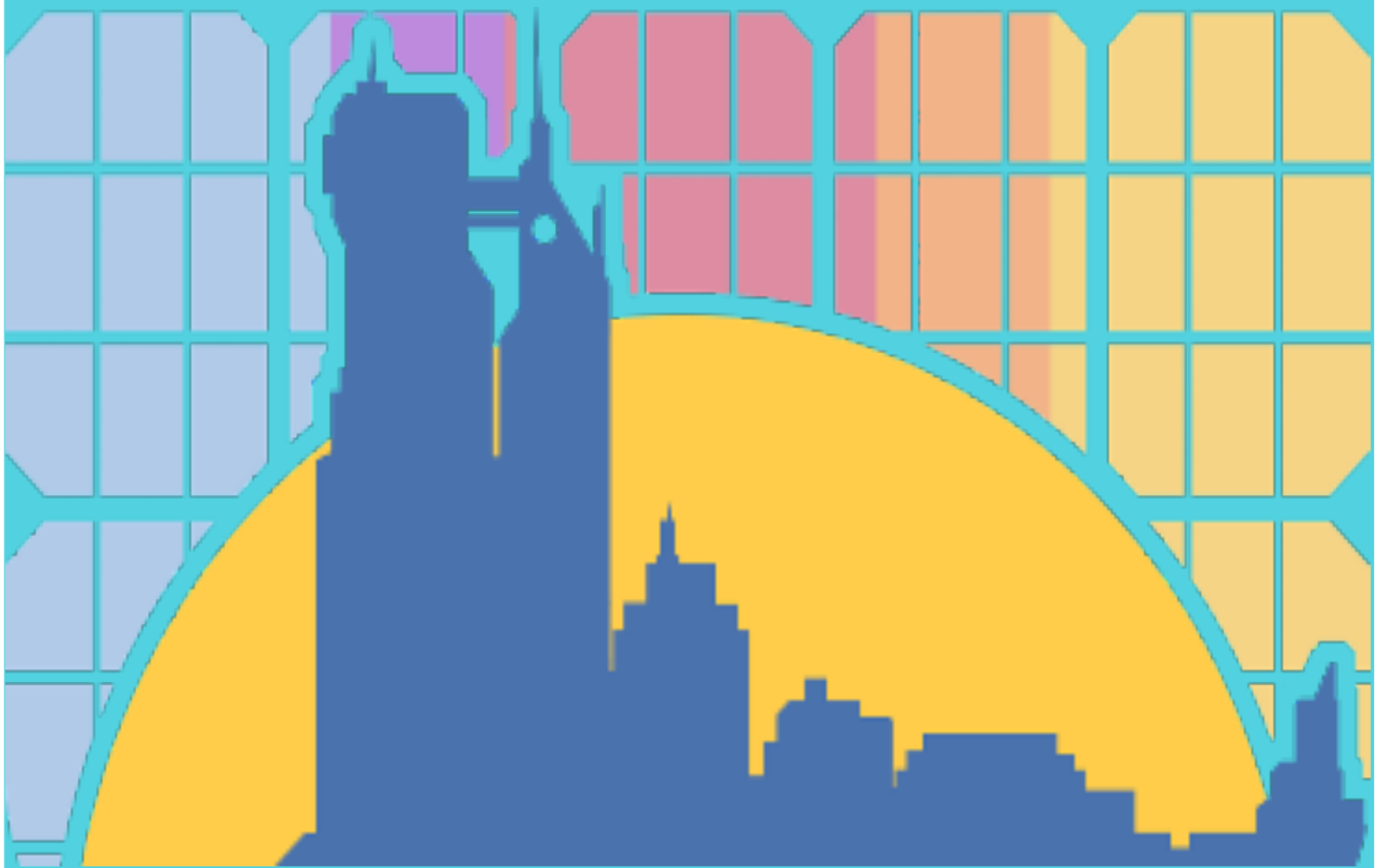

Solar Energy Application Lab

School of Property, Construction
and Project Management



BIPV Design Methods and Workflows in Australia

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Executive Summary

The contribution of Building integrated photovoltaic (BIPV) technology to the built environment and the total PV generation in Australia is very limited. Unlike other building envelope materials BIPV systems consists of electrical, mechanical, structural elements that impact the building and BIPV energy production. Complexities in the design, planning and construction process of BIPV envelopes can be identified as a reason for slow uptake of BIPV projects. Therefore, it is important to identify the correct BIPV design that would provide the best out come in terms of building requirement and energy generation.

Various methods, approaches and workflows are available to design and analysis of BIPV designs. This study uses a questionnaire survey to investigates the operative approaches, methods, and workflows in BIPV design and integration in Australia. The study evaluated findings from thirty-seven building design and construction and BIPV professionals in Australia.

This study identified methods, approaches and workflows in BIPV design and analysis in Australian context can be categorized under 1. workflows and methods used in solar irradiation modelling and simulation 2. workflows and methods used in BIPV power output modelling or simulation 3. workflows and methods used in building performance modelling or simulation and 4. workflows and methods used in financial and design outcome. The findings suggest the necessity of BIPV specific digital platforms to facilitate BIPV design professional in Australia.

Table of Contents

Executive Summary	4
Table of Contents	5
List of Tables	6
List of Figures	6
1. Introduction	1
2. Survey for design workflows for building envelopes	2
2.1 Questionnaire survey.....	2
2.2 Respondent’s profile.....	3
3. Survey findings	5
3.1 Workflows and methods used in solar irradiation modelling and simulation	5
3.1.1 Tools used for modelling BIPV envelopes.....	5
3.1.2 Tools used for simulating BIPV envelopes	5
3.1.3 Methods used for identifying the location (i.e., longitude and latitude) in simulation tools	6
3.1.4 Methodology for modelling the geometry of the building and surrounding environment..	7
3.1.5 Methods for photorealistic visualization for BIPV projects	8
3.1.6 Commonly used 3D format for data exchange between collaborators or data import	8
3.1.8 Type of weather data for designing BIPV projects.....	10
3.1.9 Type of weather file formats used in BIPV projects.....	10
3.1.10 Models in software to estimate Plane of array irradiation (POA)	11
3.1.11 POA sky diffuse model to estimate POA irradiance.....	11
3.1.12 Methods for shading approximations.....	12
3.2 Workflows and methods used in BIPV power output modelling or simulation	13
3.2.1 Methods used to import properties of the technical components of BIPV modules	13
3.2.2 Methods used for calculating the Electric DC output of BIPV	14
3.3 Workflows and methods used in Building performance modelling or simulation	14
3.3.1 Methods used for identifying the energy consumption patterns of a building.....	14
3.3.2 Suitable interval to be considered in energy consumption data	15
3.3.3 Data file formats for storing building energy consumption data	16
3.3.4 CO ₂ emissions associated with BIPV	16
3.3.5 Methods used to identify the thermal impact of BIPV designs	17
3.3.6 Method(s)/software to simulate the heat island impact.....	17
3.3.7 Methods used to identify the impact on daylighting.....	18
3.3.7 Structural loads considered during the planning and development of BIPV designs	18
3.3.8 Software used to identify the fire related impact in BIPV designs	19

3.4 Workflows and methods used in Financial and design outcome	19
3.4.1 Indicators considered for identifying the economic feasibility.....	19
3.4.2 Capital cost (initial costs) of BIPV	20
3.4.3 Operations and maintenance costs of BIPV.....	21
3.4.5 Life cycle income of BIPV	21
3.4.6 Material cost offset as a benefit of BIPV projects.....	22
3.4.7 Optioneering/ decision making methods	23
3.4.5 Factor(s) that impact the optimum design of BIPV.....	23
Conclusions	24
References	25

List of Tables

Table 1 Profiles of 37 respondents	3
Table 2 Areas of experience of the respondents	4
Table 3: Software used to simulate thermal load in BIPV designs	17
Table 4: Methods used to identify the impact on daylighting.....	18
Table 5: Software used in daylight analysis	18

List of Figures

Figure 1: Experience of the survey respondents	4
Figure 2: Tools used for modelling BIPV envelopes.....	5
Figure 3:Tools used for simulating BIPV envelopes.....	6
Figure 4: Methods used for identifying the location	7
Figure 5: Methods for modelling the geometry of the building and surrounding environment.....	7
Figure 6: Methods for photorealistic visualization for BIPV projects	8
Figure 7: Commonly used 3D format for data exchange	9
Figure 8: Weather parameters	9
Figure 9: Type of weather data for designing BIPV projects.....	10
Figure 10: Type of weather file formats	10
Figure 11: Models for estimating POA irradiation.....	11
Figure 12: POA sky diffuse model to estimate POA irradiance.....	12
Figure 13: Methods for shading approximations	12
Figure 14: Weather data step values.....	13
Figure 15: Methods to import properties of the technical components.....	13
Figure 16: Methods for calculating the Electric DC output of BIPV	14
Figure 17: Methods for identifying the building energy consumption patterns	15
Figure 18: Intervals in energy consumption data	15
Figure 19: Data file formats for storing building energy consumption data	16
Figure 20: CO ₂ emissions associated with BIPV	16

Figure 21: Methods used to identify the thermal impact of BIPV designs	17
Figure 22: Consideration of impact on the heat island effect in BIPV project design	18
Figure 23: Structural loads in BIPV	19
Figure 24: Indicators considered for identifying the economic feasibility	20
Figure 25: Capital cost (initial costs) of BIPV	20
Figure 26: Operations and maintenance costs of BIPV.....	21
Figure 27: Life cycle income of BIPV	22
Figure 28: Considering material offset	22
Figure 29: Optioneering/ decision making methods	23
Figure 30: Factor(s) that impact the optimum design of BIPV	23

1. Introduction

Building Integrated Photovoltaics (BIPV) consist solar photovoltaic panels integrated into building envelope elements. BIPV applications can include roof and façade applications such as walls, windows, curtain walls, balconies, canopies, roof tiles, skylights, and roof sheets and shading devices. BIPV design process should be done considering both building envelope and PV elements in the BIPV system.

BIPV design simulation and analysis process can be done using various operative approaches, methods, and workflows. These operative approaches, methods, and workflows relevant to each domain of BIPV design and integration can be divided into 4 categories:

- Workflows and methods used in solar irradiation modelling and simulation
- Workflows and methods used in BIPV power output modelling or simulation
- Workflows and methods used in building performance modelling or simulation
- Workflows and methods used in financial and design outcome

This study is a part of IEA PVPS Task 15 Subtask No D on BIPV Digitalization. The study explores the approaches, methods, and workflows used in BIPV design simulation and analysis process globally. A web-based questionnaire survey was distributed to building design and construction and BIPV professionals to identify what methods and techniques are used under the above four categories of approaches, methods, and workflows. The study obtained the RMIT university human research ethics approval under reference no: 21583-06/18. This report discusses the findings of the survey in the Australian context.

First section of this report discusses about the questionnaire survey and the respondent profile. The second section discusses the questionnaire survey findings under workflows and methods used in solar irradiation modelling and simulation, workflows and methods used in solar power output modelling or simulation, workflows and methods used in building performance modelling or simulation and workflows and methods used in financial and design outcome. The conclusions are presented in the third section.

2. Survey for design workflows for building envelopes

2.1 Questionnaire survey

The online survey was developed aiming to investigate the operative methods and workflows relevant to building envelope design and digital process. The questionnaire consists of two sections as follows:

1. Background information

Questions on respondents' professional background such as country, profession and level of experience.

2. Approaches, methods and workflows used in building envelope/building envelope with solar panel design

Questions on BIPV design related operative methods and workflows relevant to building envelope design under 4 subsections:

- **Solar irradiation modeling and simulation:**
 - Based on location
 - Solar irradiation analysis for a specific building envelope
- **Solar power output modeling and simulation**
 - Power output of building envelope with solar panels
- **Building performance modeling and simulation**
 - Building energy consumption
 - Structural loads
 - Thermal loads
 - Daylighting
 - Fire safety
- **Financial and design outcome**
 - Building envelope financial analysis
 - Decision making in design

The targeted population considered in this study were professionals with BIPV design and management experiences in Australia. However, professionals who have BIPV design experience are limited in the Australian context. Therefore, both the professionals in building envelope design and professionals in BIPV design and management process in Australia were selected for this study. Therefore, participants from the below categories were chosen for the survey;

- Architects
- Façade Engineers
- Electrical engineer
- Mechanical/Structural engineer

- Fire engineer
- ESD consultant
- Academia, research, and development
- PV Consultant
- Infrastructure suppliers/ retailers
- BIPV system installation

The questionnaire survey was conducted through Qualtrics, a web-based application for building, distributing and analysing online questionnaire surveys. A recruitment email was sent to the participants with the link to the web-based questionnaire survey and the Participant Information Sheet, which describes the project and the project team, how the potential participants are selected, why they are chosen and what they have to do. The participants were requested to fill a web-based questionnaire survey and submit it Online. Submitting the completed questionnaire was considered an indication of the participants' consent to participate in the study, and no other written permission was requested.

2.2 Respondent's profile

Thirty-seven valid survey responses received. Table 1 displays the profiles of the respondents who completed the questionnaire survey. Most of the respondents were from academic, research and development and ESD consultants.

Table 1 Profiles of 37 respondents

Profession	No of respondents
Academic, research and development	10
Architect	5
PV Consultant	5
Electrical engineer	3
ESD consultant	8
Fire engineer	2
Mechanical/Structural engineer	4

Table 2 shows the involvement of the respondents in the building envelope simulation and analysis and BIPV designs related to simulation and analysis. As the Table shows, thirty (30) of the respondents have experiences in building envelop simulation and analysis, and only twenty (20) have experience related to BIPV designs. Therefore, the majority of the respondents have experience related to building envelope simulation and analysis.

Table 2 Areas of experience of the respondents

Profession	Experiences in the building envelope (façade & roof) simulation and analysis		Experience related to simulation and analysis of BIPV designs	
	Yes	No	Yes	No
Academic, research and development	8	2	9	1
Architect	5	0	3	2
Consultant	4	1	3	2
Electrical engineer	0	3	2	1
ESD consultant	8	0	3	5
Fire engineer	2	0	0	2
Mechanical/Structural engineer	3	1	0	4
Total	30	7	20	17

Figure 1 shows the respondents' experience in years. The respondents' experience impacts their knowledge on the methods, workflows, and techniques used in BIPV system designs. Therefore, the respondents with at least two years of experience in building design and construction or BIPV industry was selected for this study.

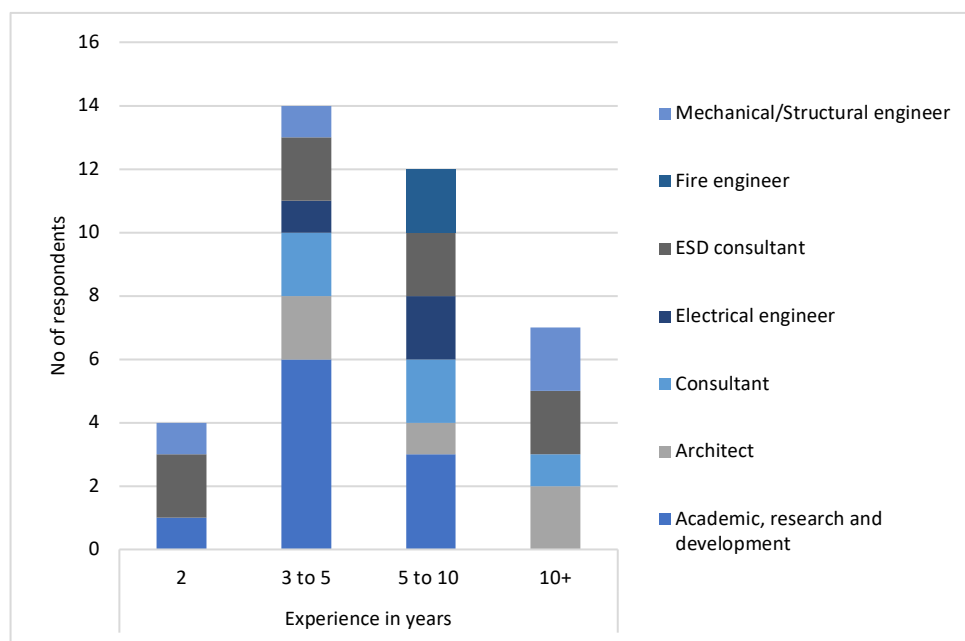


Figure 1: Experience of the survey respondents

3. Survey findings

3.1 Workflows and methods used in solar irradiation modelling and simulation

3.1.1 Tools used for modelling BIPV envelopes

Software can be used for designing a BIPV system to identify the building parameters such as building’s location, orientation, energy consumption, roof and façade layout etc. Figure 2 shows the survey results on software/tools used for modelling BIPV projects.

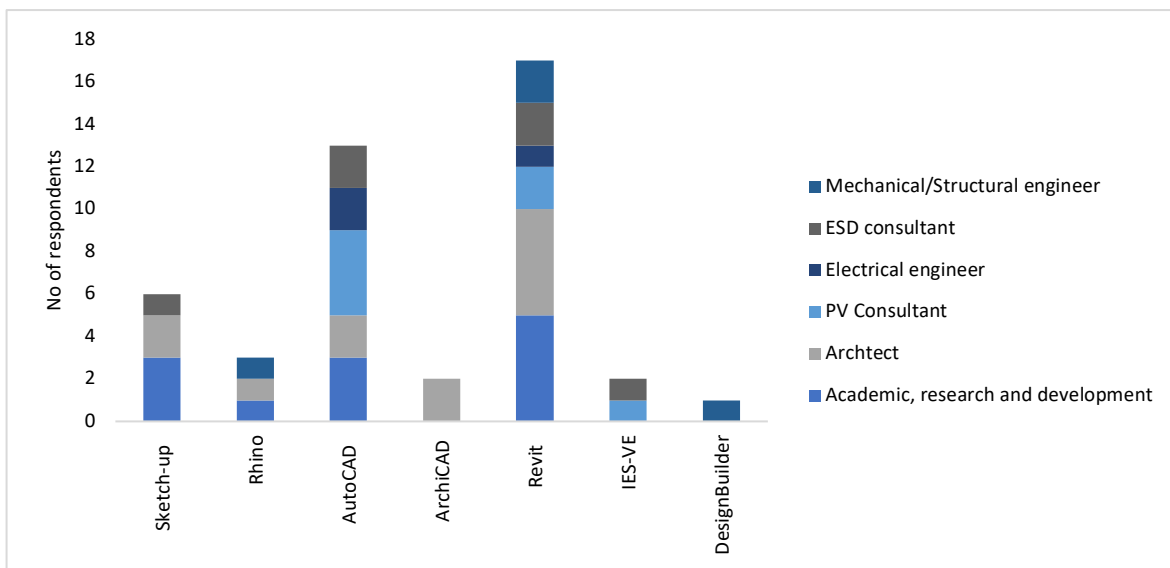


Figure 2: Tools used for modelling BIPV envelopes

Survey findings shows SketchUp, Rhino, AutoCAD, ArchiCAD, Autodesk Revit, IES VE and designbuilder are currently used for modelling building envelopes. All this software can be used to generate 3D models of the building and elements of the building envelope. As shown in Figure 2, Autodesk Revit, a 3D BIM software was selected as the most preferred software for modelling BIPV projects. AutoCAD is the second most preferred for BIPV designs.

3.1.2 Tools used for simulating BIPV envelopes

Many solar PV design and simulation tools are available for calculating solar irradiance, shading loss, energy output, and economic viability of BIPV projects. Figure 3 shows the survey results on software/tools used for simulating BIPV projects.

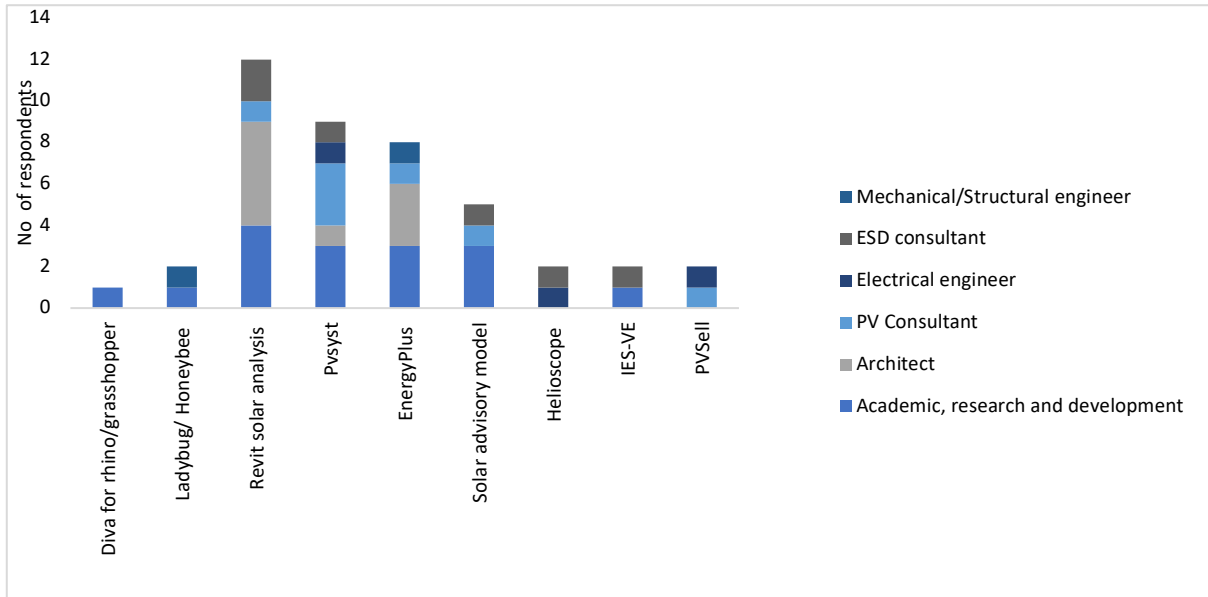


Figure 3: Tools used for simulating BIPV envelopes

The results show, Diva, Ladybug/ honeybee for rhino/grasshopper, Revit solar analysis, Pvsyst, EnergyPlus, Solar advisory model, Helioscope, IES-VE and PVSell are currently used to simulate solar potential, energy output of building envelopes. Pvsyst, Solar advisory model, Helioscope and PVSell can be used for roof integrated PV designs. Whereas Ladybug/ honeybee for rhino/grasshopper, Revit solar analysis, EnergyPlus and IES-VE can be used for in both roof and façade integrated PV designs. Apart from IES VE, ladybug/ honeybee, Revit solar analysis and EnergyPlus add-ons or plugins that can be used to analyze the solar potential of a building model in Autodesk Revit and Rhino3D.

3.1.3 Methods used for identifying the location (i.e., longitude and latitude) in simulation tools

Simulation tools typically requires the user to identify the location of the building in order to collect local weather data parameters. There are three common ways to identify the building location in simulation tools. They include google maps, IP address and select from software’s own database. Figure 4 shows the survey results on the methods for identifying the BIPV project location for simulating BIPV projects. Many 11 respondents use Google maps to determine the location and 5 respondents identify the location manually from a list.

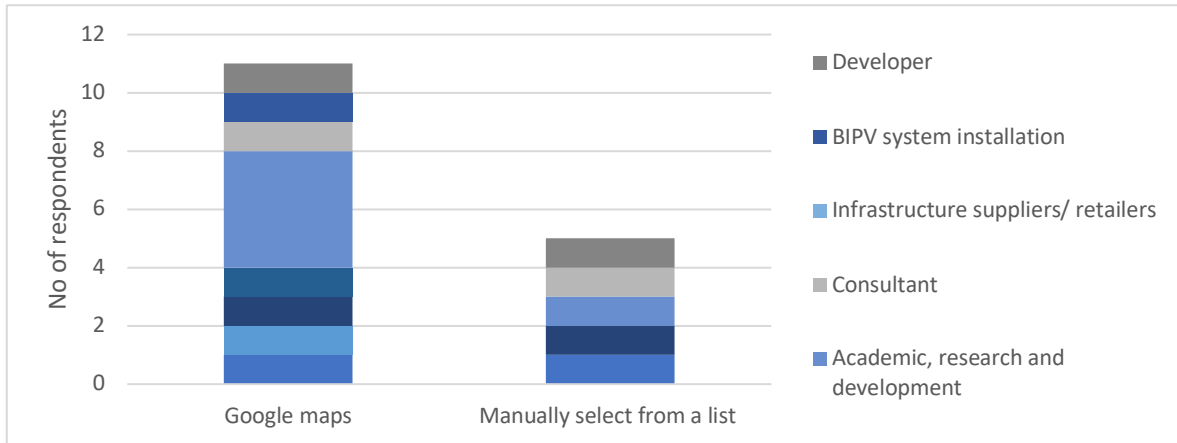


Figure 4: Methods used for identifying the location

3.1.4 Methodology for modelling the geometry of the building and surrounding environment

2D CAD, 3D CAD, GIS-based modelling, and Point-cloud data using LIDAR-assisted modelling are preferred technologies for modelling the geometry of the buildings and surrounding environment. Figure 5 shows the survey results on the preferred methods for modelling BIPV projects.

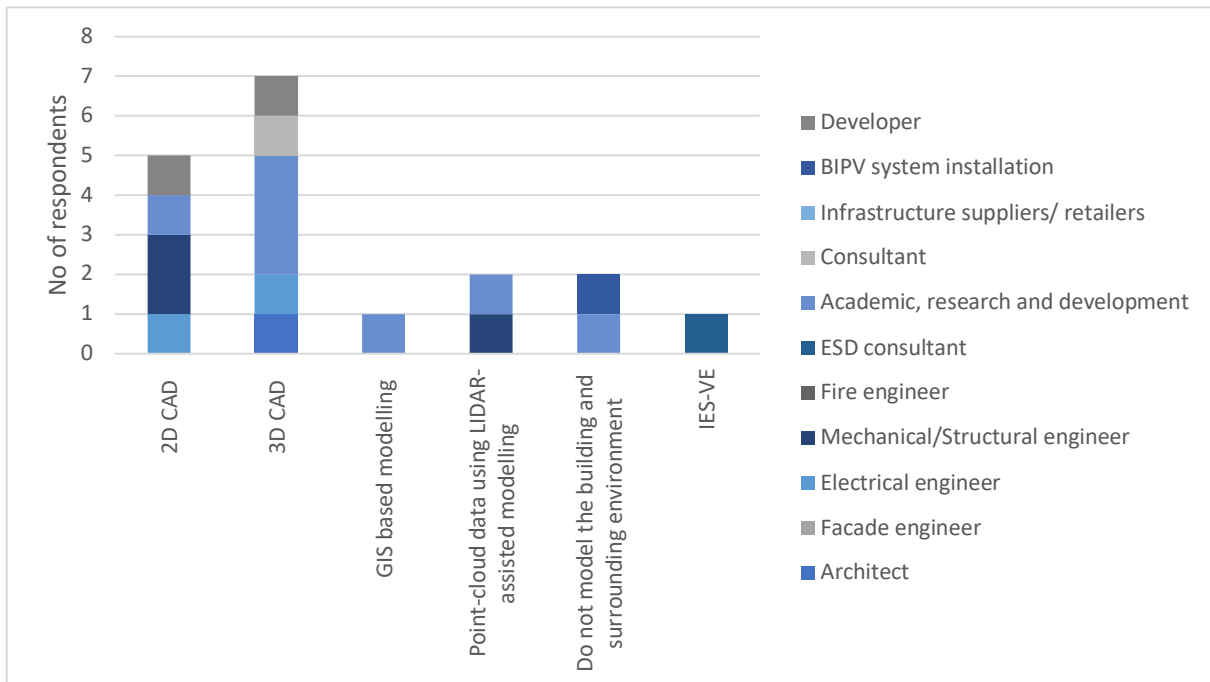


Figure 5: Methods for modelling the geometry of the building and surrounding environment

The survey results illustrate that 3D CAD modelling process is the most popular choice for modelling the geometry of the building and surrounding environment of a project among Architects, electrical engineers, Academics, BIPV system installers and developers. Not many have selected GIS-based modelling, and Point-cloud data using LIDAR-assisted modelling.

3.1.5 Methods for photorealistic visualization for BIPV projects

Photorealistic architectural visualization is used to graphically represent the aesthetical appearance of a BIPV envelope (Jakica et al. 2019). As shown in Figure 6 not many use photorealistic visualization for BIPV projects. Only three respondents have mentioned that they use photorealistic visualization using Autodesk Maya software.

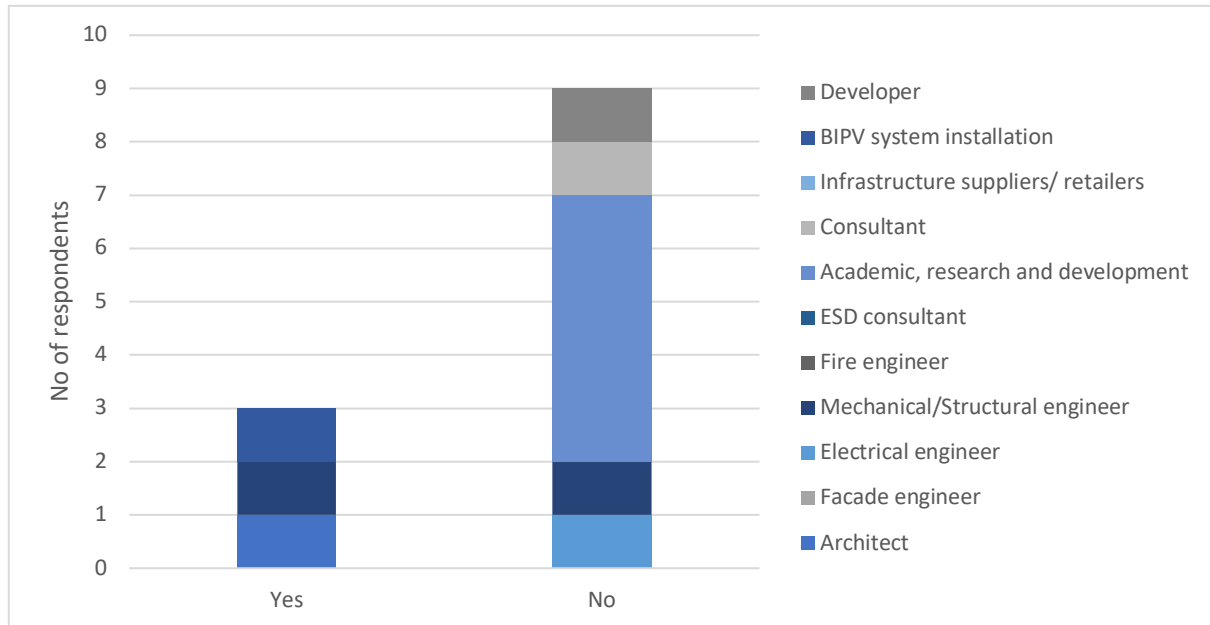


Figure 6: Methods for photorealistic visualization for BIPV projects

3.1.6 Commonly used 3D format for data exchange between collaborators or data import

In BIPV project designs, several 3D files formats can facilitate interoperability between BIPV design and simulation software such as proprietary formats:

- Trimble® SketchUp®.skp
- AutoDesk® .dwg or. fbx
- Rhinoceros® .3DS
- Open BIM (ISO) .ifc
- GreenBuilding XML(gbXML) .xml
- EnergyPlus™ format .idf
- AutoDesk® REVIT®.rvt
- AutoDesk® REVIT®family.rfa

Figure 7 presents the survey results on the common 3D formats adopted for the data exchange between collaborators in BIPV projects in Australia. These methods mainly depend on the software/tools used by the respondents. The survey results show that in Australia, AutoDesk® REVIT®.rvt and open BIM (ISO) format (.ifc) are used by Architects, Mechanical/structural Engineers, ESD consultants and Academics.

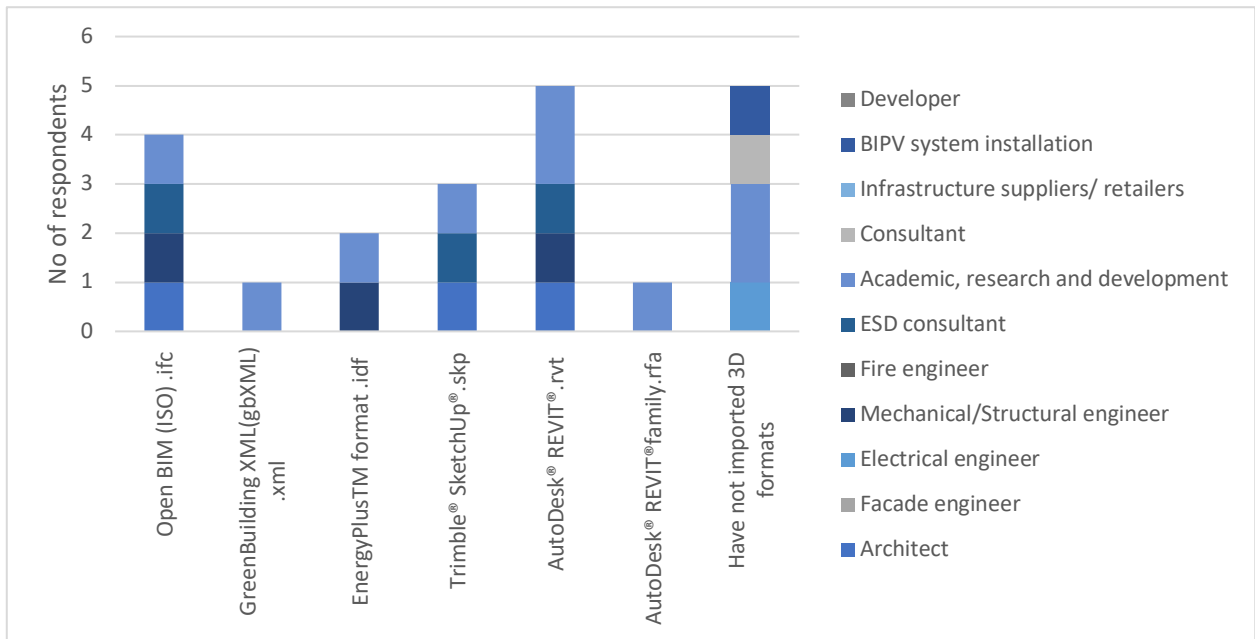


Figure 7: Commonly used 3D format for data exchange

3.1.7 Weather parameters for identifying solar potential (Plane of array irradiation)

Estimation of POA irradiation need to consider solar irradiation data such as Beam/Direct normal irradiance, diffuse horizontal irradiance, and global horizontal Irradiance. As shown in Figure 8, the Beam/Direct normal irradiance, diffuse horizontal irradiance, and global horizontal Irradiance components have been confirmed by the survey respondents.

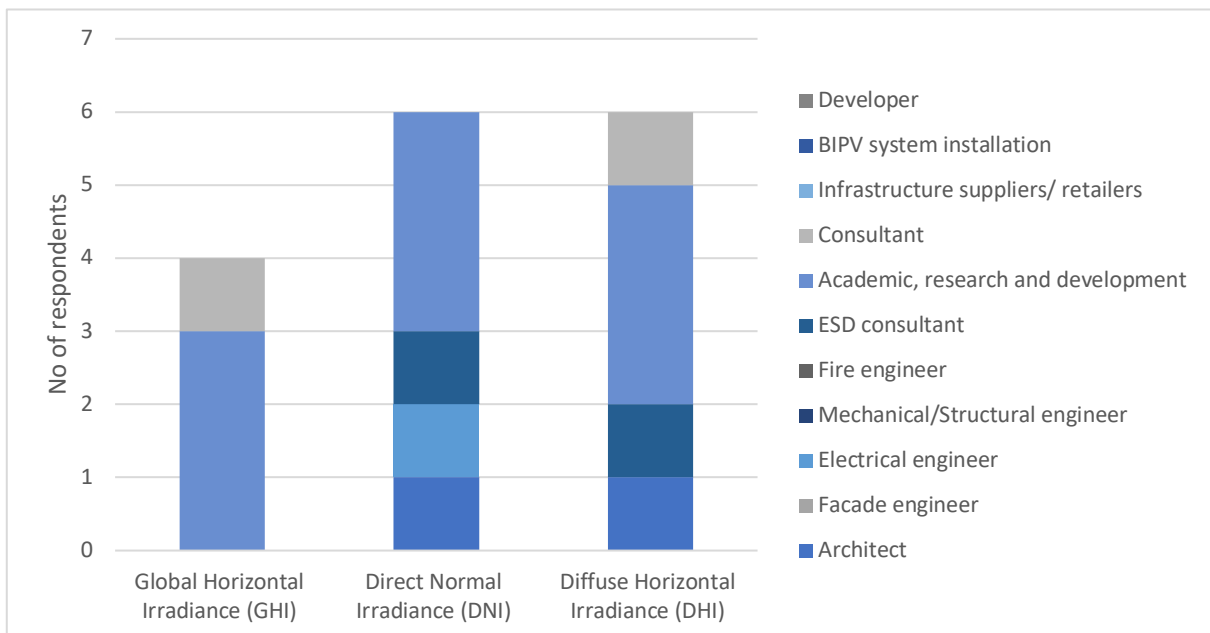


Figure 8: Weather parameters

3.1.8 Type of weather data for designing BIPV projects

Weather data are obtained from different types of observing stations around the world. The main methods used to collect weather data include ground mounted meteorological stations, satellite based meteorological data, measured at site, hybrid method (i.e. combination of ground mounted meteorological data and data measure at site and long-term averaged data. As shown in Figure 9, long-term averaged solar data is the most popular type used by the respondents for simulating BIPV projects followed by data from ground mounted meteorological stations.

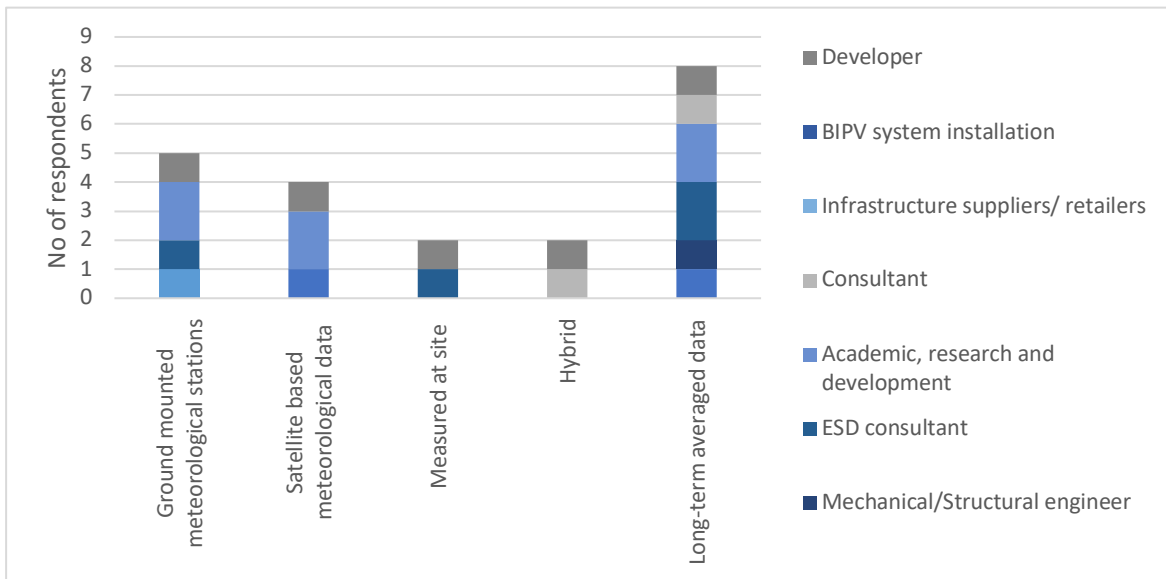


Figure 9: Type of weather data for designing BIPV projects

3.1.9 Type of weather file formats used in BIPV projects

Weather data formats commonly used in BIPV simulation are Typical Meteorological Year (TMY) and EPW files from the EnergyPlus website. As shown in Figure 10, Both EPW files and typical meteorological year (TMY) are considered in BIPV design in Australia. Most ESD consultant have selected EPW files and respondents from academic, research and development have selected Typical Meteorological Year weather format.

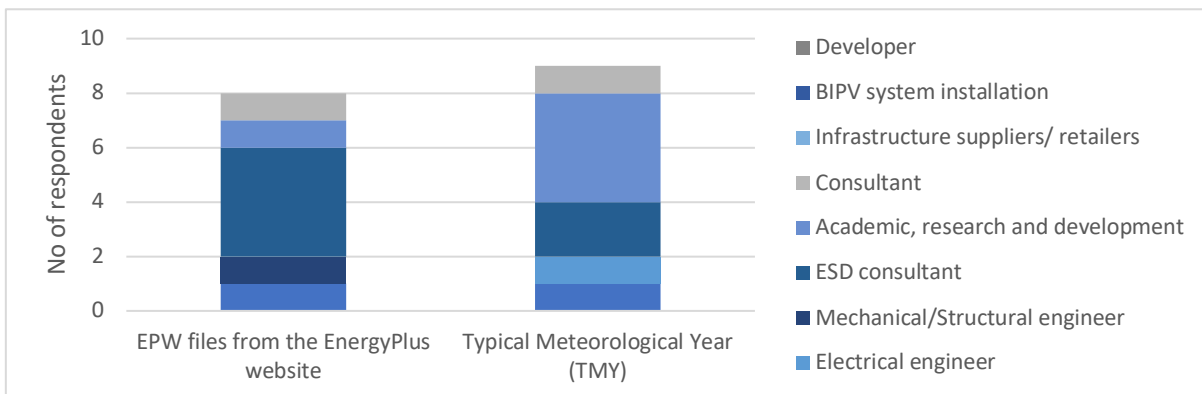


Figure 10: Type of weather file formats

3.1.10 Models in software to estimate Plane of array irradiation (POA)

Several methods are available to estimate Plane of array irradiation (POA) in BIPV projects such as:

- POA (Beam only)
- POA with shading and ground reflected (Albedo)
- POA sky diffused
- Ray tracing with radiosity
- Ray tracing with rasterization

Figure 11 shows the survey results on the components used for estimating POA irradiation. The result show that POA sky diffuse irradiance and POA Beam with shading and albedo is important for estimating POA irradiation. BIPV projects should consider both POA sky diffuse irradiance and POA with shading and ground reflectance for estimating POA irradiation.

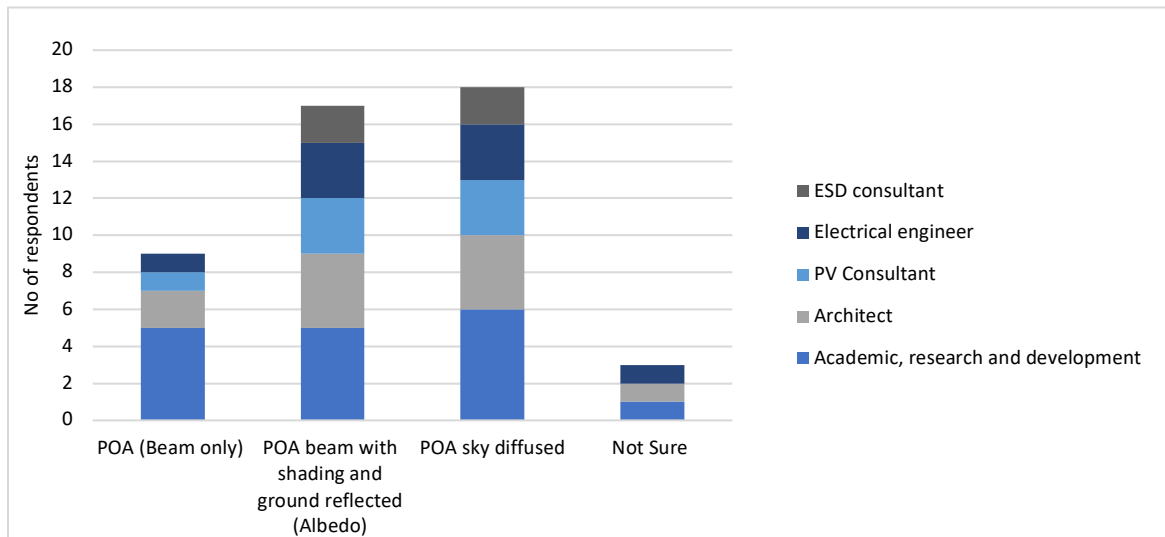


Figure 11: Models for estimating POA irradiation

3.1.11 POA sky diffuse model to estimate POA irradiance

Several methods can be used to estimate POA sky diffuse irradiation in BIPV projects such as:

- Isotropic Sky Diffuse Model (Sandia National Laboratories 2018)
- Simple Sandia Sky Diffuse Model (Sandia National Laboratories 2018)
- Hay and Davies Sky Diffuse Model (Hay and Davies 1980)
- Reindl Sky Diffuse Model (Reindl, Beckman, and Duffie 1990)
- Perez Sky Diffuse Model (Perez et al. 1987)

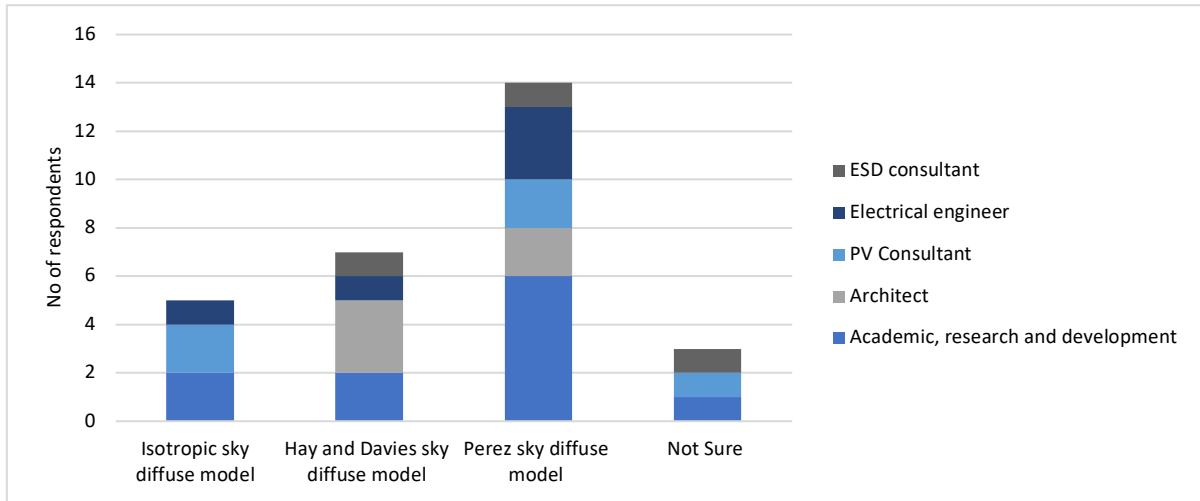


Figure 12: POA sky diffuse model to estimate POA irradiance

Figure 12 shows the survey results on the POA sky diffused models used for estimating POA irradiation in BIPV projects. Isotropic sky diffuse model, Hay and Davies sky diffuse model and Perez sky diffuse model were selected by the survey respondents. Compared to Isotropic sky diffuse model and Hay and Davies sky diffuse model, many respondents have agreed that Perez sky diffuse model is suitable for BIPV applications.

3.1.12 Methods for shading approximations

Figure 13 shows the survey results on methods used for estimation of shading in BIPV designs. The results show that shading percentage is used by many respondents for identifying the shading impact. Far-field shading horizon map and near-field shading factor is used in most PV simulation software for identifying the effects of shading on the solar irradiation.

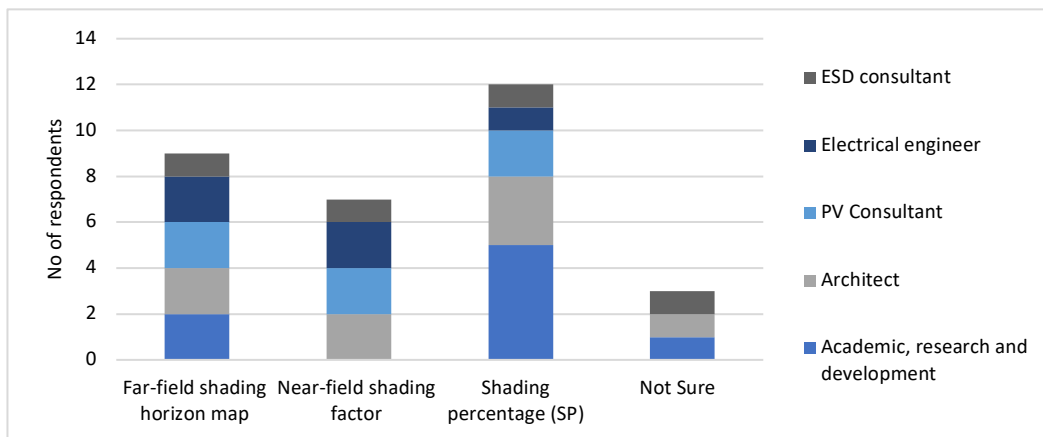


Figure 13: Methods for shading approximations

3.1.13 Weather data step values used for solar irradiation data

Weather data interval values can be by Minute, Hourly, Daily, Monthly or Annually. It may vary based on the design phase of the BIPV project. For example, for conceptual design stage, monthly and annual values can be considered whereas, in detailed design stage, minute or hourly data is more useful. Figure 14 shows the survey responses on the weather data step

values. Annual weather data is used at the conceptual design phase and hourly weather data is considered in the detailed design phase.

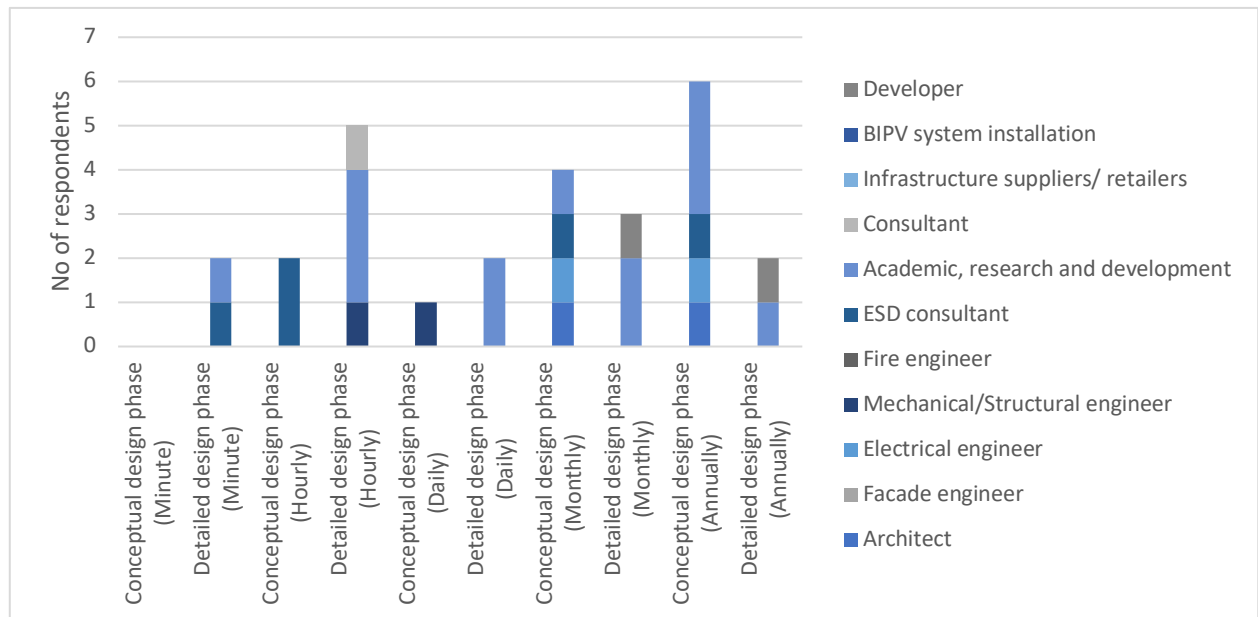


Figure 14: Weather data step values

3.2 Workflows and methods used in BIPV power output modelling or simulation

3.2.1 Methods used to import properties of the technical components of BIPV modules

In the current PV simulation software BIPV product information can be identified through: 1 a database 2. adding the properties manually and 3. use of an online platform with BIPV product information. As shown in Figure 15, the use of a database has been confirmed by the survey respondents.

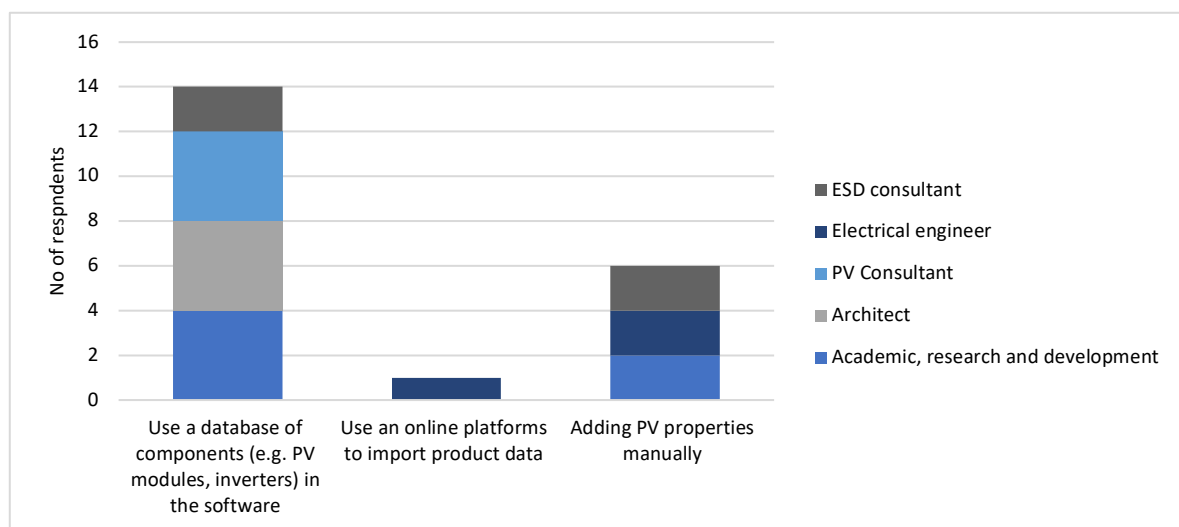


Figure 15: Methods to import properties of the technical components

3.2.2 Methods used for calculating the Electric DC output of BIPV

Several methods are available for estimating the amount of electricity produced by a BIPV system. Figure 16 shows the survey results on method used to estimate the BIPV power output. Eight respondents have replied with forecasting power output using PV cell temperature model which has the highest number of responses. Single diode model and simple PV power formula each have 5 responses. The Sandia PV array performance model was selected by 4 respondents. Not many use the two-diode model.

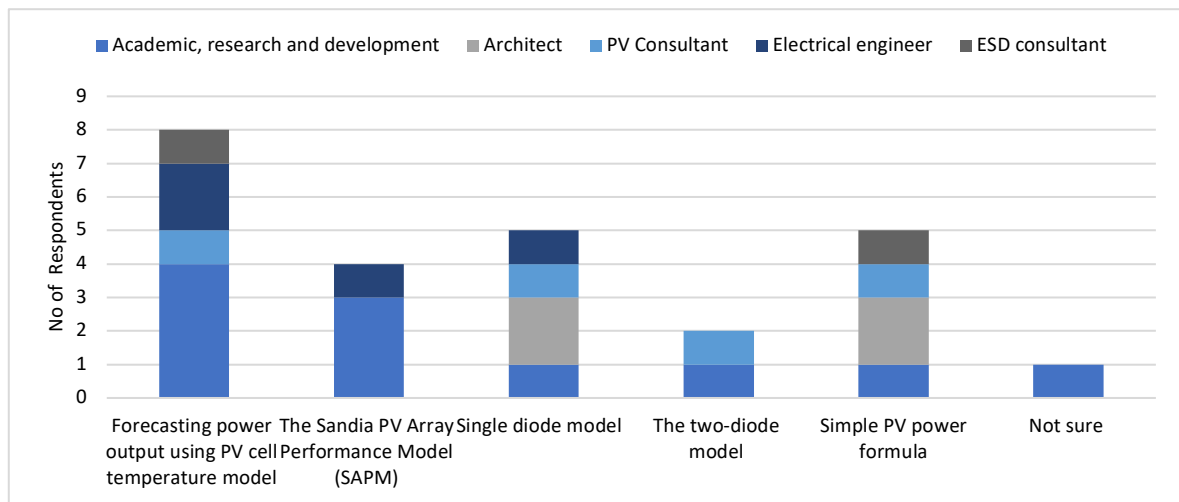


Figure 16: Methods for calculating the Electric DC output of BIPV

3.3 Workflows and methods used in Building performance modelling or simulation

3.3.1 Methods used for identifying the energy consumption patterns of a building

To identify the amount of energy fed to the building and to the grid, building energy consumption need to be identified. There are several ways to identify building energy consumption. Figure 17 shows survey results on the methods used for identifying the energy consumption patterns of a building. Eighteen respondents selected use of historical information from energy bills to identify the energy consumption patterns of the building which has the highest number of responses. The figure clearly shows, Academics, Architects and Electrical Engineers favours historical information from energy bills. Whereas ESD consultants prefer the use of simulation software to identify the energy consumption patterns of the building.

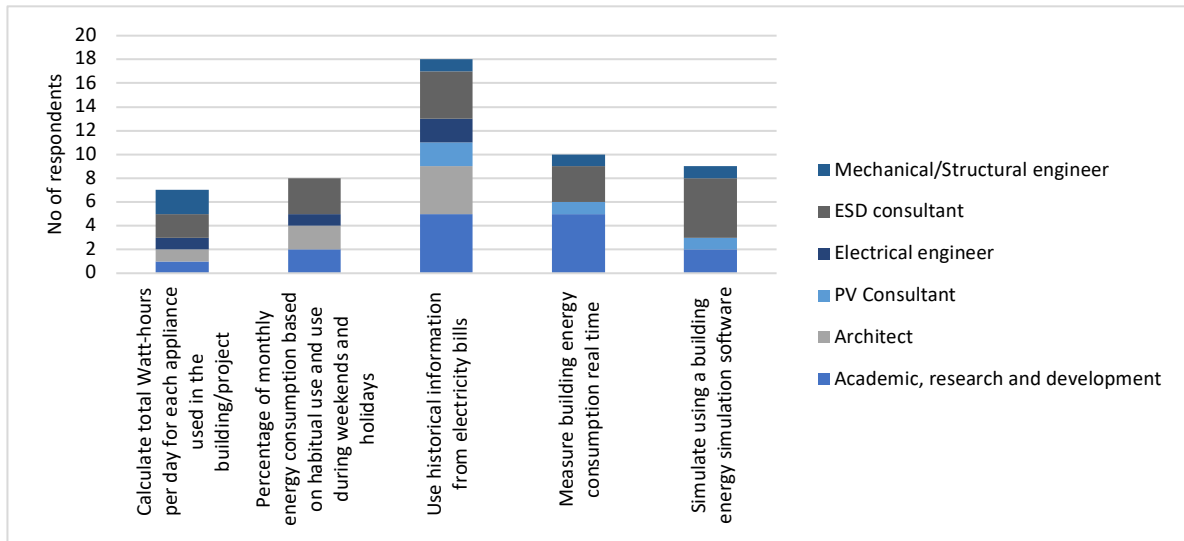


Figure 17: Methods for identifying the building energy consumption patterns

3.3.2 Suitable interval to be considered in energy consumption data

Figure 18 shows the survey results on energy consumption data intervals. Annual building energy consumption values are considered by most in the conceptual design phase followed by monthly and daily energy consumption values. Sub hourly building energy consumption values considered by most in the detailed design phase. However, for accurate results hourly building energy consumption values can be considered in the conceptual design phase.

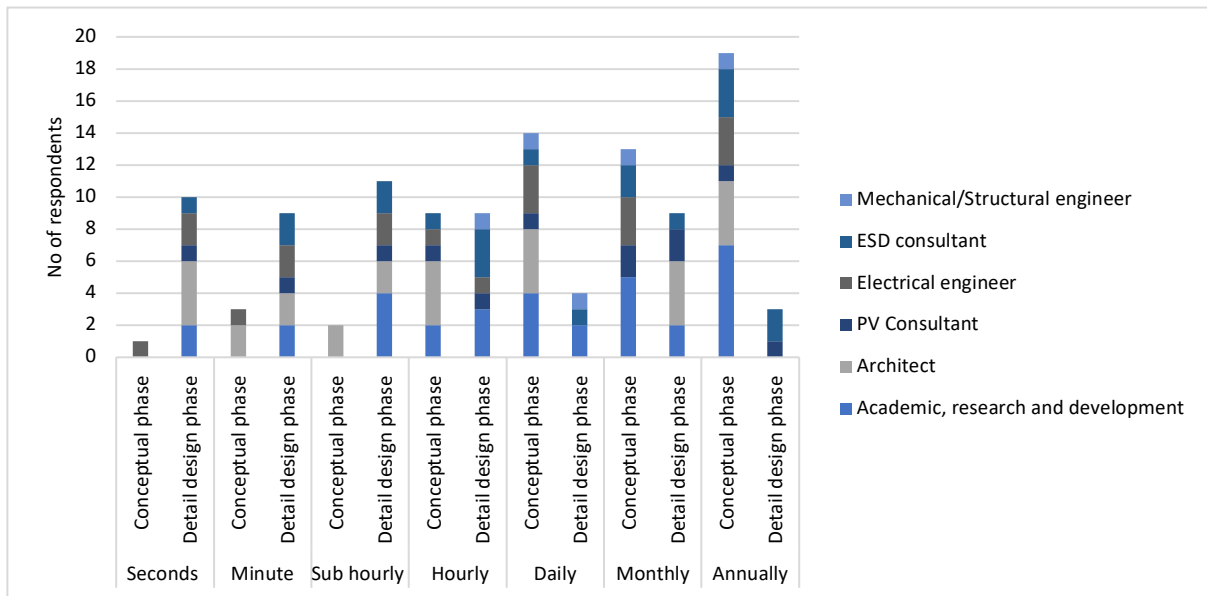


Figure 18: Intervals in energy consumption data

3.3.3 Data file formats for storing building energy consumption data

Building energy consumption data can be stored as excel files, text files or as Comma Separated Value (CSV) files. As shown in Figure 19 most respondents preferred using MS Excel spreadsheets to store building energy consumption values, followed by CSV files.

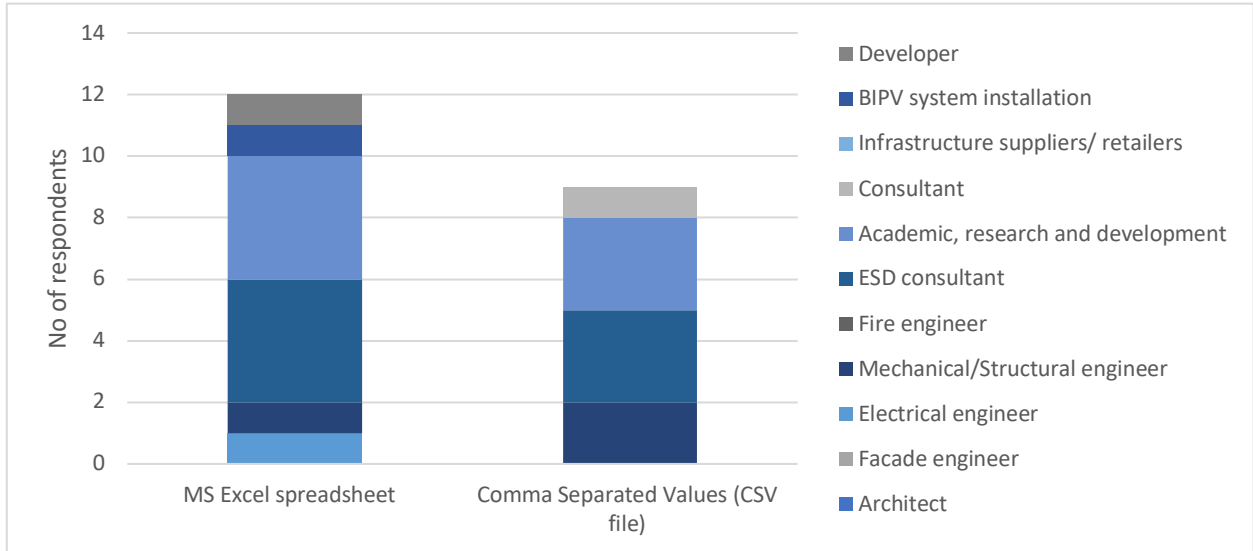


Figure 19: Data file formats for storing building energy consumption data

3.3.4 CO₂ emissions associated with BIPV

There are two methods to identify the CO₂ emissions in BIPV projects: 1. Calculating the emissions avoided; 2. Calculating the embodied emissions of the BIPV system which include emissions caused in manufacturing, construction, O&M and decommissioning phase. As shown in Figure 20, thirteen (13) respondents confirmed calculating the emissions avoided to be a suitable approach for BIPV designs. Not many professionals calculated the embodied emissions of the BIPV system.

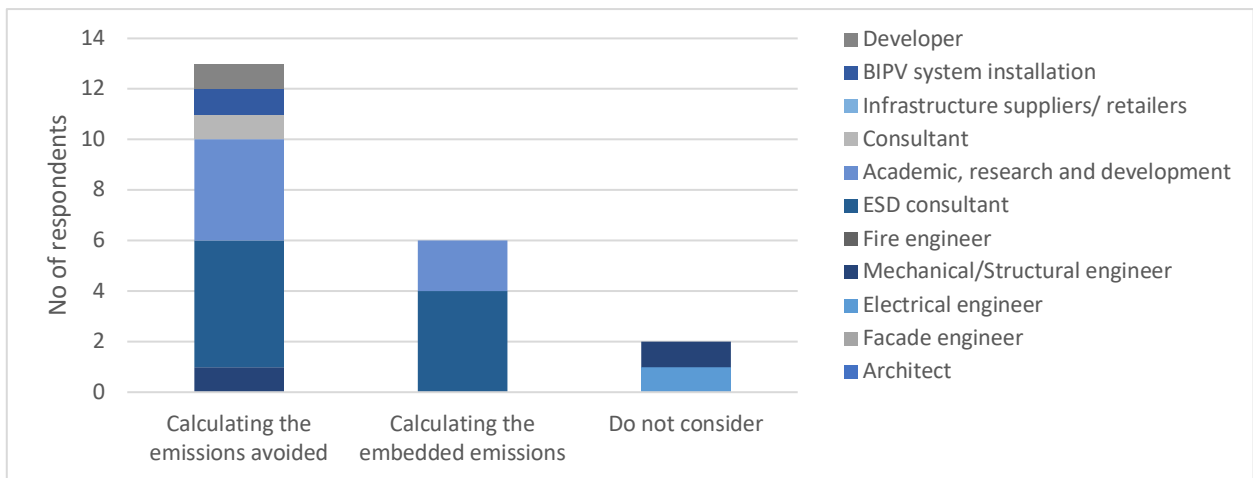


Figure 20: CO₂ emissions associated with BIPV

3.3.5 Methods used to identify the thermal impact of BIPV designs

BIPV envelopes need to comply with the Australian building standards relating to building thermal parameters such as U value and R value. This can be done by calculating solar heat gain manually or simulate using a building energy simulation software such as IES-VE, Honeybee and Ladybug components for Rhino Grasshopper interface to OpenStudio component and EnergyPlus, Autodesk Revit insight and EnergyPlus.

As shown in the Figure 21 below, many respondents use simulation software to identify thermal impact. Simulation of thermal load needed to be done considering the whole building project. Therefore, the respondents employ building simulation software such as IES VE, HAP, grasshopper, designbuilder and Autodesk green building studio as shown in Table 3.

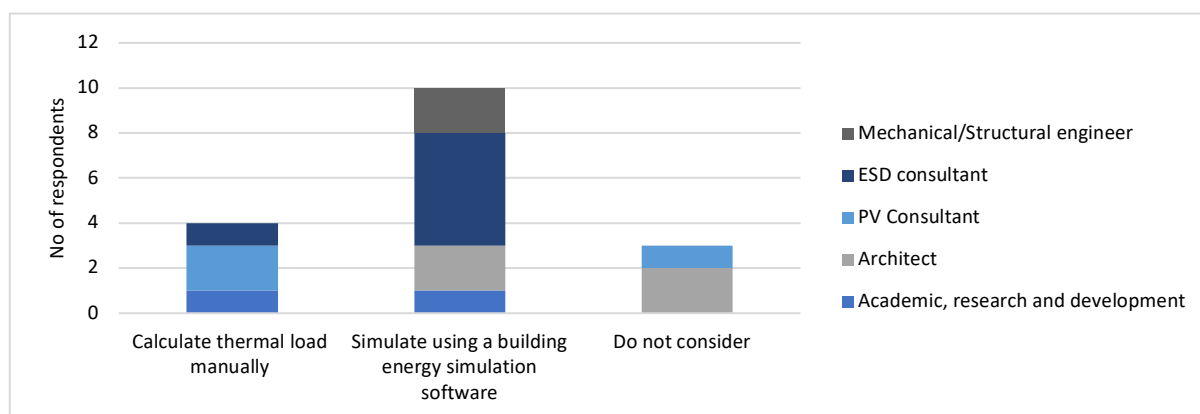


Figure 21: Methods used to identify the thermal impact of BIPV designs

Table 3: Software used to simulate thermal load in BIPV designs

Profession	hap	EnergyPlus	designbuilder	Autodesk green building studio	IES-VE
Academic, research and development	-	1	-	-	-
Architect	-	-	-	1	1
ESD consultant	-	-	-	1	4
Mechanical/Structural engineer	1	-	1	-	1

3.3.6 Method(s)/software to simulate the heat island impact

There are not many methods to explore heat island effects of BIPV systems. As shown in Figure 22, only one ESD consultant has simulated the heat island impact. The respondent has used Rhino and grasshopper for simulating heat island impact. All the other respondents have not considered heat island effect in BIPV projects.

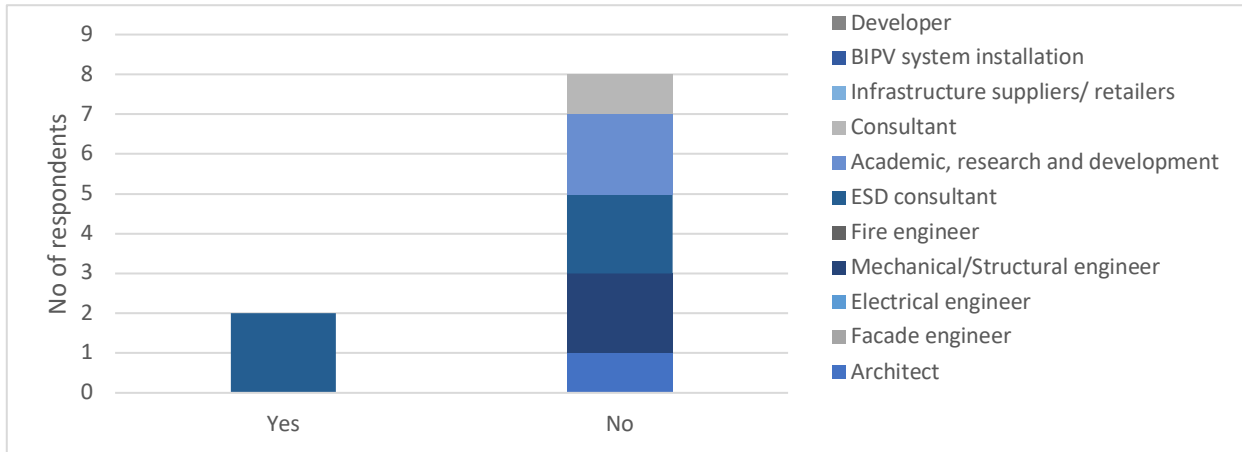


Figure 22: Consideration of impact on the heat island effect in BIPV project design

3.3.7 Methods used to identify the impact on daylighting

A BIPV façade can impact natural lighting because of opacity of the solar cells in the panels. Impact of BIPV system on the building daylighting need to be in accordance with the building regulations. As shown in Table 4, the survey results confirmed that simulation software were used to identify the impact of BIPV on the natural lighting coming to building. As shown in Table 5, the survey results identified IES VE, Grasshopper, Radiance and Revit daylight analysis were used for building daylight simulations.

Table 4: Methods used to identify the impact on daylighting

Profession	Simulate using a building energy simulation software	Do not consider
Academic, research and development	1	0
Architect	3	2
PV Consultant	-	2
ESD consultant	5	0

Table 5: Software used in daylight analysis

Profession	IES VE	Radiance	REVIT Daylight analysis	Grasshopper
Academic, research and development	-	-	-	-
Architect	2	-	1	-
ESD consultant	4	3	-	2

3.3.7 Structural loads considered during the planning and development of BIPV designs

BIPV envelopes should comply with the Australian standards related to dead load, wind load, earthquake (seismic) load, live load, rain load, snow loads imposed on the building structure. As shown in Figure 23, the respondents from PV consultancy and mechanical/structural engineering confirmed these factors.

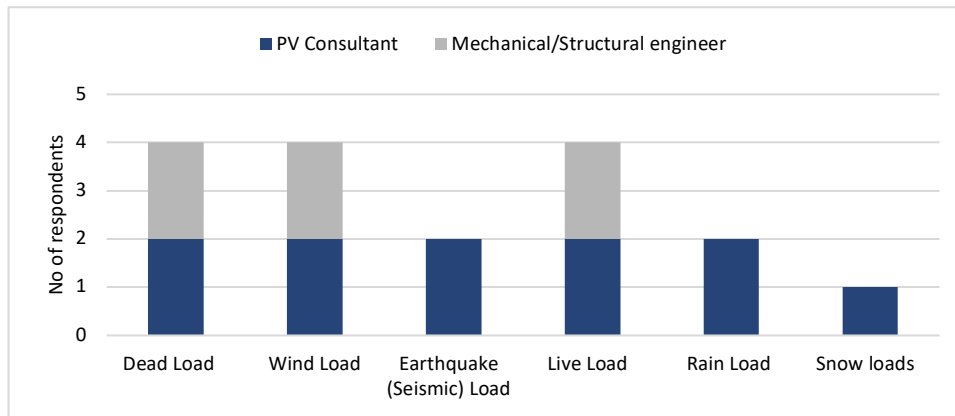


Figure 23: Structural loads in BIPV

The survey findings show that mechanical/structural engineers mathematically calculate or use SpaceGass software for structural analysis. Several other tools can also be used for structural analysis such as Tekla Tedds (Trimble 2021) and Autodesk Revit with Dynamo and Robot Structural Analysis (El-Khoury and Nguyen 2020) are several software that can be used for structural analysis of BIPV projects.

3.3.8 Software used to identify the fire related impact in BIPV designs

BIPV envelopes should maintain fire safety building codes and standards. Fire safety related to BIPV systems involved product testing and confirmation. Therefore, specialised software is required. According to the survey findings (two Fire Engineers) specialised software such as Thermal Radiation Analysis (TRA) is used. Fire Engineering Software (2016) and Spearpoint and Dimyadi (2007) recommends software such as Thermal Radiation Analysis, BRANZFIRE and Fire Dynamics Simulator (FDS) for fire safety related simulations.

3.4 Workflows and methods used in Financial and design outcome

3.4.1 Indicators considered for identifying the economic feasibility

For BIPV projects, there are a variety of economic indicators. The selection of economic indicators should depend on the emphasis of the economic analysis and the need of audience. The following 6 indicators are included:

- Net present value (NPV)
- Simple Payback period (PB)
- Discounted payback period (DPB)
- Internal rate of return (IRR)
- Return on investment (ROI)
- Levelized cost of energy (LCOE)

Figure 24 shows the survey results on methods used for evaluating the economic feasibility of BIPV projects. NPV is selected by many respondents followed by discounted payback period and Internal rate of return.

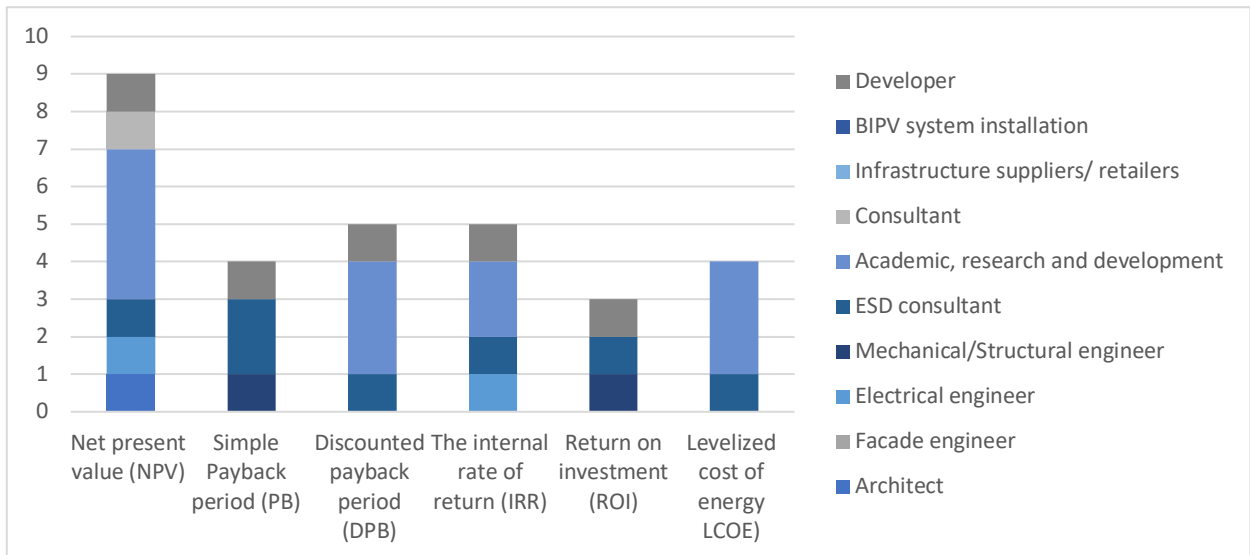


Figure 24: Indicators considered for identifying the economic feasibility

3.4.2 Capital cost (initial costs) of BIPV

Capital costs are fixed, one-time expenses incurred on installing a BIPV system. Total capital cost of a BIPV project consists of:

- Solar PV module costs
- Solar PV mounting structure cost
- Solar PV installation cost
- Costs of electrical devices (Balance of System) and installation costs
- Contingency

As shown in Figure 25, the above costs have been confirmed by the survey respondents.

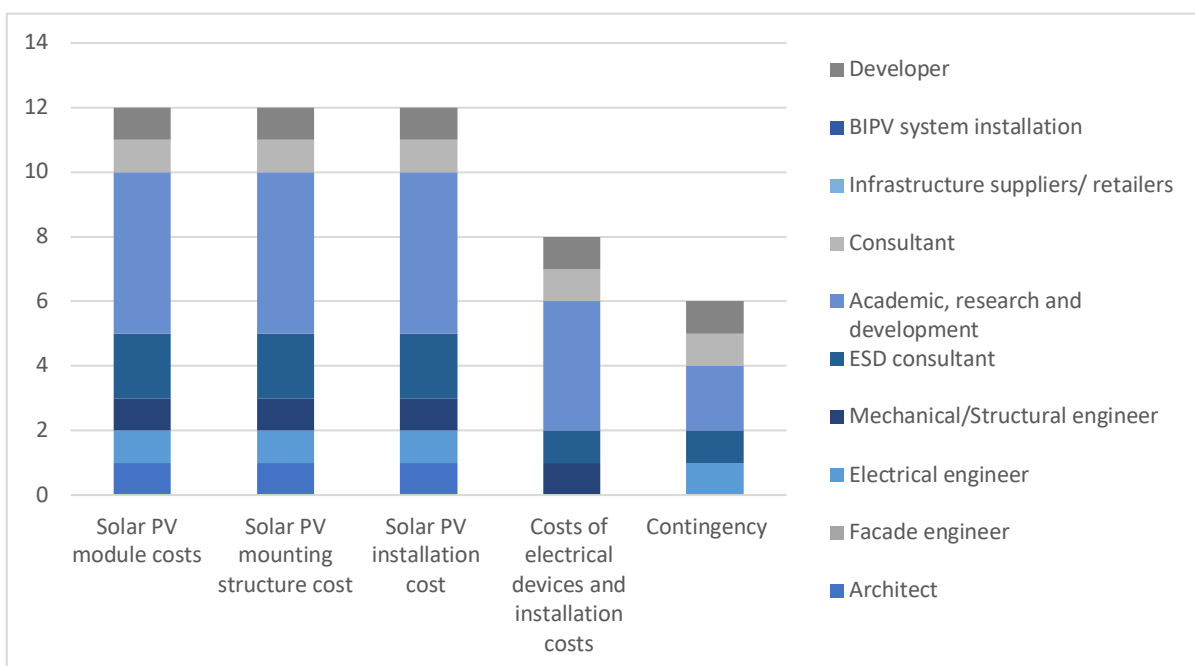


Figure 25: Capital cost (initial costs) of BIPV

3.4.3 Operations and maintenance costs of BIPV

The Operation and Maintenance (O&M) costs of BIPV system is the cost associated with operating and maintaining of the BIPV system throughout its lifetime. O&M costs of a BIPV system can include the following:

- Cleaning costs
- Repair of solar PV modules
- Repair of electrical devices (Balance of System)
- Repair of mounting system
- Replacement of solar PV modules
- Replacement of electrical devices (Balance of System)
- Replacement of mounting system
- Insurance
- Depreciation

As shown in Figure 26, the above costs have been confirmed by the survey respondents.

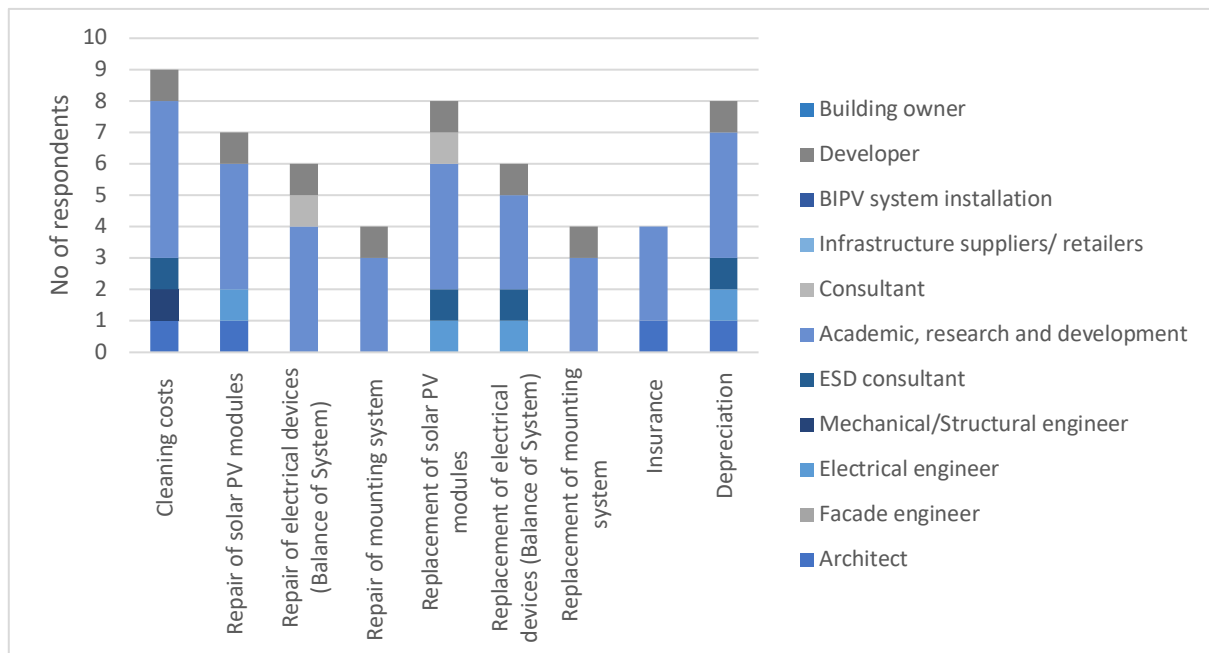


Figure 26: Operations and maintenance costs of BIPV

3.4.5 Life cycle income of BIPV

Life cycle income of BIPV systems refers to the profit generated by the BIPV system throughout its lifetime. The benefits from BIPV systems that can be considered as life cycle income are listed below:

- Saving from energy self-consumption
- Income from feed in tariffs
- Salvage value at the end of BIPV system life
- Savings from reducing building cooling load

As shown in Figure 27 the selected benefits under life cycle savings have been confirmed by the respondents.

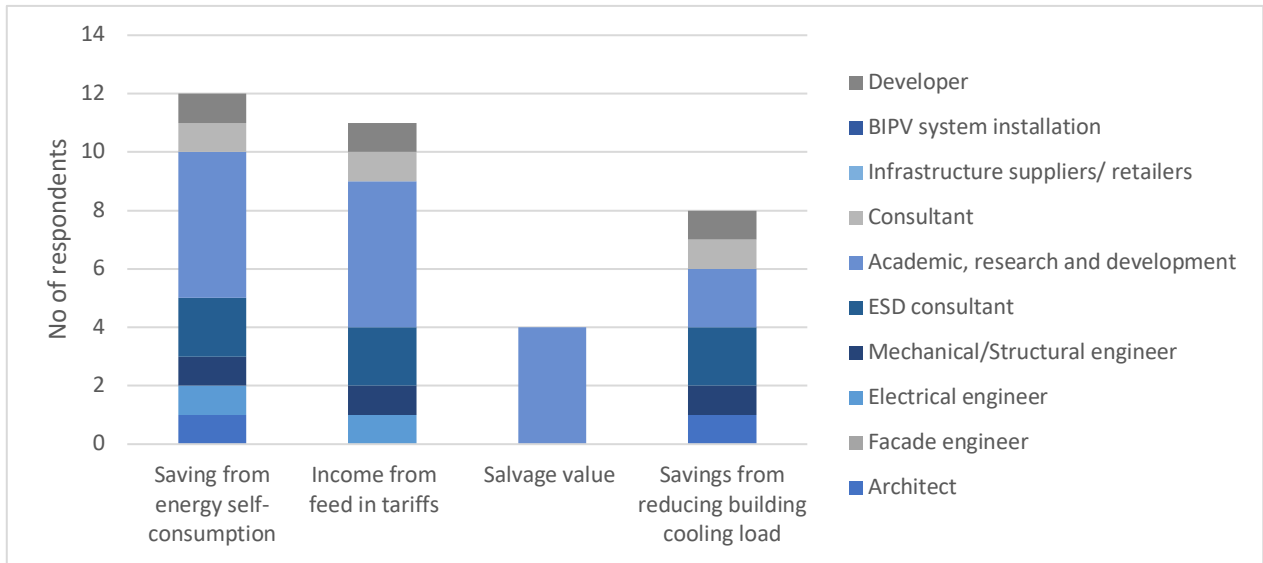


Figure 27: Life cycle income of BIPV

3.4.6 Material cost offset as a benefit of BIPV projects

One benefit of BIPV modules is that they completely replace traditional building materials. BIPV products completely replace traditional building materials. Therefore, the overall system costs should reflect the corresponding cost offset in the design evaluation (Eiffert 2003). As shown in Figure 28, material offset benefit of BIPV is confirmed by the respondents.

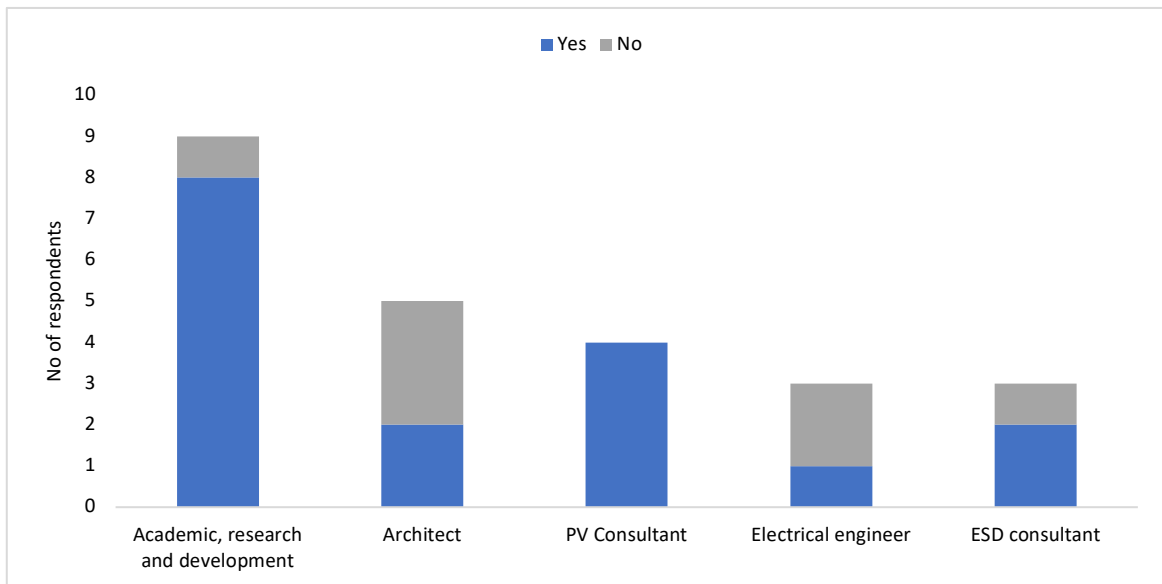


Figure 28: Considering material offset

3.4.7 Optioneering/ decision making methods

There are several methods that can be used to evaluate BIPV design options (Jakica et al. 2019):

- Multiple solution comparisons using parametric workflows which use of parametric software to generate feasible BIPV design options
- Multiple solution comparisons using traditional workflows which use 2D design drawing and software such as MS excel or manual calculation methods to identify the feasible BIPV design options.
- Integrated optimization: Integrated optimisation which uses methods such as machine learning techniques to identify the feasible BIPV design options.

As shown in Figure 29, parametric workflows are the most popular methods for evaluating multiple design options in BIPV conceptual design process followed by optimization methods. Parametric method is preferred by Architects, electrical engineers, mechanical/structural Engineers, ESD consultants, Academics, BIPV system installers and developers.

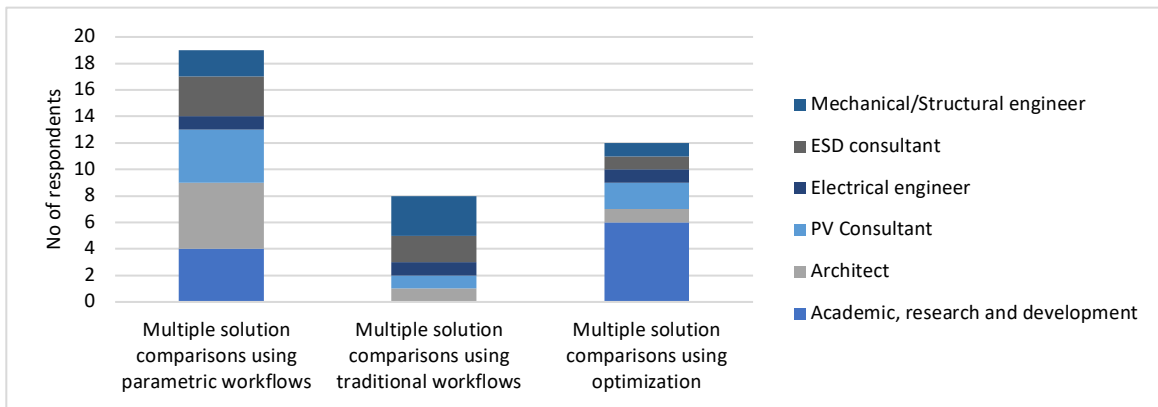


Figure 29: Optioneering/ decision making methods

3.4.5 Factor(s) that impact the optimum design of BIPV

Figure 30 shows the results of different factors that impact the decision for selecting BIPV designs. Cost, energy generation and reduction of CO₂ emissions and thermal impact of BIPV projects were confirmed by the respondents.

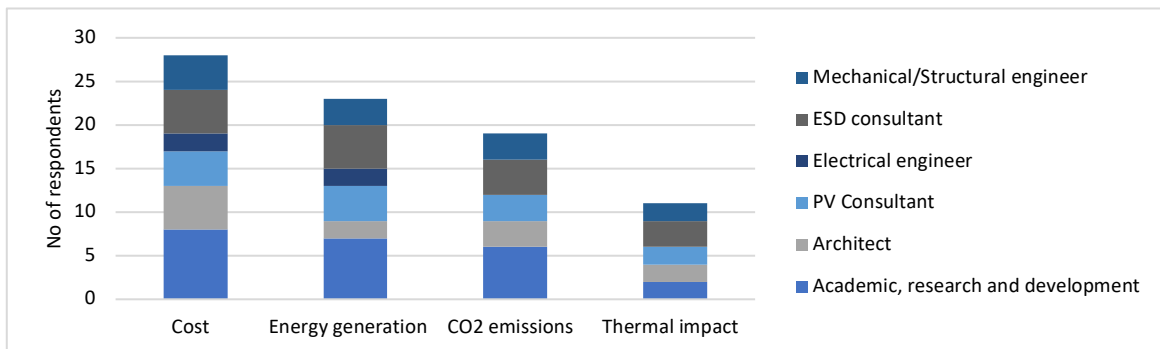


Figure 30: Factor(s) that impact the optimum design of BIPV

Conclusions

This study identified operative approaches, methods, and workflows in BIPV design and analysis process under 4 categories: 1. Workflows and methods used in solar irradiation modelling and simulation 2. Workflows and methods used in BIPV power output modelling or simulation 3. Workflows and methods used in building performance modelling or simulation and 4. Workflows and methods used in financial and design outcome.

A questionnaire survey was used to collect data on approaches, methods, and workflows in BIPV design and analysis process from 37 respondents in building design and construction and BIPV industry in Australia. The findings show that not many professionals have BIPV project design experiences as there are limited BIPV applications in Australia. Further, the survey findings identified various popular methods used under solar irradiation modelling and simulation, BIPV power output modelling or simulation, building performance modelling or simulation and financial and design outcome.

Based on the above findings, the suggested future work are as follows:

- Development of a BIPV specific digital platform for BIPV design and simulation considering the BIPV design and analysis methods and workflows identified in this study. The Solar Energy Application Lab at RMIT has developed 'BIPV enabler', which is a user-friendly platform that integrates product, regulation, technical, economic and construction data to create the best BIPV solution at conceptual design /feasibility stage.
- Developing digital product database for BIPV. The BIPV digital products can be used across BIM and 3D modelling software to facilitate BIPV design professionals to integrate PV into BIPV designs under their various use cases.
- Exploring feasible BIPV design applications using the identified methods for BIPV design and analysis. For example, simulation of BIPV design under different POA estimation methods, parameters, or optimisation methods to identify feasible BIPV design solutions.
- Enhancing digitalization in building envelopes at urban level which could facilitate to identify the feasibility of BIPV application in cities, regions, or national level.

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SEAL undertakes applied research to enable the integration of solar energy in buildings and suburban. We aim to support energy transformation towards higher solar adoption in the building sector and urban environment.

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