88.2	$2,360.33
Lubbock_TX	863.26	1.57	0.83	$3.10	$2,676.11	80.8	$2,162.29
Miami_FL	863.26	1.57	0.83	$3.10	$2,676.11	89.7	$2,400.47
Mobile_AL	863.26	1.57	0.83	$3.10	$2,676.11	83.9	$2,245.25
Savannah_GA	863.26	1.57	0.83	$3.10	$2,676.11	77.7	$2,079.33

Table A.13 NET PRESENT VALUE COSTS FOR BIPV ROOFS FOR THE 7 LOCATIONS FROM CLIMATIC ZONE 1 (COOL ZONE)

Zone 1	**Initial investment I**	**Operation maintenance and repair(OMR) in NPV**	**Energy costs**	**Energy savings (gain on investment) in NPV**	**Total NPV**
Bismarck_ND	$25,611.99	-$27,784.67	$0.00	-$15,914.58	-$11,870.09
Cheyenne WY	$25,611.99	-$27,784.67	$0.00	-$14,559.16	-$13,225.51
Fargo_ND	$25,611.99	-$27,784.67	$0.00	-$16,255.50	-$11,529.17
Kalispell_MT	$25,611.99	-$27,784.67	$0.00	-$16,423.70	-$11,360.97
Mason city_IA	$25,611.99	-$27,784.67	$0.00	-$14,898.68	-$12,885.99
North platte NE	$25,611.99	-$27,784.67	$0.00	-$14,557.37	-$13,227.30
Rapid city_SD	$25,611.99	-$27,784.67	$0.00	-$15,227.33	-$12,557.34

Table A.14 NET PRESENT VALUE COSTS FOR BIPV ROOFS FOR THE 7 LOCATIONS FROM CLIMATIC ZONE 2 (TEMPERATE ZONE)

Zone 2	Initial investment I	Operation maintenance and repair(OMR) in NPV	Energy costs	Energy savings (gain on investment) in NPV	Total NPV
Burns_OR	$25,611.99	-$27,784.67	$0.00	-$14,475.35	-$13,309.32
Chicago_IL	$25,611.99	-$27,784.67	$0.00	-$15,509.60	-$12,275.07
Colorado springs_CO	$25,611.99	-$27,784.67	$0.00	-$13,305.78	-$14,478.89
Grand island NE	$25,611.99	-$27,784.67	$0.00	-$14,114.07	-$13,670.60
Omaha NE	$25,611.99	-$27,784.67	$0.00	-$14,773.20	-$13,011.47
Pueblo_CO	$25,611.99	-$27,784.67	$0.00	-$13,031.49	-$14,753.18
Reno_NV	$25,611.99	-$27,784.67	$0.00	-$13,168.19	-$14,616.48

Table A.15 NET PRESENT VALUE COSTS FOR BIPV ROOFS FOR THE 7 LOCATIONS FROM CLIMATIC ZONE 3 (MODERATE TEMPERATE ZONE)

Zone 3	Initial investment I	Operation maintenance and repair(OMR) in NPV	Energy costs	Energy savings (gain on investment) in NPV	Total NPV
Baltimore_MD	$25,611.99	-$27,784.67	$0.00	-$15,173.50	-$12,611.17
Covington_KY	$25,611.99	-$27,784.67	$0.00	-$15,310.34	-$12,474.33
Eugene_OR	$25,611.99	-$27,784.67	$0.00	-$16,202.88	-$11,581.79
Knoxville_TN	$25,611.99	-$27,784.67	$0.00	-$14,862.51	-$12,922.16
Lousville_KY	$25,611.99	-$27,784.67	$0.00	-$14,880.49	-$12,904.18
North bend_OR	$25,611.99	-$27,784.67	$0.00	-$15,573.34	-$12,211.33
Tucson_AZ	$25,611.99	-$27,784.67	$0.00	-$12,254.41	-$15,530.26

Table A.16 NET PRESENT VALUE COSTS FOR BIPV ROOFS FOR THE 7 LOCATIONS FROM CLIMATIC ZONE 4 (HOT AND ARID ZONE)

Zone 4	**Initial investment I**	**Operation maintenance and repair(OMR) in NPV**	**Energy costs**	**Energy savings (gain on investment) in NPV**	**Total NPV**
Amarillo TX	$25,611.99	-$27,784.67	$0.00	-$13,109.34	-$14,675.33
Asheville_NC	$25,611.99	-$27,784.67	$0.00	-$14,634.64	-$13,150.03
Birmingham_AL	$25,611.99	-$27,784.67	$0.00	-$14,394.92	-$13,389.75
El paso TX	$25,611.99	-$27,784.67	$0.00	-$12,416.41	-$15,368.26
Fresno_CA	$25,611.99	-$27,784.67	$0.00	-$13,577.00	-$14,207.67
Huntsville_AL	$25,611.99	-$27,784.67	$0.00	-$14,488.64	-$13,296.03
Memphis_TN	$25,611.99	-$27,784.67	$0.00	-$14,223.96	-$13,560.71

Table A.17 NET PRESENT VALUE COSTS FOR BIPV ROOFS FOR THE 7 LOCATIONS FROM CLIMATIC ZONE 5 (HOT AND HUMID ZONE)

Zone 5	**Initial investment I**	**Operation maintenance and repair(OMR) in NPV**	**Energy costs**	**Energy savings (gain on investment) in NPV**	**Total NPV**
Abilene_TX	$25,611.99	-$27,784.67	$0.00	-$13,212.29	-$14,572.38
Brownsville_TX	$25,611.99	-$27,784.67	$0.00	-$14,046.72	-$13,737.95
Fortworth_TX	$25,611.99	-$27,784.67	$0.00	-$13,762.38	-$14,022.29
Lake charles_LA	$25,611.99	-$27,784.67	$0.00	-$14,222.73	-$13,561.94
Lufkin_TX	$25,611.99	-$27,784.67	$0.00	-$14,042.76	-$13,741.91
Midlands	$25,611.99	-$27,784.67	$0.00	-$12,924.96	-$14,859.71
New orleans_LA	$25,611.99	-$27,784.67	$0.00	-$14,234.86	-$13,549.81

Table A.18 NET PRESENT VALUE COSTS FOR ASPHALT ROOFS IN THE 35 LOCATIONS FROM THE 5 CLIMATIC ZONES

Zone 1	**Area(sq.ft)**	**Final cost**	**OMR In Present Value**	**E costs**	**E savings**	**Net Present Value –costs**
Casper WY	863.26	2,173.00	-2,508.22	0.00	0.00	-2,508.22
Eagle_CO	863.26	2,435.26	-2,770.48	0.00	0.00	-2,770.48
Grand junction_CO	863.26	2,448.64	-2,783.86	0.00	0.00	-2,783.86
Lander TX	863.26	2,162.29	-2,497.51	0.00	0.00	-2,497.51
Minneapolis_MN	863.26	3,010.62	-3,345.84	0.00	0.00	-3,345.84
Pierre_SD	863.26	2,127.50	-2,462.72	0.00	0.00	-2,462.72
Saint cloud_mn	863.26	2,914.28	-3,249.50	0.00	0.00	-3,249.50
Zone 2						
Cedar city_UT	863.26	2,336.24	-2,671.46	0.00	0.00	-2,671.46
Cleveland_OH	863.26	2,668.08	-3,003.30	0.00	0.00	-3,003.30
Goodlands KA	863.26	2,312.16	-2,647.38	0.00	0.00	-2,647.38
Las vegas_NV	863.26	2,834.00	-3,169.22	0.00	0.00	-3,169.22
Pittsburg_PA	863.26	2,700.19	-3,035.41	0.00	0.00	-3,035.41
Redmond_OR	863.26	2,657.37	-2,992.59	0.00	0.00	-2,992.59
Seattle_WA	863.26	2,809.91	-3,145.13	0.00	0.00	-3,145.13
Zone 3						
Bristol_TN	863.26	2,170.32	-2,505.54	0.00	0.00	-2,505.54
Dodge city_KS	863.26	2,306.80	-2,642.02	0.00	0.00	-2,642.02
Evansville_IN	863.26	2,448.64	-2,783.86	0.00	0.00	-2,783.86
Lexington_KY	863.26	2,325.54	-2,660.76	0.00	0.00	-2,660.76
Lynchburg_VA	863.26	2,237.22	-2,572.44	0.00	0.00	-2,572.44
Roanoke_VA	863.26	2,215.82	-2,551.04	0.00	0.00	-2,551.04
Wichita_KS	863.26	2,231.87	-2,567.09	0.00	0.00	-2,567.09
Zone 4						
Arcata_CA	863.26	2,839.35	-3,174.57	0.00	0.00	-3,174.57
Athens_GA	863.26	2,181.03	-2,516.25	0.00	0.00	-2,516.25
Charlotte_NC	863.26	2,047.22	-2,382.44	0.00	0.00	-2,382.44
Fort smith_AR	863.26	2,194.41	-2,529.63	0.00	0.00	-2,529.63
Greensboro_NC	863.26	2,039.19	-2,374.41	0.00	0.00	-2,374.41
Long beach_ca	863.26	2,796.53	-3,131.75	0.00	0.00	-3,131.75
Tulsa_OK	863.26	2,090.04	-2,425.26	0.00	0.00	-2,425.26
Zone 5						
Baton rouge_la	863.26	2,261.31	-2,596.53	0.00	0.00	-2,596.53
Corpus christi_TX	863.26	2,076.66	-2,411.88	0.00	0.00	-2,411.88
Keywest_FL	863.26	2,360.33	-2,695.55	0.00	0.00	-2,695.55
Lubbock_TX	863.26	2,162.29	-2,497.51	0.00	0.00	-2,497.51
Miami_FL	863.26	2,400.47	-2,735.69	0.00	0.00	-2,735.69
Mobile_AL	863.26	2,245.25	-2,580.47	0.00	0.00	-2,580.47

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