BIPV-facades and Fire Safety:

Risks and Possible Solutions

Gustav Dahl
BRANDTEKNIK | LTH | LUNDS UNIVERSITET

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Gustav Dahl

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Författare/Author: Gustav Dahl

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Abstract

The construction industry has always been changing and adapting to new innovations, values, requirements, and goals from the outside world. These days are no different. The climate change is still mostly relevant and everything we could do to mitigate this should be applied in the construction sector. It is nowadays a known fact that buildings represent a significant portion of the carbon dioxide emissions to our atmosphere. This calls for green solutions, and one of the more prominent innovations in modern times are the photovoltaic (PV) systems. PVs has been around for some years now and it seem to just keep growing. The newest innovation in the PV evolution is the use of Building Integrated Photovoltaic Systems (BIPVs), where the system has been integrated into the wall and produces energy for the building it is serving. This student thesis aims to contribute to an increased knowledge in the subject, identify challenges and solutions relating to the use of BIPV's in residential and commercial developments. This to present a good starting platform for any consultant involved in projects where BIPV's will be integrated in the building.

First step was to conduct a literature review to gain greater understanding of the subject and to come up with relevant questions for the interview study. The interview attendees was chosen from different fields in the industry and different countries, this to get a wider scope and more opinions as their focus might vary depending on their roll and where they are located. Recommendations from colleagues and other actors were also very useful to find relevant attendees for the interviews. Manufacturers, fire brigades, and fire engineers were interviewed. Focus was to interview actors who has been in contact with this new technology and to learn from two BIPV-projects, Sara Kulturhus and 550 Spencer Street. Issues and possible solutions were identified as a result of the literature review and interview study.

The conclusions show that BIPVs are ahead of legislation, as there is a gap in both Swedish and Australian legislation. This puts pressure on the fire engineer. Full-scale testing is recommended to be used to get a full understanding of the facades fire behaviour, highlighting that the design and fire behaviour differs between manufacturers. Once we know more about the facades fire behaviour, then we can provide measures to mitigate the identified issues. Small-scale testing might be enough in the future, but the industry is not there just yet. BIPVs are also much more complex to implement than the older regular PVs. A couple of solutions was identified that were used in both Sara Kulturhus and 550 Spencer Street. A performance solution should always be used. Comparing BIPV-façade to curtain walls, laminated glazing, etc, as some projects have done, is an oversimplification, as it is more complex than that. To have a holistic approach is necessary to understand these facades and the risks. Worries from the brigade was also highlighted, which mainly was the risk of electrocution, evacuation, falling panels, and lack of information.

Brandteknik
Lunds tekniska högskola
Lunds universitet
Box 118
221 00 Lund

www.brand.lth.se
Telefon: 046 - 222 73 60

Division of Fire Safety Engineering
Faculty of Engineering
Lund University
P.O. Box 118
SE-221 00 Lund
Sweden

www.brand.lth.se
Telephone: +46 46 222 73 60

Foreword

This report is a student thesis for the Fire Engineering Program at the Division of Fire Safety Engineering at Lund University. The work includes 22,5 HP, and the report is written by me, Gustav Dahl from Bi19.

I am very grateful for all the help I have received during the course of this student thesis. This work would not have been possible without the input and help from certain people, for which I am extremely grateful. I would like to express my gratitude to these people.

Nils Johansson for his support as a supervisor, as well as honest and relevant feedback. Also made it work very well despite the great distance and time difference.

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All the attendees who agreed to be interviewed and to be a part of this thesis. Your info was extremely important. I would like to extend an extra big thank you to Tobias Salomonsson, who contributed with inspiration, input, and material both before and during the work, which was very important to reach a good level on this student thesis. Heja Rögle!

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Last but not least, I want to thank my family, who despite the great distance have managed to motivate and support me when it was most needed. You are the best.

Sammanfattning

Byggbranschen har alltid förändrats och anpassat sig till nya innovationer, värderingar, krav och mål från omvärlden. Klimatförändringarna är fortfarande högst relevant och så mycket som möjligt borde göras för att minska byggsektorns påverkan på klimatet. Det är numera ett känt faktum att byggnader står för en stor del av koldioxidutsläppen till vår atmosfär. Detta kräver gröna lösningar, och en av de mer framträdande innovationerna i modern tid är solcellssystem. Den senaste innovationen är användningen av Building Integrated Photovoltaic Systems (BIPV), där systemet har integrerats i väggen och producerar energi till byggnaden.

En annan studentuppsats från Lunds Universitet gjord av Jonathan Jonsson gav inspiration till denna uppsats. Syftet var att tillföra kunskap till slutsatserna från Jonathans examensarbete för att nå en kunskapsnivå som kan vara användbart för brandingenjörer involverade i framtida BIPV-projekt. Förslag på framtida forskning och lärdomar från metoden och resultatet från Jonathans examensarbete har beaktats för att nå en god kvalitet på detta examensarbetet. Slutsatser från Jonnathan var det faktum att lagstiftningen inte har kunnat hänga med i utvecklingen av denna nya teknik. Lagstiftningen anses därför inte vara tillräcklig eftersom den inte tar upp alla risker relaterade till BIPVs. Det råder också en brist på exempelprojekt och vedertagna lösningar relaterat till dessa BIPV-fasader. Detta sätter i slutandan mycket press och ansvar på brandingenjören vid implementering av BIPVs i nya byggnader. Jonathan föreslog därför för framtida forskning att tillämpa ett bredare perspektiv på forskningen och intervjuerna, samt även ta en titt på verkliga BIPV-projekt för att se hur de hanterade brandsäkerhetsfrågorna relaterat till denna nya teknik. Fler fullskaliga tester av BIPV-fasader föreslogs också av många av Jonathans intervjudeltagare. Därför gjordes ett försök att komma i kontakt med personer från olika länder och olika kompetensområden, som varit i kontakt med BIPV-fasader i projektarbete och/eller fullskaliga tester av dem. Tillverkare, brandingenjörer, och brandkårer runt om i världen kontaktades som en del av denna process.

Första steget var att göra en litteraturundersökning för att få en större förståelse för ämnet och för att komma med relevanta frågor för intevjustudien. Rekommendationer från kollegor och andra aktörer var också mycket användbart för att hitta relevant material och deltagare till intervjuerna. Tillverkare, brandkårer, och brandingenjörer intervjuades. Fokus var att intervjua aktörer som varit i kontakt med denna nya teknik och att lära av två BIPV-projekt, Sara Kulturhus och 550 Spencer Street. En sammanfattning av intervjuerna skickades efteråt ut till varje deltagare för godkännande innan det användes i detta examensarbete. Problem och möjliga förbättringar identifierades som ett resultat av litteraturundersökningen och intervjustudien.

Slutsatserna visar att BIPV-fasader ligger före lagstiftningen, då det finns en lucka i både svensk och australiensisk lagstiftning. Fullskaliga test rekommenderas för att få en en full förståelse för fasadernas brandbeteende. Brandbeteende och design kan skilja mycket mellan fasader och tillverkare. När vi vet mer om fasadernas brandbeteende kan vi vidta åtgärder för att mildra de identifierade riskerna. Småskaliga tester kan potentiellt vara tillräckligt i framtiden, men branschen befinner sig inte i det läget annu. BIPVs är också mycket mer komplexa att implementera jämfört med de äldre vanligare solpanelerna. Ett par lösningar identifierades som användes i både Sara Kulturhus och 550 Spencer Street. Analytisk dimensionering bör alltid användas. Att jämföra BIPV-fasader med curtain walls, laminatglas, etc, som vissa projekt har gjort. Vilket är en grov förenkling. Det är mer komplext än så. Att ha ett helhetsperspektiv är nödvandigt för att förstå dessa fasader och riskerna med dem. Oron från brandkåren lyftes också fram, vilket främst berörde risken för elstöt, evakuering, och bristande information.

Summary

The construction industry has always been changing and adapting to new innovations, values, requirements, and goals from the outside world. The climate change is still mostly relevant and everything we could do to mitigate this should be applied in the construction sector. It is nowadays a known fact that buildings represent a significant portion of the carbon dioxide emissions to our atmosphere. This calls for green solutions, and one of the more prominent innovations in modern times are the photovoltaic (PV) systems. The newest innovation in the PV evolution is the use of Building Integrated Photovoltaic Systems (BIPVs), where the system has been integrated into the wall and produces energy for the building it is serving.

Another student thesis from Lund University made by Jonathan Jonsson gave inspiration to this thesis. The aim was to add knowledge to the conclusions from Jonathans thesis to reach a state of knowledge that can be useful for fire engineers involved in future BIPV-projects. Suggestions on future research and lessons learned in methods and results from Jonathans thesis has been considered to reach a good quality of this thesis. Conclusions from Jonathan was the fact that the legislation has not been able to keep up with the development of this new technology. The legislation is therefore not considered adequate as it is not addressing all the risks relating to BIPV's. There is also a lack of example projects and accepted solutions relating to these BIPV-facades This ultimately puts a lot of pressure and responsibility on the fire safety designer when implementing BIPV's in new buildings. Jonathan therefore suggested for future research to apply a wider scope on the research and interviews, and to also have a look at real BIPV projects to see how they addressed the fire safety issues relating to this new technology. More full-scale testing of BIPV-facades was also suggested by many of Jonathans interview attendees. An active effort was therefore made to get in contact with people from different countries and different areas of expertise, that has been involved in projects with BIPV-facades and/or full-scale testing of them. Manufacturers, fire engineers, and fire brigades around the world were contacted as a part of this process.

First step was to conduct a literature review to gain greater understanding of the subject and to come up with relevant questions for the interview study. Recommendations from colleagues and other actors were also very useful to find relevant material and attendees for the interviews. Manufacturers, fire brigades, and fire engineers were interviewed. Focus was to interview actors who has been in contact with this new technology and to learn from two BIPV-projects, Sara Kulturhus and 550 Spencer Street. A summary of the interviews was afterwards sent out to each attendee for approval, before it being used in this thesis. Issues and possible improvements were identified as a result of the literature review and interview study.

The conclusions show that BIPV-facades are ahead of legislation, as there is a gap in both Swedish and Australian legislation. Full-scale testing is recommended to be used to get a full understanding of the facades fire behaviour, highlighting that the design and fire behaviour can differ a lot between facades and manufacturers. Once we know more about the facades fire behaviour, then we can provide measures to mitigate the identified issues. Small-scale testing might be enough in the future, but the industry is not there just yet. BIPVs are also much more complex to implement than the older regular PVs. A couple of solutions was identified that were used in both Sara Kulturhus and 550 Spencer Street. A performance solution should always be used. Comparing BIPV-façade to curtain walls, laminated glazing, etc, as some projects have done. This is an oversimplification. It is more complex than that. To have a holistic approach is necessary to understand these facades and the risks connected to them. Worries from the brigade was also highlighted, which mainly was the risk of electrocution, evacuation, and lack of information.

List of Acronyms

BIPV – Building Integrated Photovoltaics

BAPV - Building Applied Photovoltaics

PV – Photovoltaics

DtS – Deemed-to-Satisfy

DC – Direct Current

AC – Alternating Current

NFPA – National Fire Protection Association

NSW – New South Wales

RMIT – Royal Melbourne Institute of Technology

BCA – Building Code of Australia

NCC – National Construction Code

ABCB - Australian Building Code Board

EV – Electric Vehicle

SOU – Sole Occupancy Unit

BBR – Boverkets Byggregler

PBF - Plan- och byggförordningen

PBL – Plan- och bygglagen

AFCI – Arc Fault Circuit Interrupter

BMS - Battery Management System

Contents

1 Introduction

The construction industry has always been changing and adapting to new innovations, values, requirements, and goals from the outside world. These days are no different. The climate change is still mostly relevant and everything we could do to mitigate this should be applied in the construction sector, this is where values, requirements, and goals from the outside world comes in play. It is nowadays a known fact that buildings represent at least 39% of the carbon dioxide emissions to our atmosphere (World Green Building Council, 2023). Where 28% comes from operational emission, from energy needed to heat, cool, and power them, and the remaining 11% from materials and construction. This is obviously not something that is sustainable in the long run, and the industry is therefore looking for new climate-smart solutions to try to slow down the climate impact. Finding green energy solutions has therefore been a hot topic for a while, with solar cells at the forefront compared to other green alternatives, surpassing wind for the first time in history. In recent years, the use of photovoltaics has increased drastically. The evolution has just continued from the early 2000's and the technology is getting more used all around the world, as presented in Figure 1 and Figure 2 below, where GWp is short for "gigawatt peak". The latest statistics from the International Energy Agency states that the global cumulative installed capacity passed the 1 TW mark in 2022, reaching an estimated 1,185 GW (International Energy Agency - PVPS, 2023). The statistics show that 25 million households currently use photovoltaics, a number that is expected to quadruple to 100 million around the year 2030 (International Energy Agency, 2022).

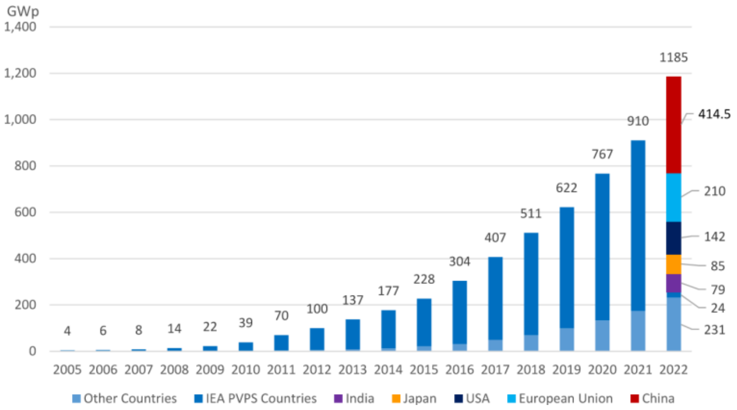

Figure 1: Global Evolution of Cumulative PV Installations (International Energy Agency - PVPS, 2023)

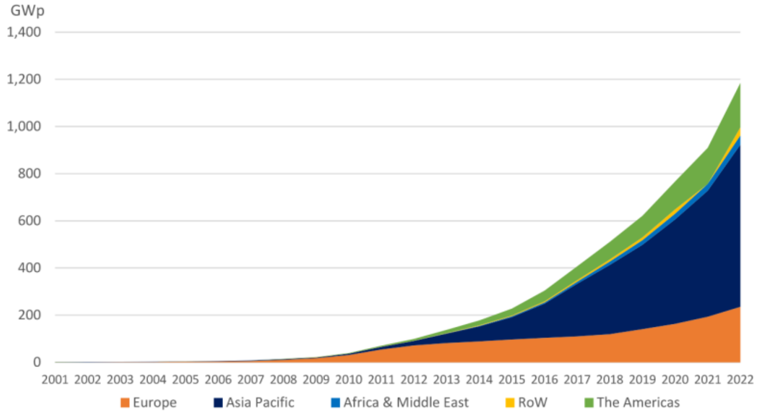

Figure 2: Evolution of Regional PV Installations (International Energy Agency - PVPS, 2023)

When a lot of effort is put into sustainability and green energy, it cannot be forgotten what fire engineers are actually here for, which is building safe buildings. Something that becomes more challenging as new technology is being integrated into the buildings.

Initially, there were solar cells attached to the outside of the building, most often on the roof. The latest in the line of innovations is the use of BIPV's (Building Integrated Photovoltaic Systems). The solar panels are here instead integrated as part of the building itself and can replace entire building parts at the same time as it produces its own energy for the building. In Australia, 550 Spencer Street was completed in 2024, which is the country's first BIPV building of its kind (550 Spencer, 2023). There are other examples like Magasin X (White Arkitekter, 2022) and Frodeparken (Bengt Stridh, 2014) in Uppsala, both considered as modern BIPV buildings. Another one is Sara Kulturhus in Skellefteå, Sweden (Fahlander, 2020), which will form a part of this thesis. Buildings like these are expected to become increasingly common, as the use of BIPV's does not seem to be decreasing. As of 2050, it is estimated that more than 70% of the world's population will live in cities (International Energy Agency, 2021), which is expected to create a massive demand for efficient energy alternatives for urban environments. An area where BIPV's are expected to be the most effective option.

One problem with this rapid technical development has already been identified in a previous student thesis (Jonsson, 2023). Which is the fact that the legislations globally has not been able to keep up with the development of this new technology. The legislation is therefore not considered adequate as it is not addressing all the risks relating to BIPV's. Jonsson also concluded that there is a lack of example projects and accepted solutions relating to these BIPV-facades Which ultimately puts a lot of pressure and responsibility on the fire safety designer when implementing BIPV-facades in new buildings.

This report aims to add knowledge to the Jonssons student thesis (Jonsson, 2023) through a literature review and an interview study, where suggestions for future studies and lessons learned has also been considered. The objective is to contribute to an increased knowledge connected to fire safety challenges when implementing BIPV-facades. This thesis will provide a good starting point for fire engineering consultants who are involved in BIPV projects.

2 Background

This section presents the theory that will form the base for the literature review and the interview study. The aim being to provide the reader with a base of knowledge to be able to follow and understand the discussion later on in this report. The systems components and their functions will be presented along with history of the technology, how it has developed over the years, and fires that has occurred involving PV's. The different types of photovoltaics are also presented along with a very basic explanation of the installation and maintenance procedure. Lastly, the legislation of both Australia and Sweden will be compiled to get an idea of how well adapted the legislations are for the technology, along with a presentation of some of the relevant standards that exists globally.

2.1 Photovoltaics

Photovoltaic cells, also known as solar cells, is a technology that can convert sunlight directly into electricity, using the photovoltaic effect. When discussing photovoltaics, cells, panels, and systems are often mentioned. The cells are the ones producing the electricity directly from the sunlight (Solar Guide, 2023). Below presents a basic explanation of the process and components of the system.

1. Sunlight hits the panels and converts into DC electricity.
2. DC electricity flows through a DC-switch.
3. The DC electricity is inverted into AC electricity using a solar inverter.
4. In some systems, DC electricity is stored in a solar battery.
5. AC electricity travels through an electricity meter.
6. AC electricity can free flow through the household electric system via the household Fusebox.
7. Solar energy is then used as electric power across the entire household.
8. The solar electricity that is not used or stored is fed to the grid.

Multiple solar cells can be connected to gain a higher amount of energy, as multiple solar cells produce higher current and therefore more energy. This is what is called a solar panel (Infinite Energy, 2021). The solar panels can be connected to multiple panels, creating what is called a solar array, which is the final PV system. The connection depends on the required voltage and current specifications for the components used in the system, along with the design of the subject building (Hadi & Nayfeh, 2023). A BIPV module is a PV module attached to a construction product designed to be a component of the designed building, while a BIPV system is the solar panel along with all the electrical components and parts of the mechanical mounting system (IEA PVPS Task 15, 2024).

Apart from the multiple solar panels, the system often consists of an electricity meter, AC Isolator, Fusebox Inverter, battery, charge controller, generation meter, DC Isolator, cabling, mounting, and a tracking system (Infinite Energy, 2021).

2.1.1 Components and Functions of the Photovoltaic Module

The cells are the component of the panel that converts the sunlight into electricity (Office of Energy & Renewable Energy, 2023). These are usually producing around 1 or 2 watts and have a thickness of less than four human hairs. The cells consist of two different semiconductors. The word "semi" originates from the fact that the material can conduct electricity better than an insulator, but not as well as a conductor like metal.

The two semiconductors are of two different types. One of them is called a p-type and the other one is called an n-type (Energy Education, 2023). Together they create a p-n junction to create an electric field, which is essential for the whole PV system to function. The semiconductor absorbs the lights energy and transfer the energy to the electrons. The electrons will then flow through the material as an electrical current, with the help of conductive metal contacts, and can then distribute this energy to the building and the electric grid.

The efficiency of PV cells can vary a lot, depending on characteristics of the incoming light and attributes of the cell, such as intensity, angles, and wavelength. Another important parameter for the PV semiconductors is the so called, bandgap (Office of Energy & Renewable Energy, 2023). The bandgap decides what wavelengths of light the material can absorb and convert. If the bandgap matches the incoming lights wavelengths, then the material can absorb and convert all the available energy. Silicon is by far the most common material used in semiconductors. The silicon semiconductors represent approximately 95% of the modules sold around the world today (Office of Energy & Renewable Energy, 2023), and provides a combination of high efficiency, long lifetime, and low cost. There are also crystalline silicon cells, which is silicon atoms connected to one another, forming a crystal lattice. This organized structure makes conversion of light into electricity even more efficient.

The solar inverter converts direct current (DC) into alternating current (AC). The different types of inverters are listed below (Beny New Energy Co, Ltd, 2022):

- **String Inverters:**
  - Directly connected to the grid with usually no battery backup. This is the most used inverter for both commercial and residential buildings.
- **Micro-inverters:**
  - Usually smaller and not as powerful compared to the string inverters, also more expensive. Capacities around 200-350 watts. These types of inverters are way more efficient in partially shaded areas compared to the other inverters on the list. The micro inverters are mounted on the back of the specific panel that is going to convert DC to AC.
- **Central Inverters:**
  - A very effective system if managed and maintained in the correct way. Usually, a bit larger system than the rest on the list, containing its own storage area, exhaust system, etc. Capacities over 400 kW is the standard.
- **Grid-tied inverters:**
  - Grid-tied inverters matches the frequency and phase of the grid, to convert solar energy into electrical. These types of inverters can also shut down for safety reasons automatically as they are connected to the utility grid.
- **Off-grid inverters:**
  - Also known as “stand-alone inverters” or “independent inverters”. The name comes from the fact that these inverters do no need to be synced with a solar panel to function, converting energy into electricity on its own. Popular choice for people who wants to live off the grid.
- **Battery-based inverters or Hybrid solar inverters:**
  - Mix of grid-tied and off-grid inverter. Gives the user a choice. Can connect with the grid if needed, for example if there has not been enough sunlight or a higher power consumption is needed.

Apart from the solar inverters, there are a couple of other components worth mentioning that sometimes forms a part of the PV system, these are listed below (Beny New Energy Co, Ltd, 2022):

- **DC Isolator Switch:**
  - Component that can interrupt the DC electricity, located between the solar panels and the power inverter. Important component as the owner or the fire brigade need to be able to switch off the electricity in the system during installation, maintenance, and potential fire brigade intervention.

- **Rapid Shutdown Device:**
  - This component was included by the National Fire Protection Association (NFPA) in the National Electrical Code (NEC) (National Electrical Installation Standards, 2023) to make sure that fire brigade intervention can be conducted in the safest way possible. The system can be turned off in less than a minute with a rapid shutdown advice. Allowing the brigade personnel, if needed, to go up on the roof and fight the fire.

- **Surge Protective Device:**
  - Surge Protective Devices (SPDs) protects the system from electrical surges and spikes, that can be caused by lightning.

- **DC Fuse Holder:**
  - Primarily protecting the systems wiring from overheating and starting a fire. Also protects the systems devices from catching fire or getting damaged by short circuits.

- **Charge Controller:**
  - A charge controller is only needed if the system is provided with a battery bank. The charge controller regulates the DC coming from the solar panel, so the battery does not overcharge.
- **Combiner Box/Junction Box:**
  - Electrical enclosures that make it possible to connect multiple solar panels at the same time. It also stores bypass diodes and connectors that are vital for the system to function safely. These boxes shall be rated for outdoor use and located in close proximity to the panels that are being used.

There are also other components that are not electrical in the system, these serve as a protective covering for the solar cells, and the other components. The non-electrical components are listed below (Svarc, 2023):

- **EVA Film**
  - Ethylene Vinyl Acetate. It is a plastic layer designed to keep the solar cells in place during manufacturing and must be able to withstand extreme temperatures and humidity. The EVA also serves a major role of keeping dirt and moisture away from the cells, which is important for the long-term performance of the system.

- **Tempered Glass**
  - Located in front of the solar cell and front EVA film. Typically, 3-4 mm of high strength glass, designed to protect the cells from mechanical loads, extreme temperature, and hailstorms. The International Electrotechnical Commission (IEC) standard impact test is testing solar panels impact from hailstones of 25 mm in diameter, with a speed of 27 m/s. In the event of an accident where the glass breaks, the tempered glass is much safer than standard glass as it breaks into many small pieces instead of sharper bigger pieces that could potentially destroy the solar panel and the cables.

- **Aluminium Frame**
  - Located in the front of the panel. Protecting the EVA and providing a structure that can stably mount the solar panel. The aluminium is extremely lightweight, designed to withstand extreme weather and winds.

- **Backsheet**
  - Located in the back of the panel serving as a protective covering from moisture, mechanical protection, and electrical insulation. The backsheet material is usually polymers or some kind of plastic, with various levels of protection, thermal stability, and UV-resistance. There are also variants where the backsheet is made of dual glass panels. The glass is more durable than most backsheet materials.

2.1.2 PV System Types

The components of a PV system varies depending on what kind of PV system is being used. PV systems are normally divided into three different categories (Nikolaos & Laochoojarenkit, 2012) as described below:

Grid-Tied System

System that can use the electricity produced by the system, or the energy from the grid. The system will use the produced electricity when the sunlight is reaching the panels. During the night, or other times where the system is not able to produce energy, the building can receive electricity from the grid (Nikolaos & Laochoojarenkit, 2012).

Grid-Tied with Battery Backup System (Hybrid System)

This is a popular choice for people living in areas that are often affected by power outages (Nikolaos & Laochoojarenkit, 2012). The user can use the electricity from the grid while the battery can store electricity for future use, for example during a power outage. Systems including a battery backup is more expensive than a system without a battery (PES Solar, 2024).

Stand Alone or Off-Grid System

Common choice for people living in remote areas (Nikolaos & Laochoojarenkit, 2012). In this case the system produces all the electricity for the house without any backup from the grid.

2.1.3 Different Kinds of Photovoltaics

This section will outline the differences between Building Applied Photovoltaics and Building Integrated Photovoltaics.

Building Applied Photovoltaics

The BAPV’s are installed on the outside of the building. Which makes it easier to apply to existing buildings compared to BIPV’s (Rodriguez-Ubinas & Alhammadi, 2022). These systems are only accessible from the outside. The BAPV’s can be installed in different ways depending on the building design. If the primarily goal is to produce as much energy as possible, then the main focus will be on the PV’s location, angle, and construction to be as beneficial as possible to convert the energy from the sunlight. If the appearance of the building is more important, the BAPV’s will be installed parallel and as close to the wall/roof as possible.

Building Integrated Photovoltaics

BIPV’s replaces whole components of the construction while it produces energy for the building at the same time (Rodriguez-Ubinas & Alhammadi, 2022). The different BIPV components that can be found on the market right now consists of roof, walls, envelopes, skylights, spandrels, windows, curtain walls, atriums, and even walkable PV tiles or modules, just to mention a few. When it comes to accessibility, these types of systems can be non-accessible from within the interior, accessible from within the interior, and/or have accessible exterior elements (Rodriguez-Ubinas & Alhammadi, 2022). Rodriguez-Ubinas states that BIPV’s are much harder to adapt into existing buildings compared to BAPV’s. There are also a lot more options compared to the BAPV alternative.

2.1.4 Installation and Maintenance

One of the main reasons for fire initiation in PV systems is the result of a faulty system, specifically faulty DC isolator switches and inverters (CHOICE, 2021). This highlights the importance of correct manufacturing, installation, and maintenance to avoid a fire breaking out in the system and building.

The following roles relating to installation and maintenance applies for New South Wales, Australia only (NSW Government, 2021). It is assumed that other countries will have similar roles and not differ remarkably.

There are four main roles in the solar industry, and they all serve a major role in the process of providing a safe and well working system for the client. The different actors are presented below with a short explanation of their role. These actors are also known as a "person conducting a business or undertaking" (PCBU), and one PCBU can act as more than one of these roles (NSW Government, 2021):

- **System Designers:**
  - It is the Solar PV System Designer that must consider the accessibility and provide safe means of access for installation, maintenance, and fire brigade intervention.
- **System Manufacturers:**
  - The System Manufacturers must ensure the product is safe and adequate testing has been carried out. It is also their job to provide all the information needed to the installers, consultants, and users of the system.
- **Solar Retailers:**
  - The person marketing and selling the systems. It is also their job to confirm that the installation contractors are undertaking work safely.
- **Solar Installers:**
  - Installs the solar components, electrical equipment, and all the wiring. They must have the proper knowledge, skills, and qualifications. Required to implement supervision to ensure all the workers are undertaking work in a safe way.

Fire and Rescue NSW advises that regular service and maintenance of the system is a major factor to prevent fires (CHOICE, 2021), while the Clean Energy Council (CEC) recommends having a check of your system once a year.

2.1.5 Fires involving Photovoltaics

It is hard to get an idea of how the fire statistics related to PV's has developed over the years. The National Fire Data Center states that there is no older information of fires in PV-panels, as they did not have a category back in the day and the fires was therefore categorized as "other" (Weaver, 2019). Newer statistics shows that the number of fires has increased significantly in recent years (Hoey, 2023). Data from 2022 shows that there were six times more fires involving PV's than there were a decade ago. Also worth mentioning recent statistics from Germany (Fraunhofer ISE, 2023), where 1.4 million solar power installations currently exist. Going back 20 years in time, approximately 350 of these PV systems have caught fire. This represents 0.006% of all the installations across Germany. Fraunhofer also concluded that in 120 of these cases it was something faulty with the PV system. 75 of these resulted in severe damage to the building, while in ten cases the result was complete building loss. The most common reason for fire in the systems was faults in the cabling and connections, highlighting the importance of correct installation when applying these systems to buildings.

A couple of examples of recent fires involving PV systems will be presented in this section along with a short summary of how the fire started and the following consequences. These specific events were chosen to be presented as they occurred quite recently and are presenting multiple different examples of how an accident can occur and the following consequences. The incidents also took place in different parts of the world, as getting examples from Europe, Australia, the US, and Asia felt important to get a wide scope. Worth highlighting that none of these examples involves BIPV-facades. Throughout the research, not one incident involving BIPV-facades specifically could be found. Fires involving the more regular PVs is believed to get an idea of what potential risks could be present when implementing BIPV-facades.

Arizona, USA (2019)

Occurred on a major battery storage facility. The fire initiated because of thermal runaway in a damaged battery cell (Sylvia, 2020). It was also concluded that the fire suppression system, thermal barriers, and the ventilation was not adequate to protect the system. The brigades did not have a lot of experience from fires in these systems and was therefore not prepared with an effective plan to handle the situation. Large amount of gases were released in the battery storage enclosure, caused by the thermal runaway (Sylvia, 2020). Three hours after fire initiation, the fire fighters decided to open the door. During this time the enclosure had developed a flammable atmosphere. Once the door was opened, the gases was probably in contact with a heat source which led to the explosion. As a result, eight firefighters and one police officer were hospitalized.

Lauterbach, Germany (2023)

The fire brigades were called to a two-family house after an explosion caused the eastern wall of the house to collapse. The fire brigade could later conclude that the explosion was caused by the PV’s storage battery (Enkhardt, Germany, Austria hit by multiple solar battery fires in September, 2023). Investigations shows that the explosion was probably caused by a technical defect in the battery. Two of the homeowners and one neighbour was left with minor injuries. The house was left uninhabitable (Enkhardt, German home destroyed by 30 kWh battery explosion, 2023). Enkhardts article also explains that five similar incidents happened in Germany and Austria during 2023, three in Germany and two in Austria.

Våxtorp, Sweden (2021)

A smaller hotel was caught on fire and all guests managed to evacuate. The fire started in the PV panels, spreading to the attic and roof construction (Sjöström, 2021). The fire later spread from the attic/roof construction to the ground floor, which is the hotel part of the building. The subject building was destroyed, in the end there was nothing left to save. Spread to the neighbouring buildings was stopped. Sjöströms investigation shows that the fire probably initiated in the inverter, or the cables connected to it.

Noardburgum, Netherlands (2021)

A major fire started in a PV module in a warehouse, no people were injured (Bellini, Major fire at solar-powered warehouse in the Netherlands raises concerns among nearby residents, 2021). The municipality later got 73 notifications from residents in the area, claiming they had thin, sharp parts of PV modules on their land. These parts had spread several kilometres away from the location of the fire. Municipalities later advised the residents in the area to not let the livestock eat the fragments or the contaminated grass.

Amazon Facilities, USA (2020-2021)

In April 2020 the brigades were called to an Amazon warehouse in Fresno, California. Approximately 220 panels were destroyed by a fire that initiated in the system because of a defect in one of the components (Palmer & Kolodny, 2022). Same thing happened a year later in an Amazon facility in Perryville, Maryland. This time the fire was even bigger. Fires occurred on at least four different Amazon facilities months after these incidents. It has also been concluded that at least one of these fires was caused by a faulty inverter (Palmer & Kolodny, 2022). Amazon decided to take their PV systems offline to inspect if they are designed, installed, and maintained correctly, before being brought back online. Findings from the investigations shows that mismatched connectors, poor installation and maintenance of connectors/wiring, and water entering the inverters are possible reasons for fire initiation.

Mannum, Australia (2024)

Fire started in a battery storage on a solar farm in Mannum, South Australia (Vorrath, 2024). The brigade managed to stop the spread of fire from the battery, which was located in a container. The reason for fire initiation was a faulty inverter. One worker had to be taken to hospital, and the damages on the farm was estimated to $250,000.

Horsens, Denmark (2023)

Gedved School in Horsens, Denmark had a fire breaking out in their PV systems located on the roof (DBI - Dansk Brand- og sikringsteknisk Institut, 2023). The reason for fire initiation has not been established yet, but the solar cells contributed to the spread of fire. No people were injured.

Ichihara & Kyushu, Japan (2020)

Japan’s largest floating PV installation, located in Ichihara, was destroyed following a typhoon (Willuhn, 2020). Even though the installation was believed to follow the Japanese guidance and recommendations, it was still not enough to withstand the winds measuring up to 207 km/h (57.5 m/s). This is also worrying as this typhoon is not the strongest recorded in Japan (Willuhn, 2020). It is concluded that the anchors of the floating installation failed, which led to bolts to collapse. Parts of the system was blown away, curled up, and some parts were stacked on top of each other. This ultimately led to a fire spreading throughout the floating installation. Two weeks after the incident in Ichihara, another floating PV installation caught fire after a typhoon in Kyushu. No people were injured during these fires, but expensive damages was done.

2.1.6 International Recommendations, Standards, and Tests

There are a set of international standards that are created to standardize the requirements, testing, and implementation of BIPV’s internationally. These standards does not have any legal requirements in the country where it is implemented unless they refer to the standard in the legislation (Jonsson, 2023). RMIT Solar Energy Application Lab has created a global database collecting info from manufacturers around the world. 218 products from 34 manufacturers has been collected, showing what standard they were using when testing their product. This shows that 81% of the manufacturers used IEC 61730, 15% used UL 1703, and 4% used EN 13501-1 which is referenced by the European standard EN 50583 (Jonsson, 2023).

Other international standards that exists, as mentioned by Jonsson (Jonsson, 2023), are IEC 63092, ISO/TS 18178, EN/IEC 61215, and IEC TR 63226. A choice was made to focus on the most used ones from the RMIT database. These three are presented below.

IEC 61730

International standard. Contains requirements regarding fire tests that needs to be done before the system is deemed safe for usage. These fire tests relates to test for common fire initiations, hot-spots, high temperatures, flammability, and fire resistance (Jonsson, 2023). IEC 61730-1 specifies the construction requirements for PV modules, while IEC 61730-2 specifies the requirements for the testing (International Electrotechnical Commission, 2024). The standard is designed for PV modules used for long-term use in an operating temperature of less than 70°C.

UL 1703

International standard that specifies the requirements for PV modules and panels integrated/attached to buildings and freestanding modules (Jonsson, 2023). The standard addresses systems installed on roofs, independently, or in combination with the roof covering. It also specifies that when testing BIPV’s, the UL 790 standard test (Fire Tests of Roof Coverings) should be used (Intertek, 2024). This test evaluates the fire resistance performance of BIPV materials used on roofs in residential and commercial buildings that are being exposed to fire sources from the outside.

EN 13501-1 (as referenced by EN 50583)

European standard created to standardize the requirements for BIPV’s in EU. It is divided into two parts, where the first part evaluates the PV as a module and the second part evaluates the PV as a system (Jonsson, 2023). There is also a standard called SS-EN 50583, which is a Swedish version based on the European EN 50583.

EN 50583 focuses on electrical and construction related difficulties (Motistech, 2024). EN 13501-1 test addresses three different product categories: construction products, floorings, and linear insulation products. The product must be tested in at least 4 of the 5 different test methods presented in the standard, refer to Figure 3 below. The products later receives a performance class from A to F. Worth mentioning that the standard are getting widely used outside of EU (Motistech, 2024), from manufacturers trying to enter the European market.

EN 13823	Reaction to fire tests for building products — Building products excluding floorings exposed to the thermal attack by a single burning item.
EN ISO 1182	Reaction to fire tests for building products — Non-combustibility test.
EN ISO 1716	Reaction to fire tests for building products — Determination of the gross heat of combustion (calorific value).
EN ISO 9239-1	Reaction to fire tests for floorings — Part 1: Determination of the burning behavior using a radiant heat source.
EN ISO 11925-2	Reaction to fire tests — Ignitability of building products subjected to direct impingement of flame — Part 2: Single-flame source test.

Figure 3: Test method/standards involved in EN 13501-1 (Motistech, 2024)

3 Problem Statement and Objective

The lack of example projects and standard solutions, along with the fact that the legislation is not adequate when it comes to BIPV-facades, puts a lot of pressure on the fire engineer in BIPV-projects. This thesis will add knowledge to previous student thesis (Jonsson, 2023) to reach a state of knowledge that can be useful for fire engineers involved in future BIPV-projects. Suggestions on future research and lessons learned in methods and results from Jonssons thesis has been considered to reach a good quality of this thesis. The previously conducted interviews mostly involved fire engineers that has never been in contact with BIPV-facades, they were all located in Sweden as well (Jonsson, 2023). It was therefore suggested in Jonssons thesis that a wider scope could have been applied to get different perspectives on the subject. It was also suggested for future research to have a look at designs of BIPV-facades from real projects, as there are no standard solutions out there.

The objective of this student thesis is to contribute to an increased knowledge connected to fire safety challenges when implementing BIPV-facades. This includes identifying challenges relating to fire safety, possible improvements, solutions, and pros and cons with this technology. There will also be a closer look at projects that has been using BIPV-facades and what their solution looked like and lessons learned. This thesis will provide a good starting point for fire engineering consultants who are involved in BIPV projects.

3.1 Research Questions

The following research questions has been developed to assist in the progress of fulfilling the objectives of this thesis.

- How does BIPV's differ in terms of fire safety from the more common solar panels previously used, and the usual glass walls / curtain walls that they typically replace? What is the most important parameter or component to focus on, to mitigate fire initiation and fire spread in the façade?
- Are there any common obstacles that fire safety designers are being confronted with in BIPV projects, and are there solutions that are often being used?
- Are there any concerns from the fire brigades regarding this technology, and are there procedures in place to deal with fires in BIPV systems?
- Are there any potential areas of improvement that can be identified relating to BIPV-facades and fire safety? Any suggestions on how to improve in those areas?

3.2 Limitations and Constraints

This student thesis intends to focus on BIPV-facades and fire safety in general. However, a lot of focus has been put in residential and office buildings specifically, as the example projects used in this thesis are of these building classifications, or a mix. A few interesting BIPV buildings will be selected to look at more closely. This also depends on which project teams are willing to be interviewed and wants to be a part of this thesis.

As previously mentioned, a student thesis was done recently by Jonathan Jonsson, Lunds University (Jonsson, 2023). His thesis addresses PVs/BIPVs as well, and this student thesis aims to expand on his research and take inspiration from his lessons learned and suggestions for future research. An active effort has therefore been made to get in contact with fire engineers, fire brigades, and manufacturers that has been in contact with BIPV-facades. These actors are also spread across Australia, Sweden, Norway, and Germany to get an even wider view on the subject. As suggested for future research (Jonsson, 2023).

4 Method

This thesis was using two different phases to adress the research questions as good and effective as possible. The first stage was the literature review. Where different research, tests, and reports from around the world was studied to contribute to a greater understanding of the technology, and to get a good knowledge base before going into the interviews. After a thorough literature review, relevant people in the industry were contacted to be interviewed. The methodology of the report is illustrated in Figure 4 below.

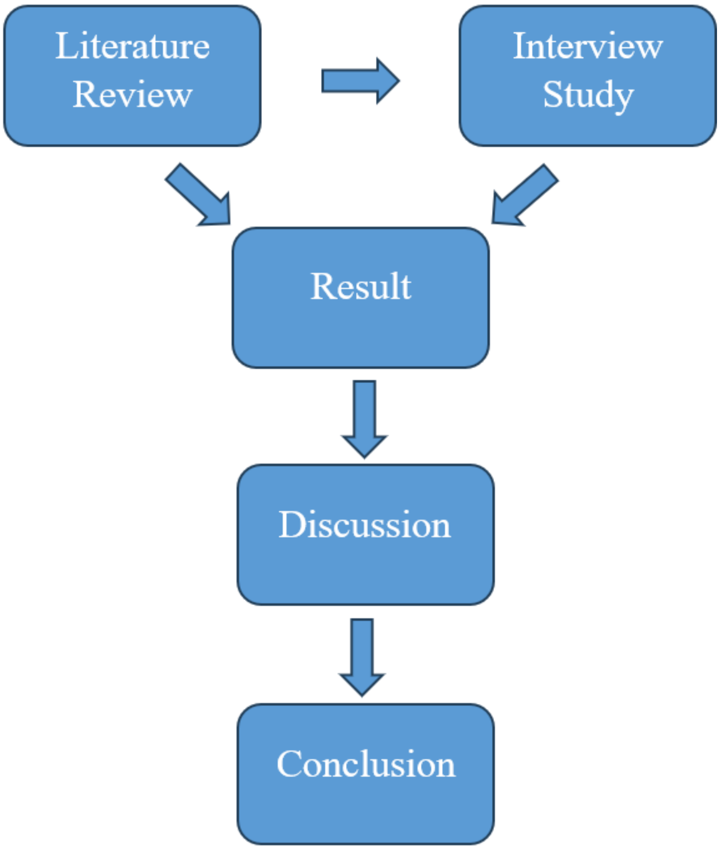

Figure 4: Flowchart of the method of the thesis

4.1 Literature Review

The first part of this student thesis consisted of a literature review. In this part, the history and development of photovoltaics was analysed in order to acquire a basic knowledge and understanding of the technology. What progress the industry has made, challenges from the past, fire related statistics, and fires involving PVs are also presented. The focus of the literature review then shifted to focus on BIPV's, which is the main focus of this thesis. Figure 5 illustrates the methodology of the literature review, see below.

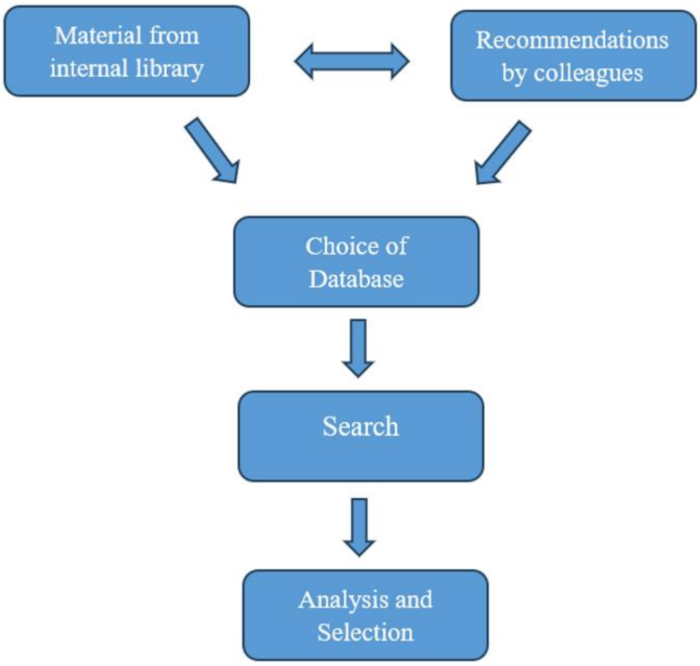

Figure 5: Methodology of the literature review

The base of the literature review was made up from articles found in Holmes Australia LPs internal library. A lot of recommendations also came in from colleagues and other actors in the fire engineering industry. Jonsson's student thesis (Jonsson, 2023) and his references also provided a good start and gave inspiration to where to put focus when conducting the literature review. Science Direct (Science Direct, 2024) was also used as a supplement search, as that seemed to be the most effective way of finding new articles and reports relating to BIPV-facades. LUBSearch and Google was also used occasionally when searching for some very specific information. This to get a wider scope when doing the search and increase the chances of finding useful information. The keywords that was used was "BIPV" and "BIPV-facades". From this word-search it was possible to identify a few articles relating to fire safety and installation procedures. Articles not addressing anything fire related was not used or considered.

The selection of literature for further study was based on the titles, summaries, and list of contents relevance. Reports relating to fire engineering and scientific articles was the main priority when searching for relevant material. Recommendations from colleagues and people in the industry was also important to consider as they are sitting on more experience and are expected to have a good idea of what could be useful and not useful for the future of the fire engineering industry. The year that the literature was written was also considered as it would impact the relevancy of the information. BIPV's and solar panels in general are a relatively new technology to the industry and older literatures would therefore not consider this technology whatsoever. A decision was therefore made to only consider literature not more than eight (8) years old, unless there are no other alternatives. The selection of literature was of course also made based on the credibility of the document.

The focus was not only on Australia. Sweden, the US, and Europe in general was also considered to create a good overall picture of the industry. Notably, several of the major BIPV manufacturers are currently based in Europe. The literature review also contains an analysis of the regulations in Sweden and Australia related to solar panels and BIPV's.

A large part of the literature review consists of research and reports by Rebecca Yang and her colleagues at RMIT (Royal Melbourne Institute of Technology). Their research relates, among other things, to fire hazards and challenges with BIPV's, and how well adapted the regulatory framework is for this new technology globally. The latest tests related to BIPV-facades also forms a part of this thesis, for example the full-scale SP Fire 105 test conducted by RISE in Norway (Stølen, Li, Wingdahl, & Steen-Hansen, 2024).

The focus was also put on completed projects such as 550 Spencer Street in Melbourne and Sara Kulturhus in Skellefteå, Sweden. Both buildings fitted with BIPV-façades.

The findings from the literature review were not only used to adress all the research questions. It was also an effective way to come up with most relevant questions for the interview study, as presented in the following section.

4.2 Interview Study

The second part of the thesis consisted of interviews with relevant people in the industry. The interview questions differed slightly depending on if it was a fire engineer, fire fighter, or a manufacturer who was being interviewed. This to get as much relevant information as possible, as these different groups are expected to have different knowledge areas of expertise. However, the majority of the questions were the same for all of the attendees, this to be able compare the differences in their answers.

Fire engineers involved in BIPV-projects were interviewed to get an overall picture of how the process went, problems that arose, how they arrived at the final result, as well as lessons learnt, and ideas for future BIPV-projects. Interviews was also held with manufacturers of BIPV’s to get an idea of their mindset, and to see if they have any fire considerations when these building components are being produced. Contact was also made with fire brigades in both Australia and Sweden. This is to compile their experiences with solar panels, investigate whether there are any experiences of fires in BIPV-facades, and how well prepared they are to fight a fire with one of these systems involved. The interview study was a complement to the conclusions drawn from the literature review. Figure 6 illustrates the methodology of the interview study, see below.

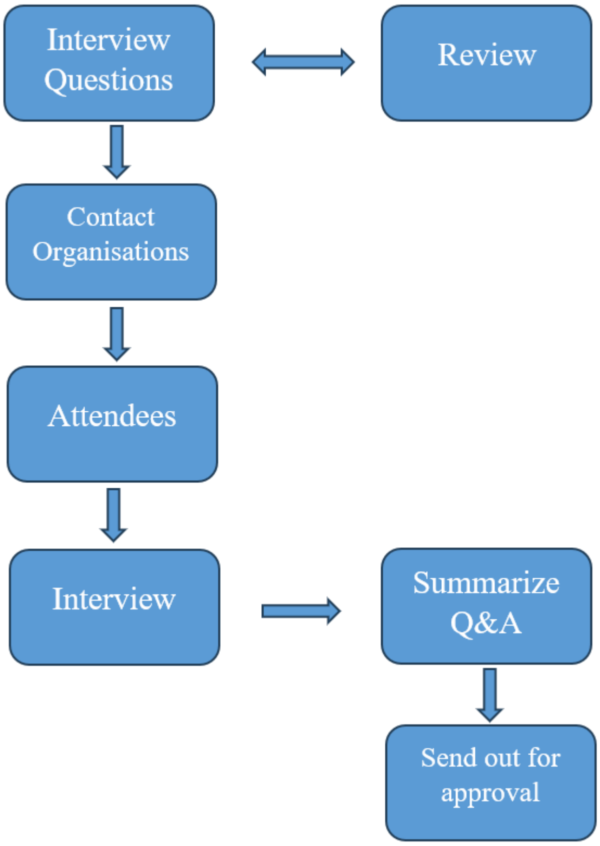

Figure 6: Illustration of the workflow for the Interview Study

The questions used in the interview study was designed during and after the literature review. This to come up with as relevant questions as possible to get a good quality of the report. The research questions and limitations was also considered when designing the questions for the interviews.

The introduction and interview questions were sent out to the different consultants, manufacturers, fire brigades, and other organisations in the fire engineering industry in Sweden, Australia, and Europe in general. This to see if they were interested, and if they had someone in their team with the competence necessary to answer the questions of this thesis. Recommendations from colleagues and other actors was very helpful to find relevant people. The main requirement being that they have been in contact with BIPV-facades either through production stages, research, testing, or involved in real projects. Some people was also found during the literature research, as their work or research seemed interesting and useful for this thesis.

A request was sent out to several big manufacturers around the world, but only a few gave an answer. The brigades was planned to be Melbourne and Uppsala, because of 550 Spencer Street and Magasin X, and to get perspectives from brigades from different countries. However, Melbourne had to cancel in the end. The Brigade from Skellefteå was then contacted because they have Sara Kulturhus in their area, and they accepted the interview on a very short notice.

BIPV-façades are still a new innovation for the industry, and there are therefore a limited amount of people who has been in contact with BIPV-facades in real projects. With this in mind, there were a couple of consultants declining the request for interview, with the answer that they do not believe they are relevant in these kinds of discussions. The people and organisations that where happy to be a part of the interview study are presented below:

- Tobias Salomonsson, Managing Director of RED Fire Engineers (Australia)
- Reidar Stølen, Researcher at RISE Fire Research (Norway)
- Kjetil Pedersen, Director of STRATEG Consulting and Board Member of the Building Appeals Board Victoria (Australia)
- Marc Wendorf, Avancis (Manufacturer, Germany. Sales Manager / BIPV Consultant)
- John Rakic, Trafalgar (Manufacturer of specialty building products, Australia)
- Daniel Haarala, Fire Brigade Skellefteå, Sweden
- Fredrik Nilsson, Fire Brigade Uppsala, Sweden

The people interviewed was provided with the interview questions beforehand, to give them a chance to come prepared and to contribute to the best interview possible. The questions in the beginning were not complex, just to get started and get an idea of the area of interest. The following questions were designed to go deeper into the subject of BIPV's. One of the goals was also to offer the people interviewed more flexibility in their answers, this to get as good answers as possible from the interview study. A decision was therefore made to use a semi-structured interview technique, which means that the questions are following a specific order, but also allowing for flexibility (Tegan, 2022). Some of the interview questions were amended depending on who was interviewed, the brigade did not get the exact same questions as the consultants or manufacturers for example. However, the majority of the questions were the same for all the different actors, this to see the differences in their answers.

Pauses in the interview was also left to let the person getting interviewed to answer the questions as openly as possible, really letting them expand their thoughts to the readers without interruption. Follow-up questions was also allowed, depending on the answers provided. The interview questions and answers are presented in Appendix D - Interview Questions and E – Summary of Interviews.

The summary of the interviews was afterwards sent to every attendee so they could approve what was being said before being used in this thesis. If something was misunderstood during the interview, they had the chance to correct it.

Finally, the information gathered during the literature review and interview study was evaluated and analysed. The final compilation aimed to create an interesting discussion within the subject, identify problems, solutions, areas worthy of further research, raise questions, and fill knowledge gaps that may arose along the way.

5 Result

This section presents the results from the literature review and interview study to adress this thesis objective and research questions and is divided into two different parts: “Fire Hazards” and “Legislation, Standards, Testing, and Design of BIPV-facades”. The first part addresses the fire hazards relating to fire initiation and the possible consequences. The second part addresses the issues with legislations, standards, testing, installation/maintenance, and the lack of example projects. To have a look at the design of BIPV-facades from real projects came as a suggestion for future studies from the previously mentioned student thesis from Lund University (Jonsson, 2023).

Potential improvements will also be presented relating to reasons for fire initiation, the following consequences, issues with legislations, standards, testing, installation/maintenance, and the lack of example projects.

5.1 Potential Fire Hazards with BIPVs

It is hard to conclude the reason for fires relating to BIPVs and BAPVs. This because the older statistics from National Fire Data Center are not that detailed (Weaver, 2019), and a lot of the fires involving PVs was characterized as “other”, as the business did not have adequate knowledge about this new technology, making it hard to conclude what initiated the fires.

A conclusion that can be drawn from the newer statistics is that there are more fires in PV systems nowadays compared to how it used to be. Data from 2022 shows that there were six times more fires involving PV’s than there were a decade ago (Hoey, 2023). It also showed that the solar capacity grew by 10,5% from 2019 to 2022, but the number of solar panel-related fires surged by nearly 50% during this time. Faulty installations without thorough inspections is believed to be the reason for this increase.

It has also been concluded from the literature review and the interview study, that there has not been a fire in a BIPV-façade yet, and it is therefore hard to learn from mistakes and fires in the past, as stated by Daniel Haarala, Tobias Salomonsson, and Marc Wendorf in the interviews. Fredrik Nilsson highlighted that technical components, etc, is similar to the older more regular PVs, and speculates that some of the risks could be similar as for the more regular PVs. A worry that was also highlighted by Fredrik Nilsson is the fact that sometimes an incident must occur before the industry realise that there is a problem, something Fredrik wants to avoid by any means necessary. Grenfell would be one example of that (Profinish Fire Protection, 2023).

5.1.1 Fire Initiation

The following section will present the main risks for fires in PVs / BIPVs, for both external and internal fire initiation. Where external means that the fire spread to the system, and internal that the fire initiated in the system.

Partial Shadowing and Hot Spots

When a solar cell in a BIPV system is not generating the same amount of current as the other cells that it is connected to, for example if the subject cell is partially covered from shadow or debris, could present a danger to the system and the building. When the cell is generating lower current, the cells that are connected to the covered cell will produce a higher amount of current (Satpathy & Pamuru, 2021). The cells producing the higher current will force the subject cells electrons to flow in the opposite direction, from anode to cathode, instead of the other way around. This is what is called “reverse bias”. The covered cell is forced into reverse bias and starts producing heat instead of energy (Rai-Roche, 2022). This will lead to the phenomenon called “hot spot” which could initiate a fire in the cells or other components.

Hot spot makes a cell in a module to reach high temperatures, with risk of causing damage to the module and other components in the system (AE Solar, 2023). Other reasons for creation of hot spots would be accumulation of dust and debris, same principle as for the partial shadowing as the debris or dust could cover the panel same way as a shadow would do. Debris could also interfere with the air flow in the system, which is important as it need to be able to transfer the heat away and keep a consistent temperature across the panel.

Same principle goes for the cavities in the BIPV system, which needs to be free from dust to be able to operate in a safe way and keep the temperature in check. The importance of the cavity design in BIPV-facades was highlighted by Reidar Stølen and Kjetil Pedersen in the interviews.

The design and construction of the system can also contribute to the creation of hot spots, for example poor insulation and ventilation. The temperature in the affected cell will reach high temperatures, causing the glass to crack, cell degradation, and fire initiation. (AE Solar, 2023). Errors in the manufacturing and installation process leading to a faulty cell could also be the reason for the creation of hot spots. The risk of fire initiation from having a faulty cell or other components was also highlighted by Reidar Stølen, Kjetil Pedersen, and John Rakic.

Electrical Arc Fault

An electrical arc is a current that travels between two conductors of electricity. This occurs in the DC cabling of PV systems, creating an intense arc of heat and light (Wattscore Energy, 2023). An electrical arc could cause damage to the system and its components.

Exactly how hot the arc gets depends on a number of parameters, but there is no doubt that the arc will be hot enough to melt glass, aluminium, copper, and potentially initiate a fire in other materials in close proximity (AC Solar Warehouse, 2023). This risk was also highlighted by Reidar Stølen in the interview study.

Thirty-six percent of these arcs occurs in enclosures where they are supposed to be protected (Walker, 2019). Electrical arcs can occur anywhere where there is electrical current flowing and are often created by a circuit that is being overheated. Possible causes of an arc fault are listed below:

- Faulty wiring from maintenance and installations;
- Wire-insulation gets damaged;
- Faulty components and/or equipment; and
- Too many fuses inside the electrical panel, also known as “Over-fusing”.

Short Circuit / Faulty Inverter

A component that short circuits can potentially start a chain reaction that results in a fire that spreads throughout the inverter (Firetrace International, 2022). Short circuits can be caused by a number of reasons, as listed below:

- High temperatures damaging the electrical components over time;
- Not adequate maintenance, management, and installation;
- Not using proper equipment;
- Small animals getting inside equipment; and
- Vegetation disturbs the equipment.

Short circuits and faulty inverters was one of the worries that was highlighted most by the attendees in the interview study. Both Fredrik Nilsson and Daniel Haarala from the two Swedish fire brigades, and John Rakic raised this as a potential risk. Reidar Stølen and Tobias Salomonsson also highlighted this risk. However, Tobias Salomonsson mentions that the risk of an inverter potentially short circuiting is very unlikely from his understanding. Based on the full-scale fire test that Tobias Salomonsson has been involved in, he is of the opinion that even if the inverter would ignite, it would not create a continuous fire spread issue on the external façade. Kjetil Pedersen is of the same opinion, and also questions if a faulty inverter would cause a big enough fire to actually cause a problem. Kjetil expands on his thought and believes in this situation, it is mainly the brigade intervention that is being affected. This because they still have to conduct an operation to put out the fire, while the panels are still alive.

Storage Batteries

The most common risk connected with lithium-ion batteries is something called "thermal runaway". Which results in an overheated battery along with release of large quantities of toxic and flammable gases (Bensen, Bowes, Franks, & Warner, 2021). Clause C3D13 (Separation of Equipment) of the BCA in Australia (National Construction Code, 2023) states that a battery system installed in a building that has a total of 12 Volts or more, and a storage capacity of 200 kWh or more must be separated from the remainder of the building by an element achieving an FRL of 120/120/120.

Fires involving lithium-ion batteries in storage systems are rare, but it can cause catastrophic consequences (Bensen, Bowes, Franks, & Warner, 2021). The thermal runaway from one cell can spread to adjacent cells, leading to production of heat and flammable gases. The gases are allowed to accumulate in the storage space, ultimately creating an explosive atmosphere. Bensen also states that a blast can injure occupants, first responders, and structures in close proximity to the subject building. It is also explained that fires in these batteries can be very hard to extinguish as they are fuelled by the damaged cells and tend to reignite even if extinguished, and that a fire in a battery can last for multiple hours.

Relating to this, Kjetil Pedersen mentioned that the Australian guidelines requires a fire engineer to be involved in projects with EV batteries / chargers. This because it is considered a special hazard. There are no such guidelines implemented for BIPV-facades just yet.

Weather Conditions

Some of the more common weather related challenges are presented below with a short explanation (Utilities One, 2023):

- **Extreme temperatures*:*** Can cause the BIPV components to expand and contract. This could potentially lead to damage of the systems components.
- **Moisture and humidity:** Can lead to corrosion, short circuit of the systems components, and reduced efficiency.
- **High winds:** Can cause structural damage to the systems components.
- **Hail and snow:** The system must be able to withstand the extra weight from snow and the effect of hailstones without compromising the systems functional design and efficiency.

Some places in the world are also presented with unique challenges. For example, in Australia where bushfires, hailstorms, dust clouds, and floodings happens every now and then. They are also very hard to predict (Cranney, Fell, & Wilson, 2020). Bushfire smoke produces particles in the atmosphere that blocks the sunlight from reaching the panel. Furthermore, the bushfire ashes can also create a layer on the panels, ultimately reducing the systems efficiency. Dust storms are generally larger particles compared to the bushfire smoke, but the impact is similar as it can damage components and reduce the efficiency of the system. Cranney also states that the impact of the dust storm depends on a number of factors such as: composition of the dust, how close the location is to the ocean, and the current weather conditions. For example, clay-like dust presents a greater threat than sandy dust, as it is much harder to remove.

Hail presents an obvious threat to BIPV's as it can damage the components. The main challenge is to create a system that can withstand these hailstorms, but not making it overly heavy and expensive (Cranney, Fell, & Wilson, 2020). The International Electrotechnical Commission (IEC) standard impact test is testing solar panels impact from hailstones of 25 mm in diameter, with a speed of 27 m/s (Svarc, 2023). A damaged component caused by external influence could hypothetically be a fire initiator as mentioned by Kjetil Pedersen in the interviews.

Installation and Maintenance

Not adequate installation and maintenance procedures is often a fire initiator in PV systems. Studies from the UK (Pester, 2017) conducted by BRE (Building Research Establishment) showed that out of 58 fires, 42 of them was caused by the installations. Poor installation and maintenance increases the risk of hotspots, electrical arc faults, falling panels/debris, short circuits, and spread of smoke/toxic gases.

Fredrik Nilsson from Uppsala Brigade highlighted that that the situation in Sweden is not ideal when it comes to installation/maintenance of PVs and BIPV's, as the installation and maintenance procedures are not working properly. The problem with the Swedish control system was clearly highlighted from Fredrik Nilsson in the interview study. Him and his colleagues anticipated beforehand that there would be major flaws in the system, but they have now also seen it in real projects where the inspections are getting completely neglected in some cases. The importance of proper installation and maintenance to avoid fire initiation was also highlighted by Daniel Haarala, Reidar Stølen, and Kjetil Pedersen in the interviews.

Jonsson concluded through his literature study (Jonsson, 2023) that four out of five installations in Sweden have faulty installations once inspections has been carried out. In some cases, according to Jonssons interview attendees, the inspection is even completely ignored.

5.1.2 Consequences

The following section will present the potential consequences caused from a fire initiation in a BIPV-facade.

Spread of Fire

One of the main concerns when it comes to implementing BIPV-facades is the potential spread of fire. The fire could potentially spread from internal areas to the BIPV façade or the other way around, through openings, roof, and external surfaces (Yang, et al., 2023). Yang also presents that flashover in a room in close proximity to the BIPV façade is likely to ignite the BIPV components. BIPV modules that are connecting multiple SOUs are also a concern as this could lead to fast fire spread to multiple SOUs, and different floors of the building. It could present a danger for the occupants of the building, impact the egress provisions, and fire brigade intervention, as it could block egress routes and cause material to fall off the façade. Tests has been made, but the industry is still in need of more testing to adress the issue with fire spread in the most effective way possible (Yang, et al., 2023).

Rebecca Yang, M.C. Hui, and their team found in their study that PV panels ignites by an ignition heat flux (IHF) of 26 kW/m^2 (Yang, Le, & Hui, Fire Safety Requirements of Applying BIPV in Australia, 2023). Which can be compared to the IHF of 75-120 kW/m^2 measured from a window opening in a fully developed compartment fire. It was also concluded in Yangs study that the ignition time of the PV module was reduced from 913s to 83s when the IHF was increased from 28 to 45 kW/m^2, and the ignition time was ten times as fast when the IHF was doubled to 56 from 28 kW/m^2. The ignition temperature for PV panels are around 420°C.

The risk of fire spread along the façade or into the building was also frequently mentioned as a worry in the interviews, as it was highlighted by all the attendees. Daniel Haarala and Fredrik Nilsson from the Swedish brigades both highlighted this risk. Both manufacturers, Marc Wendorf and John Rakic, were also aware of this potential issue. Marc Wendorf highlighted that Avancis glass-glass BIPV modules does not contribute to the fire spread, as they are certified flame retardant. This was also backed up by Tobias Salomonsson, who were involved in a full-scale test before implementing the BIPV-façade for 550 Spencer Street. In that test they concluded that if you are able to control the internal fire, the panels does not contribute to the fire spread. Instead, it will self-extinguish. Tobias Salomonsson also highlighted that it has combustible elements, and if there is a fire close by it could potentially burn. Marc Wendorf and his colleagues highlighted that their BIPV modules are often built into a ventilated curtain wall, and mentions barriers made of metal between panels to prevent fire spread. Kjetil Pedersen also believes that the cavities in the wall could potentially contribute to spread of fire in the façade if there would be enough fuel.

As stated by Magnus Nyhage (Södra Älvsborgs Räddningstjänstförbund) in Jonssons thesis-interviews (Jonsson, 2023), one improvement for future fire engineering would be to get more tests done that relates to relevant standards of the industry, for example SP Fire 105 façade test which is often used by the countries in Scandinavia. Since then, a large- and small-scale SP Fire 105 façade test has been done in Norway by Reidar Stølen (RISE Fire Research) and his team on a BIPV façade (Stølen, Li, Wingdahl, & Steen-Hansen, 2024). Conclusions made from RISEs SP Fire 105 test states that vertical flame propagation is possible in the cavities, where the highest temperature was measured to 850°C, even with a limited amount of combustible materials. The glass, glue, and aluminium construction was strongly affected by the high temperatures in the large-scale test, resulting in modules falling to the ground. It was also concluded that the fire can spread throughout the entire façade rapidly.

Electrical Shock and Fire Fighting Operations

If brigades are using water as an extinguishing method, the operator is at risk of getting electrocuted. The panel may still produce electricity even when it is on fire, as long as the sunlight reaches the panel (Yang, et al., 2023). Yang explains this applies to systems provided with shutdown mechanisms as well, as this does not ultimately make the system safe to operate during a fire. The connection between the panels and the inverter could still remain active during daylight hours.

This is known in the industry as the DC Danger Zone, which means that anyone operating near the panels when the sun is shining is engaging with electrical equipment producing lethal DC electricity (Foran, 2023). Recent studies from Germany (Fraunhofer ISE, 2023) states that no firefighters in the country has been injured from PV electricity. The study states that the greatest hazard for brigades is when fires are being fought from the inside. In this situation, the fire fighters is at risk of getting electrocuted when they enter rooms where scorched cables could get in contact with the water and/or the firefighters themselves. This risk was also highlighted by Kjetil Pedersen in the interview study.

Both Daniel Haarala and Fredrik Nilsson from the Swedish brigades highlighted the possible issue with evacuation from high-rises equipped with BIPV-facades. The concern related to the brigades possibility to evacuate occupants through windows with the help of a turntable ladder. In these situations, the brigade usually wants to lean the basket against the façade, which is not ideal when dealing with a BIPV-façade and could complicate the evacuation procedures. Fredrik Nilsson continues and speculates that it might be possible for a burning BIPV-façade to lead electricity when the ladder is eventually leaned against the façade. Fredrik is aware of operations relating to regular PVs on the roof where the ladder has been leaning against the roof, the roof has become electrically energised, and eventually shut the whole car off. No fire men were injured. Kjetil Pedersen is aware of similar situations relating to PVs on the roof, where the brigade had been using foam or similar to block the sunlight from reaching the panel. After a while the foam has started to slide off. Once the foam has slid off, the fire men working near the panels will find themselves in a dangerous situation without being aware of it. The risk of falling materials or panels from BIPV-facades was also highlighted during the interviews from Daniel Haarala, Fredrik Nilsson, Kjetil Pedersen, and Tobias Salomonsson.

Another issue raised by Fredrik Nilsson and Daniel Haarala was the lack of information they get and have on BIPV-facades. The fact that none of them were aware of the BIPV buildings in their area until recently also highlights this. They also highlighted that in some instances it is not even possible to tell the difference between the regular façade from the BIPV-façade. A situation that could lead to horrible consequences if they start fighting a fire, unaware of where the potential risks are located. Fredrik Nilsson says that if there are no guidance or info on the façade, this will result in a much more defensive operation to make sure he is not putting any of his colleagues in danger. Fredrik Nilsson continues and highlights that the brigades safety is supposed to be considered according to the Swedish BBR, and is of the opinion that this has not been a priority when implementing PVs in Sweden. Fredrik believes there is a lot to be done in this area.

The issues with evacuation from high-rises was also identified by the attendees in Jonssons thesis interviews (Jonsson, 2023).

Spread of Smoke & Toxic gases

It has been proven that fires in BIPV façades leading to smoke spread can threaten the health of the occupants of the building and complicate the evacuation. The smoke spread could potentially spread to different levels of the building through the vertical void of the façade (Aram, Zhang, Qi, & Ko, 2023). There are knowledge gaps that needs to be addressed when it comes to toxic smoke production from burning BIPV's, as this parameter is often underestimated and could potentially lead to catastrophic consequences for people inside and around the building (Yang, et al., 2023). Yang explains that the main problem being that there is currently no test method to estimate the toxic gas development from burning BIPV modules. What is known is that a burning solar panel where the solar cells gets exposed, could be highly toxic (Foran, 2023). The solar cells contains carcinogens, cadmium telluride, gallium arsenide, and phosphorous. All of them could potentially be lethal to a human.

Falling Panels or Debris

A fire in a BIPV façade could cause panels and debris to fall down because of structural breakage caused by the fire. This presents a risk to the evacuating occupants of the building as well as the fire brigade who is trying to conduct a firefighting operation (Yang, et al., 2023). Falling material could potentially affect levels below and structures in close proximity of the subject building. Yang also states that it is been concluded in an experiment that panels with non-glass back sheets tends to be affected by the fire quicker than a panel with glass-glass construction, the non-glass panel had debris falling down after a few minutes when the experiment was conducted.

The risk of falling panels or debris was also highlighted by Daniel Haarala, Kjetil Pedersen, and Reidar Stølen during the interviews. This was also considered and addressed by Tobias Salomonsson and his colleagues at RED when building 550 Spencer Street.

5.1.3 Potential Improvements

There are potential improvements that has been identified throughout the literature review and the interview study, which will be presented in this section.

Fire initiation - Improvements

A couple of potential improvements has been identified from the literature review relating to the creation of hot spots. First one is the improvement of the bypass diodes in the system. Bypass diodes is the component that prevents the reversed bias and transports the current away from the shaded area to avoid the creation of hot spots (Satpathy & Pamuru, 2021). Most modules nowadays has one diode per 20-24 cells, or 2-3 diodes per 60-72 cells. Connecting each cell to a bypass diode would potentially make the system safer. This has already been done by one manufacturer (AE Solar, 2023). The module also received TÜV certification, calling it “the world’s first hotspot free module”.

Another potential improvement could be the implementation of a long-thin cell module, subdivided into series/parallel of smaller cells. This is a solution that the largest PV manufacturer in the US has already implemented in their modules since they had problems with partial shadowing (Rai-Roche, 2022). They also highlight that proper maintenance requirements could be an effective way to go, as dust and debris is a big contributor to the creation of hot spots.

Arc Fault Circuit Interrupter (AFCI) is often used instead of a regular circuit breaker in PV systems nowadays. The AFCI is supposed to detect any potential arc faults and shut down the system before it occurs (Walker, 2019). Walker also states that AFCI’s is much more expensive compared to a regular circuit breaker, it is also hard to determine exactly how effective they are, as arc faults are still occurring in systems with AFCIs. None of the manufacturers in the interview study are implementing AFCI’s in their products. Marc Wendorf and Avancis also refers to reports from Switzerland saying that they are not using them anymore since most inverters have introduced functionalities that make them obsolete. Reidar Stølen has a similar view on AFCI’s and is sceptical to how effective they really are. From Reidars understanding, once the arc fault is detected, it might already be too late as it has already reached possible temperatures of 1000°C in these connections.

A short circuit can be caused by a number of reasons and potentially start a chain reaction. Well-developed automatic fire suppression systems could not only detect the problem in time, but also shut down the inverter before the potential chain reaction has started (Firetrace International, 2022). Firetrace also believes sprinklers is an effective protective measure to stop fire spread. Following these measures, the fire would not grow as big, equipment is saved, and spread to surrounding structures and areas are being mitigated. Reidar Stølen also speculated in the interview that systems that could potentially identify irregularities in an earlier stage would be even more useful to prevent fire initiation.

Measures that exists today relating to storage batteries in PVs are deflagration vent panels, which are designed to direct the potential blast away from the enclosure, the occupants, and the brigade (Bensen, Bowes, Franks, & Warner, 2021). That is why the outlet is usually found on the roof. Bensen continues and states that exhaust systems does also exist but is not as commonly used for battery enclosures. Gas-phase suppression systems are often included in battery systems to prevent spread of fire. Smoke and gas detectors is another commonly used suppression system for battery enclosures (Bensen, Bowes, Franks, & Warner, 2021). Bensen also states that new technologies are getting developed, designed specifically for lithium-ion battery gases, and mentions Battery Management Systems (BMS) as another component that could be referred to as the “brain” of the battery system. The BMS can detect irregularities (PowMr, 2023), measure thermal/electrical parameters at cell level, and regulate the batteries to not overcharge.

Requirements on installation, inspections, and maintenance was mentioned by six out of seven interview attendees to avoid faulty components and cables. CFPA-E Guidelines (CFPA-E, 2018) recommends PV systems to be regularly inspected by a third party both during and after installation, to make sure the system is installed and maintained properly. Sweden has requirements on the installer’s education, however, four out of five installations in Sweden are still faulty when inspected (Spånberg, 2020). The recommendations presented from IEA PVPS Task 15’s report (IEA PVPS Task 15, 2024) also identifies the issue with installations and maintenance. They are for example proposing improved technical guidance, cooperation between different sectors, training, and assurance for BIPV installations.

Installations in Australia are required to follow the requirements stated in AS/NZS 5033:2014 (Standards NZ / Standards Australia, 2014). AS/NZS 5033:2014 also requires signage stating what PV system has been applied to the building, to make it smoother for the brigade to conduct their operation. Similar recommendations was identified from Germany (Prume & Viehweg, 2018), Sweden (Stockholms Brandförsvar, 2019), Switzerland (Bonomo, Saretta, & Frontini, 2018), and the CFPA-E Guidelines (CFPA-E, 2018). As stated in recommendations from Germany and CFPA-E Guidelines, cables should never be installed between different fire compartments without protective insulation. Cables over 1 m in length must be installed on the outside of the building or be equipped with adequate protective insulation. Swiss legislation also states that fire spread between fire compartments through the façade are not allowed in any way. The report from Task 15 (IEA PVPS Task 15, 2024) recommends collaboration between relevant sectors, training, technical workshops, networking, increase loans for product testing/verifications, and clarify requirements.

One of the suggestions for the future was suggested by Fredrik Nilsson, who would like to see guidance from Boverket on how to handle PVs but also BIPVs, as this is getting more common. Fredrik Nilsson also suggests implementing some kind of standardization on how the cables will be installed in these kinds of facades, so the brigade knows what to expect and what to look out for. Fredrik also wants to see requirements for maintenance, possibly where a third party comes in and checks so the system is functioning as it should and is not damaged in any way. The main part for Fredrik Nilsson is that Sweden needs to have a functioning control system in place before BIPV-facades are being implemented, as it presents even more questions and insecurities compared to the older generation of PVs. Reidar Stølen is suggesting similar improvements and wants to see higher requirements for the final inspection, and is suggesting that the builder has to get an approval that all the electrical components and installations has been done correctly, before the façade can be used. Reidar Stølen also believes it would be a good idea to start educating people on the electrical side on BIPV's, this to make them aware of all the possible risks that can occur from a bad installation. He is also highlighting that BIPVs are much more complex than regular PVs.

CFPA-E Guidelines (CFPA-E, 2018), Germany (Prume & Viehweg, 2018), Italy (Malizia, 2012), Dubai (Dubai Electricity & Water Authority, 2015), along with all the 21 brigades from Sweden (Jonsson, 2023) recommended providing the system with a circuit breaker to make sure the fire fighters can attack the fire in the safest way possible. It has been identified from the literature review that a circuit breaker or other shutdown mechanisms does not ultimately make the panels safe to operate (Yang, et al., 2023).

Reaching harmonized recommendations from brigades across all of Swedens municipalities was also a suggestion from Jonssons thesis interviews (Jonsson, 2023). Jonsson concluded that every municipality in Sweden are giving out their own recommendations when it comes to PV installations.

Consequences – Improvements

As previously stated in Jonssons thesis-interviews (Jonsson, 2023), one improvement for future fire engineering would be to get more tests done that relates to relevant standards of the industry, for example SP Fire 105 façade test. Through e-mail correspondence with Reidar Stølen is it also concluded that full-scale tests of BIPV facades does exists, even if they are as good as impossible to find. This because these tests are usually conducted by the manufacturer of the system, and these results will not be published unless the results are good from their perspective. The reason why RISE test results (Stølen, Li, Wingdahl, & Steen-Hansen, 2024) was published was because the test was conducted by a builder who do not gain anything by keeping the results a secret. Reidar Stølen believes the results from their test would not have been published if it was conducted by one of the manufacturers.

Tobias Salomonsson does not consider external fire spread on the facade as a big risk, but also highlighting the importance of a large-scale test to fully understand the behaviour of the panel that is being used. As one panel will not have the same fire behaviour as the next one.

Reidar Stølen, Tobias Salomonsson, Fredrik Nilsson, Daniel Haarala, Marc Wendorf, and John Rakic all highlights in the interview that cavity fire barriers could be a good idea to prevent fire spread between different floors. That is also one of the products that John Rakic and his colleagues at Trafalgar are working on at the moment. Non-combustible barrier behind the panels was also proposed by Reidar Stølen, Daniel Haarala, and Fredrik Nilsson to prevent fire to spread to the inside of the building and vice versa. To have spacing between modules was another suggestion from Reidar Stølen and Fredrik Nilsson in the interviews. Marc Wendorf also confirms that this is a popular solution among Avancis clients. Sprinkler protection also seems to be an obvious choice as most of the interview attendees highlighted the importance of controlling the internal fire. Another frequently highlighted worry in the interview would be the risk of falling panels or debris, that needs to be considered to protect the brigade and evacuating occupants. Kjetil Pedersen, Reidar Stølen, and Daniel Haarala also highlighted the importance of avoiding combustible material in the cavities as much as possible to avoid fire spread. Kjetil Pedersen continues and believes a little bit could be acceptable, but how much is hard to quantify at the moment. Something he hopes to do more research on with Rebecca Yang and her colleagues at RMIT in the future. Many of these suggestions can also be identified in 550 Spencer Street (Building Appeals Board of Victoria, 2022) and Sara Kulturhus (Fahlander, 2020).

As stated in the recommendations from Jonsson thesis (Jonsson, 2023) when it comes to electrical shocks, apart from the special training for fire fighters, Waqar Akram recommends that the brigades should use “dark protection to cover the panels” during a firefighting operation (Akram, Li, Jin, & Chen, 2022). A conclusion was made that this must be evaluated to see if it is even practically possible. Something that seems to be very similar to what Akram is requesting, is this new invention that is used like a portable spray (PVStop, 2024), which is sprayed on the panels and works as a liquid blanket to mitigate the risk of electrical shock on the fire fighters operating on the system. This because the liquid blanket blocks the sun to reach the panel, and therefore no electricity is being produced. It is sprayed on the panel same way as an extinguisher would be used, shuts down the panel in seconds, and the blanket dries in about five minutes. The blanket is non-combustible, works in all weather conditions, and once it has been used, the dried blanket can easily be peeled of the panel. The blanket is non-toxic, environmentally safe, and can be thrown in domestic waste once it has been used (PVStop, 2024). Brigades using this invention are growing fast in numbers (Foran, 2023) and the idea has now been adopted by the London Fire Brigade (LFB), the New York Fire Department (FDNY), and the Singapore Civil Defence Force (SCDF). Fredrik Nilsson and Kjetil Pedersen are both aware of it, but they are sceptical on its effectiveness. Fredrik Nilsson admits it does sound interesting, but also too good to be true. He would like to have more information and experience before having a clear opinion on this, and believes it is possible to conduct an effective operation without this invention. Fredrik Nilsson also questions how effective it would be on a big façade, as it only looks like a normal extinguisher. Kjetil Pedersen does not believe in foams and sprays that are used in vertically aligned panels, as it could slide off after a while and present the brigade with a false sense of security when they are operating near the panels.

Both Fredrik Nilsson and Daniel Haarala from the Swedish brigades are requesting adequate information and signage for these types of buildings to get a chance to conduct a safe and effective operation. The possible risk of getting electrocuted and the possibility of evacuating people through the windows should be stated beforehand. Fredrik Nilsson is of the opinion that if it can not bee guaranteed that the façade will not be electrically energised, it should not be allowed to conduct these evacuating procedures from high-rise buildings. Daniel Haarala highlights that the evacuation with turntable ladder must be considered when designing these facades and believes every apartment should have at least one window that could be used for this type of evacuation.

5.2 Legislation, Standards, Testing, and Design of BIPV-facades

The following section presents the difficulties related to BIPV-facades regarding legislation, standards, testing, installation, maintenance, and lessons learned from projects.
To have a closer look at lessons learned from BIPV projects was a suggestion from Jonsson thesis (Jonsson, 2023) as an idea for future research.

5.2.1 Legislation, Standards, and Testing

The following two sections will give an idea of how the legislation in Australia and Sweden works relating to PVs. The issues with legislation globally is also presented.

Australia

The rules and legislations for the construction industry in Australia is compiled in the National Construction Code (NCC) - Building Code of Australia (BCA), Volume One (2022). This is more commonly known as the BCA, and that is the term that will be used from now on in this report. The BCA gets revised by the Australian Building Code Board (ABCB) on behalf of the Australian Government (Australian Building Codes Board, 2023). The latest version of the BCA is the 2022 version, which replaced the 2019 version last year.

The BCA classifies buildings into three different types of constructions (Australian Building Codes Board, 2023), Type A, Type B, or Type C. Every type of construction comes with different requirements, where the Type A is the most fire-resistant construction, and Type C is the least fire-resistance construction. The type of construction depends on the rise in storeys and what building classification the subject building is, refer to Figure 7 below.

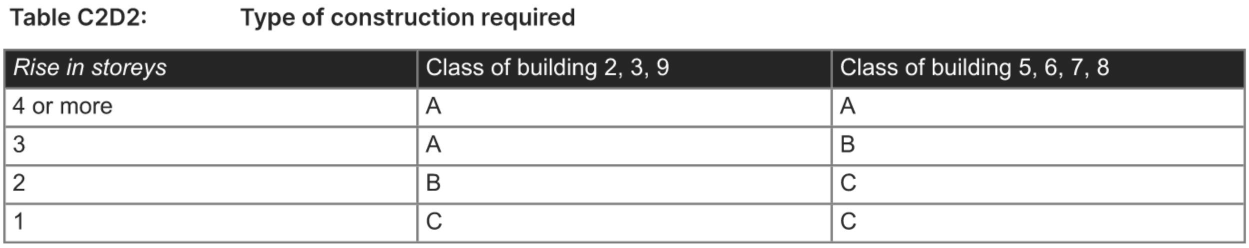

Table C2D2: Type of construction required

Rise in storeys	Class of building 2, 3, 9	Class of building 5, 6, 7, 8
4 or more	A	A
3	A	B
2	B	C
1	C	C

Figure 7: Table C2D2 - Type of Construction Required (National Construction Code, 2023)

Compliance with the BCA is achieved by complying with the “Governing Requirements of the NCC” and the “Performance Requirements” (Australian Building Codes Board, 2023). The Governing Requirements of the NCC basically states that the reader should follow the rules of the NCC. Performance Requirements are there to ensure safety and health in the building, and cover aspects like fire safety, structural integrity, accessibility, and durability. The performance requirements provide benchmarks to builders, designers, and engineering consultants to ensure buildings meet the acceptable standards. There are also clauses, which some of them will be presented later on. These clauses states what must be done to achieve a Deemed-to-Satisfy (DtS) building, and how to comply with the Performance Requirements, similar to the Swedish “Allmänna råd” in Boverkets Byggregler. The performance requirements can either be achieved through a DtS solution, Performance Solution, or a mixture of both (Australian Building Codes Board, 2023). Refer to Figure 8 below for an overview.

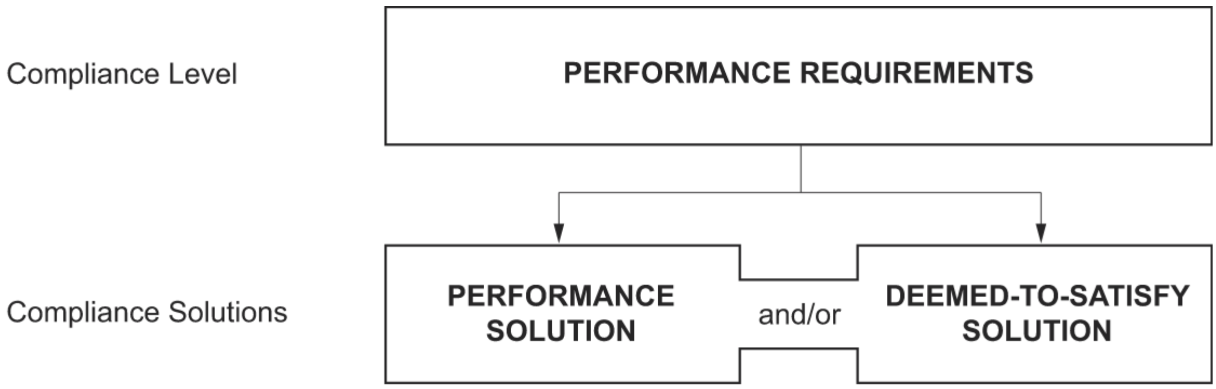

Figure 8: NCC Compliance Structure (National Construction Code, 2023)

A DtS-solution means that the clauses, also known as Deemed-to-Satisfy-Provisions, are being applied to achieve a so called "DtS building". If a Performance Solution is being used, then it must be demonstrated that the performance solution is at least equivalent to the DtS-provisions (National Construction Code, 2023). A couple of different assessment approaches can be used when doing a Performance Solution. It can be explained in three stages, where one of the alternatives is chosen in each stage. These are Comparative/Absolute, Qualitative/Quantitative, and Deterministic/Probabilistic. To give an example, two of the assessment approaches could be "Comparative approach, by way of a deterministic quantitative assessment" or "Absolute approach, by way of a deterministic qualitative assessment".

At the moment there are no clauses in the BCA specifically addressing BIPV-facades (National Construction Code, 2023). Consultants therefore must follow the clauses related to the façade instead. The clauses, specifications, and verification methods that could potentially be relevant for BIPV's are listed below with a short explanation of what it is addressing:

- **C2D10(1)(a):** External and common walls and all components (façade, covering, framing, insulation) must be non-combustible.
- **C2D14(a):** Ancillary elements must be non-combustible.
- **C3D7:** Vertical separation of openings in external walls.
- **C3D13:** Separation of equipment.
- **S5C5 (Specification 5, Clause 5):** Method of attachment not to reduce the fire-resistance of building elements.
- **C1V3 (verification method):** Fire spread via external walls.

As there are currently no DtS provisions available for BIPV-facades, consultants have to address the non-compliances through a Performance Solution (Hui, Yang, & Dr. Quang, 2023). Hui explains that the way of doing this is to meet the Performance Requirements C1P2 (Spread of Fire) and C1P4 (Safe conditions for evacuation). There are four different pathways to achieve this in accordance with the Governing Requirement A2G2 of the BCA (National Construction Code, 2023):

1) Demonstrate compliance with Performance Requirements C1P2 and C1P4.
2) Demonstrate that the solution is at least equivalent to the Deemed-to-Satisfy provisions.
3) Use one of the verification methods provided in the BCA.
4) Expert judgement.

The standard for "Installation and safety requirements for photovoltaic (PV) arrays" also needs to be considered. This standard is more commonly known AS/NZS 5033:2014 (Amdt. 1 & 2) (Standards NZ / Standards Australia, 2014). The standard has been prepared by the joint Technical Committee EL-042, Renewable Energy Power Supply Systems and Equipment. It was later approved by the Council of Standards Australia and by the Council of Standards New Zealand back in 2014.

The industry is in need of sufficient data when it comes to fire resistance level, reaction to fire, lateral/vertical fire spread, critical heat fluxes, heat release rate, smoke production, and toxic gas emission in relation to BIPV-facades (Hui, Yang, & Dr. Quang, 2023). Hui believes this data would be very useful when doing a performance solution.

Sweden

The Parliament (Riksdag) is the organ in Sweden that decides on the laws (lagar/regler) of the country (Boverket, 2023). It is then the governments (Regeringens) job to decide on ordinances (förordningar). The ordinances are there to clarify the laws. The next step in the hierarchy is the regulations (föreskrifter), which are there to clarify the laws in an even more detailed way. These are produced by the authorities (Myndigheterna). It is also the authority's who produce the "Allmänna råd", which translates to "Common advice". Boverkets advice are the equivalent to the BCA's Deemed-to-Satisfy- provisions, as presented in the previous section. The advice are recommendations on how the laws, ordinances, and regulations should be considered. If these advices are not being specifically addressed, the consultant must demonstrate that the solution presented is at least equivalent to the recommendations stated in the advice (Boverket, 2023), same way as in Australia.

Sweden must also consider EU-directives and EU-Ordinances and implement these, as Sweden is a member of the European Union (Boverket, 2023). The difference between a directive and an ordinance is that an ordinance must be implemented in the Swedish laws and every law that contradicts the new ordinance also needs to be terminated. The Eurocodes (European Commission, 2021) is one example of an EU-ordinance that has been implemented by all the members of the EU.

PBF & PBL

Plan- och byggförordningen (PBF) and Plan- och bygglagen (PBL) forms the base of the Swedish legislation for the construction business (Malmö Stad, 2023). PBF includes guidance and provisions of definitions, plans, and area regulations. It also includes requirements applicable for construction works, permits, and more.

Plan- och bygglagen (PBL) regulates the land, water, and construction planning for all of Sweden (Boverket, 2023). PBL is a law that explains where and how you are allowed to build. This to make sure new and old buildings are built in a safe way considering safety of people, nature, and the location. The municipalities need to follow the laws in the PBL when forming a detailed plan (Swedish: detaljplan) for an area (Bygglovskonsulter, 2023).

PV façades in Sweden therefore needs to meet the requirements stated in PBF. In this case it is the PBF 3 Chapter 8 § "Egenskapskrav avseende säkerhet i händelse av brand" (Sveriges Riksdag, 2011). Which translates to: "Property requirements regarding safety in the event of fire".

This ordinance states that a development must be designed and constructed in a way that the loadbearing capacity of the structure can be assumed to last a specific time, fire initiation, spread of fire and smoke within the building is limited, same principles go for spread to neighbouring buildings (Sveriges Riksdag, 2011). The egress and fire brigade intervention are also required to be considered. These requirements are the equivalent of the Performance Requirements of the Building Code Australia (BCA).

Refer to Appendix A - PBF 3 Chapter 8 § Egenskapskrav avseende säkerhet i händelse av brand, for a full excerpt of the ordinance from the PBF in Swedish.

BBR

Boverkets byggregler (BBR) is a compilation of regulations and recommendations established by Boverket (Boverket, 2023). BBR contains rules on the technical requirements stated in the Plan- och bygglagen (PBL). BBR applies to new construction, extensions, and conversions. It is the developers (Swedish: byggherrens) responsibility to make sure the work is being carried out in accordance with PBL, PBF, and BBR. The building committee (byggnadsnämnden) then decides whether the requirements have been met or not.

The façade needs to comply with requirements stated in Plan- och byggförordningen (PBF) 3 Chapter 8 § "Egenskapskrav avseende säkerhet i händelse av brand" (Sveriges Riksdag, 2011). Refer to Appendix A - PBF 3 Chapter 8 § Egenskapskrav avseende säkerhet i händelse av brand, for a full excerpt of the ordinance from the PBF in Swedish.

The building classification is based on the buildings need of protection. While the need of protection is based on the subject building's complexity, likely fire scenarios, and consequences (Boverket, 2023). Number of floors and business classes (Swedish: verksamhetsklasser) in the building needs to be considered when evaluating a buildings complexity. The building class decides what requirements applies to the subject building. The different building classes are presented below, translated into English (Boverket, 2023):

- Br0 – Buildings with a very high need for protection
- Br1 – Buildings with a high need for protection
- Br2 – Buildings with a moderate need for protection
- Br3 – Buildings with little need for protection

If it is decided that the BIPV's should be counted as façade cladding, the BIPV's must meet the requirements stated in "BBR 5:551 Ytterväggar i byggnad klass Br1" (Eng: External walls in building class Br1) and "BBR 5:552 Ytterväggar i byggnad klass Br2 och Br3" (Eng: External walls in building class Br2 and Br3) (Boverket, 2023). The ordinances and parts of the general advice for 5:551 and 5:552 are presented below in English:

BBR 5:551: External walls in building class Br1

External walls in building class Br1 is required to be constructed in a way that:

1. The separating function is maintained between fire cells;
2. Fire spread inside the wall is limited;
3. The risk of fire spreading along the façade surface is limited; and
4. The risk of people getting injured as a result of falling parts of the outer wall is limited.

Summary of the advice (Allmänt råd):

Br1 buildings can meet the requirements either through a classification as a non-combustible material (class A2-s1, d0) or approved after testing by SP Fire 105.

BBR 5:552: External walls in building class Br2 and Br3

External walls, in building classes Br2 and Br3, must be designed so that the spread of fire along the façade surface is limited (2011:26).

Advice (Allmänt råd):

Façade cladding should meet the requirements for class D-s2, d2.

Refer to Appendix B - BBR 5:551 Exterior walls in building class Br1 and Appendix C - BBR 5:552 Exterior walls in buildings in classes Br2 och Br3, for a full excerpt of BBR 5:551 and BBR 5:552 in English.

The fire classification is based on Boverkets (Boverket, 2023) fire classification system as presented in Table 1 and Table 2 below. Both tables have been translated into English.

Table 1: Boverkets Fire Classification (Boverket, 2023)

Main Class	Fire property in a room fire test (room corner)	Example of construction product	Corresponding older Swedish description
A1	No ignition with 300 kW ignition source	Brick, concrete, some mineral wool	Non-combustible
A2	No ignition with 300 kW ignition source	Mineral wool, untreated plasterboard with thin surface layer	Non-combustible
B	No ignition with 300 kW ignition source	Painted plasterboard	Class I
C	No ignition with 100 kW ignition source	Plasterboard with common wallpaper	Class II
D	Ignition after 2 min with 100 kW ignition source	Untreated wood panel	Class III
E	Ignition within 2 min with 100 kW ignition source	Some types of cellular plastic	Flame retardant
F	-	-	-

Table 2: Fire classification for burning droplets and limited amount of fire gases, BBR 5:231 (Boverket, 2023)

Fire Classification	Description
s1	The building part may emit a very limited amount of fire gases.
s2	The building part may emit a limited amount of fire gases.
s3	No requirements for limited production of fire gases.
d0	Burning droplets or particles may not be emitted from the building part.
d1	Burning droplets or particles may be emitted in limited quantities.
d2	No requirement to limit burning droplets and particles.

Boverket also states that PV’s can pose a danger to fire brigade as the panels will continue to produce electricity as long as it is exposed to sunlight (Boverket, 2023). The risk of electric shock is therefore important to consider relating to fire brigade intervention. Not only from the solar panels themselves, but also from the cables that runs from the panels to the solar inverter. It is therefore recommended that a system is in place to break the current as close to the panel as possible, this to reduce the risk of fire brigade personnel getting electrocuted and injured while working closely to the panels. Many municipalities around Sweden have issued guidelines for how solar panels should be placed when near property boundaries. This to avoid large fires and spread to the neighbouring allotment (Boverket, 2023). Recommendations specifically relating to BIPVs was not identified in Boverkets Byggregler.

Issues with legislation globally

One issue for the industry is the lack of harmonisation between legislations and requirements of BIPV-facades globally. As it is, BIPV products must be tested in different countries, using different tests, to be able meet the requirements from the different legislations around the world. This because the legislations are referring to different standards depending on which country the system is being implemented, or not referring to any standard at all. This was highlighted by Marc Wendorf in the interviews, as Avancis are struggling to implement their products in certain countries that does not want to consider other tests than the ones used in their country. This will be expensive and ultimately creates an obstacle for future development of BIPV's around the world (Yang, et al., 2023). This problem became clearer when reading RISEs SP Fire 105 test report from Norway, where Thorsten Kuhn from Germany questioned in the article if the test sample actually follows the applicable test standard EN 13501-1 (Bellini, Fire Test for BIPV Facades, 2024). Jonssons literature study and interview attendees (Jonsson, 2023) highlights the fact that manufacturers does not use the Scandinavian SP Fire 105 test and does not plan to use it in the near future either. Reidar Stølen explained that the reason why RISE test results was published was because the test was conducted by a builder who do not gain anything by keeping the results a secret.

Reidar Stølen mentioned in the interviews that it is sometimes a blurry line if it counts as a BAPV or BIPV. While the requirements related to BIPVs/BAPVs are very different. This makes it possible for consultants to go the easier way, calling it BAPV, using the DtS provisions, or comparing it to laminated glazing. Which has been stated by both Kjetil Pedersen and Tobias Salomonsson to be an oversimplification and the wrong way to implement these facades. Fredrik Nilsson also had a similar opinion about the situation in Sweden and speculates that there are not many, if any at all, who are actually addressing all the clauses that are being highlighted in BBR relating to PVs.

Tobias Salomonsson also highlights the issue with the legislation. 550 Spencer Street was the first building in Victoria, and maybe all of Australia, to get their BIPV-facade approved through the Buildings Appeal Board, where Kjetil Pedersen was one of the members. However, both Kjetil and Tobias are aware of projects that used the DtS provisions, comparing it to laminated glass or similar. Some projects have also been relying on small-scale testing to avoid the more expensive full-scale tests. Tobias Salomonsson also highlighted that BIPVs did not even exist when the latest DtS provisions was released, and mentions that the combustible cladding issue started from this kind of issue, where one product got approved from small-scale testing. Kjetil Pedersen has similar opinions, and highlights that there is no solution that fits all BIPV-facades as they will differ between different manufacturers, building designs, etc. Kjetil Pedersen believes that we have gone down the wrong path if we are starting to describe it through minimal requirements.

The current BIPV standards are not adequate to verify the implementation of this new technology (Ko, Aram, Zhang, & Qi, 2023). The technology has developed very fast, while legislation has been struggling to keep up. Therefore, some of the risks associated with BIPV's are outside of the scope of today's legislation. Ko, Aram, Zhang, and Qi highlights the fact that there are today no testing procedures to verify the production of toxic smoke from the solar cells during a fire highlights this issue, and the fact that the risk of toxic smoke from the system is underestimated, as it is known that the cells contains toxic chemicals.

The lack of harmonisation between legislations around the world, and the fact that the legislation is not keeping up with the development of PV systems was pointed out in Jonssons thesis interviews (Jonsson, 2023) as well. Some of the Swedish fire engineers highlighted during the interviews that the requirements today are very general and open for interpretation. This leads to a big responsibility being put on the fire engineer, as a performance solution will be needed. This also makes it difficult for a fire engineer with lack of experience to know how to adress this safely. Jonsson also concluded that it could possibly lead to high costs for the builder, as the solution can take time because of the complexity and problems occurring on the way. Since then, Rebecca Yang and her colleagues in IEA PVPS Task 15, which is a group created to accelerate the implementation of BIPV's across the globe, has released a report (IEA PVPS Task 15, 2024) addressing the current situation in Sweden regarding the implementation of BIPV's. Their recommendations are presented in Appendix F – IEA PVPS Task 15 – Analysis of the Technological Innovation System for BIPV in Sweden.

5.2.2 Design of BIPV-façades

Some of the attendees in Jonssons interview study (Jonsson, 2023) also highlighted that there is a lack of accepted solutions and reference objects when it comes to BIPV-façades. The consultants in Jonathan's interview study believes this will improve once the industry starts doing more research on BIPV's. The consultants also highlighted that implementing BIPV facades is a challenge as the legislation is not up to date with the new technology. Which ultimately puts a high responsibility on the consultant. The lack of reference objects and accepted solutions, along with not up to date legislations, could potentially lead to long and complicated projects which leads to big costs for the builder. Jonssons thesis (Jonsson, 2023) ends with a recommendation for further research to have a look at how BIPV-facades has been implemented by fire engineers in projects. This has been investigated in this thesis.

5.2.3 Potential improvements

The following section presents the potential improvements that has been identified during the literature review and interview study relating to legislation, standards, and testing. Examples of projects with BIPV-facades are also presented.

Legislation, Standards, and Testing - Improvements

The standardisation of BIPV's has been one of the issues when it comes to implementing BIPV's globally, even if the European standard EN 50583 that came around 2016 has led to some developments (Jonsson, 2023). The Swedish fire engineers that were interviewed in Jonsson's thesis wishes to see more SP Fire 105 tests, or other relevant tests done on BIPV products to be able to implement them in projects.

There is currently no test method to estimate the toxic gas development from burning BIPV modules (Yang, et al., 2023). This is an issue as tests and research are needed to understand the fire behaviour of the BIPV-facades better, as highlighted by Kjetil Pedersen and Tobias Salomonsson in the interviews. Rebecca Yang and her colleagues in IEA PVPS Task 15 (IEA PVPS Task 15, 2023) have also highlighted the importance of conducting tests relating to toxic smoke from BIPV's. The report states that the results could then be compared to existing building components to come up with a safe design. It is also important to use a Self-contained breathing apparatus (SCBA) when operating on PV fires (Foran, 2023), to avoid inhaling these lethal gases.

The recent report from IEA PVPS Task 15 (IEA PVPS Task 15, 2024) regarding the implementation of BIPV's in Sweden ultimately recommends increasing the diversity and focus of BIPV actors, improve technical guidance and assurance for BIPV installations, level the playing field between BIPV / BAPV, promote cultural change in construction and real-estate sectors, and enhance social networking. The report also released a summary of 20 more detailed recommendations to accomplish improvements in these areas mentioned above. Some recommendations applies to more than one section as presented in Appendix F – IEA PVPS Task 15 – Analysis of the Technological Innovation System for BIPV in Sweden.

Conclusions made from RISEs full-scale SP Fire 105 test (Stølen, Li, Wingdahl, & Steen-Hansen, 2024) states that vertical flame propagation is possible in the cavity, where the highest temperature was measured to 850°C, even with a limited amount of combustible materials. The glass, glue, and aluminium construction was affected by the high temperatures in the large-scale test, resulting in modules falling to the ground. It was also concluded that the fire can spread throughout the entire façade rapidly. RISE report also states that provision of fire barriers in the cavity is challenging, as the fire resistance of the surrounding components could get affected, and that small-scale tests does not give a lot of relevant information on the fire development in the façade, but could be an effective way to investigate material properties when it comes to ignition and heat release. These test results has later been questioned by Thorsten Kǜhn (BAIP) (Bellini, Fire Test for BIPV Facades, 2024) who refers to comparable tests in Switzerland and Germany with different results. The results from Germany and Switzerland, according to Thorsten, concludes that independent fire propagation through BIPV modules are low. Thorsten clarified that the construction of these BIPV-façades are different to the one used in RISEs test, as they are only using glass-glass BIPV modules while the modules in RISEs test had a backsheet made of plastic material. Reidar Stølen also mentioned in the interview that he believes that if glass was used on the backsheet instead, the fire initiation in the cavities and solar cells/encapsulants would not have started as easy. Reidar Stølen also mentioned that the encapsulants contributed way more to fire spread than the backsheet. He believes that once we know have done more research on what parameters are the most important to mitigate fire spread, then we could implement requirements for this, and speculates that it could be requirements on how these cavities needs to be designed, or similar.

Some of the actors involved in 550 Spencer Street, Kjetil Pedersen and Tobias Salomonsson, formed a part of the interview study. Kjetil Pedersen was one of the board members on the Building Appeals Board Victoria handling their application. Tobias Salomonsson also highlighted in the interviews that they were the first in the country to get approval to use a BIPV façade. However, Tobias Salomonsson also stated that BIPV’s might have been used before, and that those projects has not gone through the same approval pathway as the team involved in 550 Spencer Street. The consultants involved in those previous projects argued that it was Deemed-to-Satisfy, or they compared it to laminated glass or similar. A pathway that Tobias Salomonsson does not think is the right, or safest path to take. This was also highlighted by Kjetil Pedersen, as he is aware of consultants referring to DtS provisions or say it is just laminated glass, so there is no difference from what is usually being used. Kjetil Pedersen believes this is an oversimplification and not the right way to implement BIPV facades. Fredrik Nilsson agrees that a Performance Solution must be used to implement BIPV’s in a safe way. For 550 Spencer Street, a decision was made to conduct a full-scale fire test on the façade, with the same setup and design as what was proposed to be used, as highlighted by Tobias Salomonsson. This is also proposed as a minimal requirement when implementing BIPVs by Tobias Salomonsson in the interviews. Reidar Stølen suggested similar testing requirements. John Rakic also stated that full-scale testing should be used, as he did not believe in small-scale testing for BIPV-facades. Tobias Salomonsson had a similar view, but also highlighted that small-scale testing could potentially be enough if there would have been enough data available. Reidar Stølen also hopes to see that research has come so far that we can define some parameters and an interval that can be tested through small scale testing in the future. With that said, Tobias Salomonsson also highlights that the industry is not at that point just yet, and states that passing the full-scale test for 550 Spencer Street was not expected. The most important part was to understand the fire behaviour of the façade, to later use that in the assessment.

Findings from the BS 8414-2:2015 full scale test for 550 Spencer Street (Building Appeals Board of Victoria, 2022) showed that even if some of the PV panels ignited, the panels did not support flame propagation. Something that was highlighted by Marc Wendorf in the interviews as well. The determination also shows that PV panels in direct contact with the flame, did fall off. Some panels did ignite and burn to some extent. It is highlighted in the determination that the interlayer in laminated glazing, which could be used in DtS solution, also would have ignited and caused the glass panels to fall off. The PV panels in this case were glass-glass modules. The determination (Building Appeals Board of Victoria, 2022) states that except for the CIGS semiconductor layer, cables, and junction boxes, the composition is similar to laminated glass, which typically has a combustible interlayer between 0.4- 1.5 mm in thickness.

Another suggestion from the interviews came from Kjetil Pedersen where he is suggesting similar changes that has been implemented for EV chargers in Australia. Because it is a special hazard, a fire engineer is required to inspect it before it can be used. Kjetil Pedersen believes it would be a good idea to implement similar guidelines for BIPV-facades.

The European standard EN 50583 was highlighted in Jonsson's thesis (Jonsson, 2023). Jonsson also referred to a study back in 2016 (PVSites, 2016) where the standard EN 50583 was compared to the other standards available in the industry. The results from the study shows that EN 50583 could be effective for certification of BIPV-products. The fire engineers from Sweden interviewed in Jonssons thesis wished to see more SP Fire 105 tests done on BIPV-facades. The thesis also highlighted that German recommendations (Prume & Viehweg, 2018) advices the fire brigade to educate their fire fighters to operate on these kinds of systems. Their recommendations also states that extinguishing agent, beam, and the distance must be considered to avoid electrical shock. It was also found that 13 out of 21 interviewed fire brigades from Sweden (Jonsson, 2023) recommended that an action plan should be in place for bigger PV installations to avoid injuries, damages, and loss of property.

Design of BIPV-façades – Improvements and Examples

As proposed for future research by Jonsson (Jonsson, 2023), this section will present the lessons learned from BIPV projects and suggestions on how to implement BIPV-facades in future projects.

The determination for 550 Spencer Street (Building Appeals Board of Victoria, 2022) clarifies that the building is of Type A construction, comprising Class 7a (Carpark), Class 5 (Offices), and Class 6 (Retail). The building has a roof terrace and a rise in storeys of eight with an effective height of 26.64 m. The panels are installed as a unitised curtain wall system in vertical sections of Level 2 – Level 7. The determination also states that the Performance Solution made by RED Fire involved cavity barriers between the concrete slab edge and the curtain wall on each level. Furthermore, each unitised curtain wall module spans a single level, where each level is separated by glazed spandrels. The curtain wall system also includes multiple layers of non-combustible insulation. Other fire safety measures that was provided was an automatic sprinkler system, and automatic fire/smoke detection and alarm throughout the building. A Building Occupant Warning System (BOWS) was also provided. Upon activation of the general fire alarm, an automatic PV system isolation will activate. This also includes indicator and direction for manual isolation for the arriving brigade. The determination also clarifies that no PV panels has been installed above discharge points of the exits, and a concrete canopy will cover the south and east façade at ground level, protecting evacuating people from potential falling debris. The brigades booster assembly is also located here to protect the fire fighters. Recommended safety distances for fire fighters was presented as 1.6m for fog stream, and 5m for solid stream from an energised source of up to 1000 V (DC). Class A foam is ineffective and unsafe to use on an energised source of 400 V (DC) and was therefore not recommended in their solution.

Sara Kulturhus is located in Skellefteå, Sweden. The building is one of the tallest tree buildings in the world (Fahlander, 2020), and BIPV facades from manufacturer Avancis are applied to this building as well. The fire engineers from Brandkonsulten had a requirement that the building needed to have sprinkler protection throughout the building (Fahlander, 2020). Fahlanders article also clarifies that the building was fitted with an extra pump that runs with a battery located in another part of the building, as an extra safety measure. Another fire risk that the team was trying to mitigate was the potential fire initiation and spread of fires in the cavities of the construction. A production method was therefore created together with the builder to fill these cavities with stone wool. The team also decided to separate each floor of the building with a layer of stone wool as an extra safety measure to avoid spread of fire to different floors.

Reidar Stølen stated in the interviews that he believes the main difference between BIPVs and BAPVs would be the high complexity that is connected with BIPV's. As the panels are integrated into the wall there are more parameters and components to consider and how they affect each other. Kjetil Pedersen also highlighted in the interviews the complexity and uncertainties that relates to BIPVs, and how a holistic approach needs to be used to understand how all these things come together, and believes there is no solution that fits all BIPV-facades as they will differ between manufacturers, building designs, etc. Kjetil Pedersen believes describing it through minimal requirements would be the wrong approach.

The fire engineers interviewed in Jonsson’s thesis (Jonsson, 2023) also identified possible solutions. One being that fire rated material should be placed behind the BIPV-façade to stop the possibility of fire spread into the building. Sebastian Levin, also suggests in Jonssons interviews that there should be barriers in the façade, dividing it into smaller areas, to prevent fire spread between multiple floors. Sebastian Levin also highlighted the importance of sprinkler protection in these kinds of buildings. Peter Kovac, also from Jonssons interviews, suggested that plastic materials used on the backsheet should not be acceptable.

6 Discussion

This section presents a discussion regarding the answers to the research questions. Followed by a discussion on how the chosen method has been working and the results level of reliability and validity. Summary of interviews can be read in Appendix E – Summary of Interviews.

6.1 Answers to Research Questions

RQ1: How does BIPV's differ from the more common solar panels previously used, and the usual glass walls / curtain walls that they typically replace? What is the most important parameter or component to focus on, to mitigate fire spread and fire initiation in the façade?

The technology that is used in BIPVs is similar to the more regular solar panels that has been used in the past, as it is solar panels that creates energy for the building. However, they should be considered two different things when being implemented in projects from a fire safety point of view. This because BIPVs can differ a lot between manufacturers. BIPV modules are usually smaller than the more traditional BAPVs, it also has more cables, connections, etc. There will therefore be more potential weak spots in a BIPV-façade compared to BAPV's. BIPVs is also a lot more tailor-made product, where standard solutions and standardized components does not exist, which does exist for the older BAPVs. This also makes BIPVs a lot more expensive when comparing the two. A clearer line should be drawn between BIPVs and BAPVs, so builders and consultants can not choose to use the cheaper DtS pathway or comparing it to BAPVs, laminated glazing, or similar. It is a big difference in complexity when comparing the two, the legislation and the way we adress these insecurities should reflect that. BIPVs did not even exist when the latest DtS provisions were released. To say that BIPV-façades and regular curtain walls is pretty much the same thing, as some projects has done today, is an oversimplification. A system that creates energy and will have a current continuously generated is being integrated, and those risks needs to be addressed. The curtain wall is just a glass wall that is sitting there to hold the weather out.

At the moment it is hard to say which parameter is the most important one to focus on when it comes to mitigating fire spread. This because, as previously mentioned, the façades and their fire behaviour can differ a lot. It is hard to say what is needed before the fire behaviour of the specific façade that is being used is understood. Suggestions could be avoiding plastic material on backsheet, use non-combustible junction boxes, avoid combustible material in the cavities as much as possible, and use non-combustible material on the back of the panels to make fire spread into the building, and vice versa, less likely. Spacing between modules or fire barriers is a popular choice to avoid fire spread between different floors. Sara Kulturhus filled the walls cavities with stone wool. One thing that was concluded from the testing in 550 Spencer Street, was for that specific façade, if the internal fire was controlled, the panels would not contribute to fire spread. As previously stated, this could differ between facades from different manufacturers and projects. It is clear that sprinkler protection is a good choice when implementing BIPVs. Sometimes even special designed ones, as the one in Sara Kulturhus.

It is easier to identify the most important parameter for fire initiations, as it has been clear during the literature review and interview study that faulty components and cables from inadequate installations and maintenance is the biggest potential risk when it comes to fire initiation. If the panels and its components are installed in a correct and safe way, inspected both before and after commissioning, it is believed that it could stop a lot of fires from happening.

RQ2: Are there any common obstacles that consultants are being confronted with in BIPV projects, and are there solutions that are often being used, relating to fire safety engineering?

As highlighted by the manufacturers, most worries comes from clients who has never used BIPVs before. The clients are usually concerned about the wiring and cables being faulty in any way. It was also highlighted by the engineers that BIPV-projects gets delayed most of the time, because of the hesitation of using this new technology. A lot of these worries are believed to come from the issues the fire engineering industry had with the combustible cladding, which started when we used small-scale testing to understand the fire behaviour. A pathway that does not give the full picture and could trick people to think that the façade is safe to use, even if it is not.

Another common obstacle is the financial side. BIPVs are more expensive than the older BAPVs. Payback periods are always considered before implementing a BIVP-façade. It can also be hard to estimate the payback period as it can change with the labour prices and solar converted energy prices going up or down, as highlighted by Kjetil Pedersen. A lot more tailor-made solutions must be used as standard components does not exist when it comes to BIPVs, the design and components can also differ between BIPV manufacturers. Standardized modules and components will be more and more common with time, as BIPVs want to compete on prize with the more standardized BAPVs. More BIPV-facades will be used once the price difference is not as big compared to BAPVs

It is hard to identify solutions that are often being used in BIPV-projects, this because there are not that many that has been done, and as previously stated, BIPV-facades differ a lot in design and fire behaviour. Which can be seen in the different results from RISEs and 550 Spencer Streets full-scale testing of their BIPV-facades. One solution will not be appropriate for every BIPV-façade. A “solution” that has been identified in this thesis is the importance of doing a full-scale test, even if it is more expensive. A fire engineers job is to contribute to building safe buildings, a full-scale test should be a part of that process to fully understand the behaviour of the specific BIPV-façade that is being used, and what provisions that could possibly be effective to implement.

A couple of possible solutions to mitigate fire spread and fire initiation has been presented in the previous question (RQ1). Apart from the risks with fire spread and fire initiation, the project-team also has to consider the evacuation routes and the fire brigade intervention. The risk of falling panels and debris will be present when dealing with BIPV-facades. This needs to be considered. 550 Spencer Street is a good example of that, where they have provided a concrete canopy to cover evacuation paths to protect the occupants. The brigades booster assembly is also located under that canopy, providing the brigade with cover while conducting their operation. The location of the panels needs to be considered and not placed above discharge points of exits.

RQ3: Are there any concerns from the brigades regarding this new technology, and are there procedures in place to deal with fires in BIPV systems?

The biggest concerns from the brigades seem to be the lack of knowledge and information relating to BIPVs. The fact that the brigades in both Skellefteå and Uppsala has BIPV-buildings in their areas, but none of them was fully aware of it, highlights this issue. The brigades should have all info they need before they get confronted with a fire in a BIPV-façade. The risk of electrocution is the number one worry for the brigade. This because it is hard to see where the cables and components are installed, it is also hard to tell the difference between a “regular façade” and the BIPV-façade, Frodeparken in Uppsala is one example of that. Another worry that was highlighted was the evacuation procedure form high-rises, and once again the potential risk of getting electrocuted. Could parts of the façade possibly be electrically energised when the ladder is leaned against the façade? If it can not be guaranteed that the façade will not be electrically energised, then that sort of evacuation should not be allowed. This should be considered when designing these facades, and one suggestion that came out was that every apartment should have at least one window that can be used for this kind of evacuation. The risk of falling debris was another risk highlighted that needs to be considered, providing canopies or other protecting constructions for the brigade and the evacuating occupants.

This thesis has not been able to identify any special procedures in place to handle fires in BIPV-facades. It is also hard with lessons learned as a fire in a BIPV-façade has not been identified yet. Even though the brigade acknowledges that there are differences between BIPVs and regular solar panels, it is believed that the brigade intervention could be similar. One thing to consider is a safe distance to the fire when electrical components are involved not get electrocuted. Guidelines like that would be very useful. If there are no guidelines and info on, for example, where the DC cabling is installed in the façade, then this will result in a much more defensive operation and not as effective compared to if the brigade had all the relevant information beforehand. At the moment, there are no detailed procedures in place more than to keep a safe distance, contact an expert, and conduct a defensive operation because of the current that is involved.

RQ4: Are there any potential areas of improvement that can be identified relating to BIPV-facades and fire safety? Any suggestions on how to improve in those areas?

There are a few changes that could be interesting to potentially implement based on the results from the literature review and interview study. The suggestions naturally differed between the actors in the interviews as some might have other things than fire safety as their main focus.

AFCI's and other systems to mitigate fire initiation seems to be out of date as none of the manufacturers recommends it. The other attendees were of similar opinions and speculated that a system that could identify irregularities in an earlier stage would be more useful to prevent fire initiation. A clearer line should also be drawn between BAPVs and BIPVs and the requirements related to them. At the moment, consultants and builders can potentially use a DtS pathway, which does not seem to be the safe and correct option. The people involved in BIPV projects highlights the importance of full-scale testing to fully understand the fire behaviour and how to adress all the risks. The difference between façade designs between manufacturers could make all the difference. The differences in RISEs and the 550 Spencer Street teams conclusions from their full-scale testing highlights the importance of these tests. Just because one BIPV-façade had one fire behaviour, does not mean the next one will behave the same way. Small-scale testing was also the problem that started the combustible cladding issue. A requirement of a full-scale test when implementing BIPV-facades could therefore be an interesting change to implement in the future, at least until there is more data and more research has been done. Adequate requirements for installation and maintenance should also be implemented as this could mitigate a lot of risks relating to fire initiation, as faulty components and cables could potentially be identified before it is too late. Sweden should definitely have a closer look at the control system and implement requirements for this, as it has been concluded in both Jonathan Jonssons thesis and in this thesis that the control system is not working. A requirement for a final inspection from a third party to be done to have a look at all the electrical components and installations before the façade is allowed to be used is another suggestion that could be interesting. It would also be a good idea to start educating electrical engineers and other actors that might be involved in the installation on the fire risks and complexity that comes with these BIPV-facades. This to make them aware of all the possible risks that can occur from a bad installation, as fire safety will not be the main focus for the electrical engineer/installer.

Glass-glass modules seems to be the superior choice instead of plastic backsheet. To not allow plastic backsheets could be an interesting requirement for the future, and to reduce the amount of combustible material in general. After more research and testing has been done, it is believed that standardized BIPV components will be more common in the future as they want to compete in price with the more regular BAPVs. The difference in price at the moment is one reason why builders and consultants often chose BAPVs instead. The costs that comes with full-scale testing compared to small-scale is probably also one of the causes why some projects chose to use the DtS pathway or similar. This feels like a small price difference to pay if all the benefits that comes with a full-scale test is being considered. Especially when using new innovations like BIPVs, where there is so many design variations, gaps in legislation, and insecurities at the moment.

Another change that would make sense is to require a fire engineer to be involved when dealing with BIPV-facades, because it is a special hazard. Similar changes has already been implemented for EV chargers in Australia. It has also been concluded that it is hard to implement minimal requirements when it comes to BIPVs and fire safety provisions. This because these facades differs a lot in design and fire behaviour. To understand the fire behaviour is critical. It will be easier to decide what solution to use once the risks are identified. That could be everything from cavity fire barriers, barrier on the back of the panels, spacing between modules, sprinkler system designed with an extra pump, filling cavities with stone wool, just to mention a few.

6.2 Method and Results

To gather information specifically related to BIPVs was a hard task as it is still a new innovation, and that can be seen in the background section where a lot of the information actually relates more to BAPVs and the older more regular solar panels.

There are differences between BAPVs and BIPVs. The legislation and recommendations relating to BAPVs does not apply for BIPVs, as it is much more complex to implement. It was understood early that the best chance of getting relevant information on BIPVs was to talk to relevant people who has been in contact with BIPVs through projects or research. Something that Jonathan Jonsson also highlighted in his thesis. This was very useful to get relevant information on the subject. The idea of applying a wider scope to this thesis, also as suggested by Jonathan, was also effective. This because more perspectives were involved, and it was interesting to see the differences in answers and experience. This was also the reason why the interview questions was very much the same regardless of if it was a manufacturer, fire engineer, or the fire brigade that was being interviewed. In some cases, in some cases the information provided was not allowed to be used as it was sensitive information for an ongoing project, or the information were planned to be used in literature in the near future.

The variation on the interview attendees could have been even wider, as the plan was to interview one more fire engineer that was involved in Sara Kulturhus. That would have been interesting to get an in-person interview with him as well to compare his answers with the other fire engineers. Same thing goes for the brigade in Melbourne. It would have been interesting to compare their answers to the Swedish brigades. Unfortunately, both these actors had to cancel the interview in the end because of lack of time. Lack of time was also the reason why more interview attendees were not contacted. To get an even wider scope would have been a good idea. To have a chat with consultants involved in BIPV projects where they chose to go the DtS pathway would have been interesting. This to understand their way of thinking and why they chose to not do a full-scale test or how they justify their comparison to laminated glazing or similar.

The choice of doing interviews instead of a questionnaire, which was considered initially, feels like the right choice. The questionnaire would provide more answers and the chance to get answers from a bigger number of actors. However, I believe the best way to discuss this is face to face, to get a good conversation going. It is also a lot easier to understand, ask follow-up questions, etc, if the person is in front of you, rather than having the answers in writing.

Jonathan also highlighted in his thesis that the questions asked could have related more to his research questions, and he believed some of the questions asked did not contribute to his results whatsoever. This was also a helpful reflection from Jonathan, as it made me sit down and really think about how I can connect the questions and answers to my research questions. Something that I was satisfied with in the end. The answers from the interview study was the most relevant information found during this thesis. Being in contact with actors that has actually been in involved with BIPVs seems to be the most effective way of getting answers and information at the moment, as there seems to be a bit of confusion in the industry where actors are of different opinions when it comes to BIPVs.

A couple of measures has been used to reach a high level of reliability throughout this thesis. First being that relevant information was gathered, with information from several sources to confirm that the information is relevant and correct. Most relevant information came from my colleagues in Holmes Australia LP, people I was in contact with during the thesis, and the interview attendees. These people were very important in the process of gathering relevant information, as it is not that much information out there. Another measure would be the fact that the interviews was recorded, and after the interviews were done, the interview attendees got a summary sent to them for approval before being used in the thesis. This to be sure that everything that was said is correct, and that I understood them correctly. Highlighting that I was speaking my second language during the interviews most of the time.

The level of validity in the thesis first and foremost relies on that the interview attendees are telling the truth. The questions used was asked in a way so they would not be identified as sensitive or leading, refer to Appendix D - Interview Questions. There was nothing in the interviews that intended that the attendees were not telling the truth. Quite the opposite, as the feeling I had was that the attendees happily saw this as an opportunity to vent their worries and express their honest opinion. Many of them highlighting that this is an area that needs more attention and research.

I believe that this type of thesis will be even more interesting in the future as more general information will be available, more example projects, and more fire engineers has been involved in projects with BIPV-facades. This will make it easier to conduct interviews with a very wide scope, compare how the different projects solutions were presented, and how they addressed all the risks. This is only the beginning for BIPVs, and that can be seen through the confusion in the industry and gaps in legislation that exists on how to handle these facades.

7 Conclusion

The objective with this thesis was to provide fire engineers with a good starting point when involved in projects with BIPV-facades. Answering the following research questions, as presented in section 6.1, has helped achieving that objective.

- How does BIPV’s differ from the more common solar panels previously used, and the usual glass walls / curtain walls that they typically replace? What is the most important parameter or component to focus on, to mitigate fire spread and fire initiation in the façade?
- Are there any common obstacles that consultants are being confronted with in BIPV projects, and are there solutions that are often being used, relating to fire safety engineering?
- Are there any concerns from the brigades regarding this new technology, and are there procedures in place to deal with fires in BIPV systems?
- Are there any potential areas of improvement that can be identified relating to BIPV-facades and fire safety? Any suggestions on how to improve in those areas?

It is always hard when new innovations are ahead of the legislation. There are uncertainties when it comes to BIPV-facades and its fire behaviour. It is a tailor-made product where standardized components does not exist, and the designs differ between facades and manufacturers. The industry is in need of more research and testing in this area. Full-scale testing feels like the correct way to go to fully understand the fire behaviour of the facade, acknowledging that it is more expensive than small-scale testing. BIPVs are also more expensive than BAPVs.

There is currently a gap in legislation both in Australia and Sweden when it comes to BIPV-facades. There are no clear recommendations or directives to follow. At the moment, it is possible to use a DtS pathway. This is clearly an oversimplification, as BIPVs is much more complex. The DtS provisions did not even exist when BIPVs came around. The use of small-scale testing instead of full-scale testing is also another opportunity for consultants. Small-scale testing could potentially be enough in the future once we have more data and knowledge, but the industry is not there yet. The costs connected to BIPVs and its complexity makes some consultants to take a faster and cheaper pathway.

BIPV-facades will present new difficulties for the brigades and their intervention. The risk of electrocution and the evacuation through windows seems to be the biggest worries. It was also highlighted that the control system in Sweden is not working. A lot of fires can be avoided by having a proper control system in place, identifying the risks before it becomes an issue. It has also been concluded that inadequate installation and maintenance is the number one risk for fire initiation in BIPV-facades, but also the older more regular PVs.

8 Future Studies

BIPVs will continue to grow and be used more and more in projects around the world. The complexity attached to it and the gaps in legislation will inevitably present a lot of challenges in the future, especially for us fire engineers. A couple of knowledge gaps has been identified during this thesis that could be very interesting areas to conduct more research and studies on in the future. These suggestions of future studies are presented below:

- The variety in designs of BIPV-facades between manufacturers has been clearly identified in this thesis. To compare different full-scale tests on BIPV-facades to see how their fire behaviour differ from each other could be a very interesting area to have a closer look at. This to get more knowledge and to highlight this potential risk for the industry. It would also be an effective way to get a greater understanding of what parameters are the most important ones to focus on when it comes to fire spread.

- As the brigades in Sweden does not seem to have special procedures in place, it would be interesting to see what the brigades in other countries are doing. The fact that there has not been a fire in a BIPV-façade yet makes it hard to get an idea of the brigade intervention, but there could be ideas that possibly could be useful for other brigades around the world, where we can learn from each other.

- To have a closer look at Swedens control system when it comes to BIPVs, but also the older more regular BAPVs. This has been identified as an issue in this thesis and in Jonathans. It would be interesting to get more knowledge in this area to understand of what we are doing wrong in Sweden. Comparing it to different countries and their effectiveness would be an interesting idea.

- Possibly do more research on the production of toxic gases from both BIPV and BAPV panels. At the moment it is very hard to quantify.

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9 Appendix

A - PBF 3 Chapter 8 § Egenskapskrav avseende säkerhet i händelse av brand

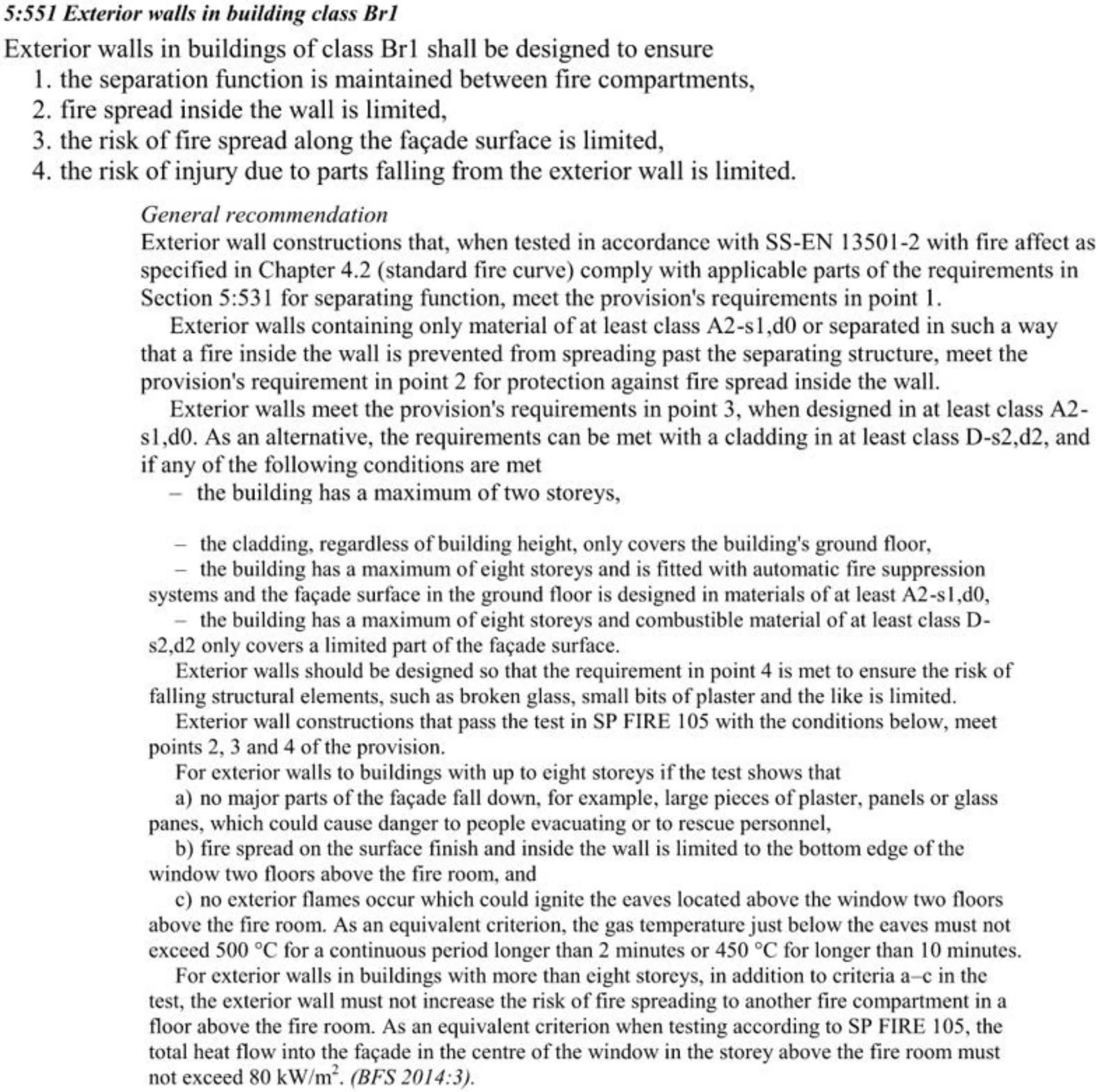
Egenskapskrav avseende säkerhet i händelse av brand

8 § För att uppfylla det krav på säkerhet i händelse av brand som anges i 8 kap. 4 § första stycket 2 plan- och bygglagen (2010:900) ska ett byggnadsverk vara projekterat och utfört på ett sätt som innebär att

1. *byggnadsverkets bärförmåga vid brand kan antas bestå under en bestämd tid,*
2. *utveckling och spridning av brand och rök inom byggnadsverket begränsas,*
3. *spridning av brand till närliggande byggnadsverk begränsas,*
4. *personer som befinner sig i byggnadsverket vid brand kan lämna det eller räddas på annat sätt, och*
5. *hänsyn har tagits till räddningsmanskapets säkerhet vid brand.*

Figure 9: PBF 3 Chapter 8 "Egenskapskrav avseende säkerhet i händelse av brand" (Sveriges Riksdag, 2011)

B - BBR 5:551 Exterior walls in building class Br1



5:551 Exterior walls in building class Br1

Exterior walls in buildings of class Br1 shall be designed to ensure

1. the separation function is maintained between fire compartments,
2. fire spread inside the wall is limited,
3. the risk of fire spread along the façade surface is limited,
4. the risk of injury due to parts falling from the exterior wall is limited.

General recommendation

Exterior wall constructions that, when tested in accordance with SS-EN 13501-2 with fire affect as specified in Chapter 4.2 (standard fire curve) comply with applicable parts of the requirements in Section 5:531 for separating function, meet the provision's requirements in point 1.

Exterior walls containing only material of at least class A2-s1,d0 or separated in such a way that a fire inside the wall is prevented from spreading past the separating structure, meet the provision's requirement in point 2 for protection against fire spread inside the wall.

Exterior walls meet the provision's requirements in point 3, when designed in at least class A2-s1,d0. As an alternative, the requirements can be met with a cladding in at least class D-s2,d2, and if any of the following conditions are met

– the building has a maximum of two storeys,

– the cladding, regardless of building height, only covers the building's ground floor,

– the building has a maximum of eight storeys and is fitted with automatic fire suppression systems and the façade surface in the ground floor is designed in materials of at least A2-s1,d0,

– the building has a maximum of eight storeys and combustible material of at least class D-s2,d2 only covers a limited part of the façade surface.

Exterior walls should be designed so that the requirement in point 4 is met to ensure the risk of falling structural elements, such as broken glass, small bits of plaster and the like is limited.

Exterior wall constructions that pass the test in SP FIRE 105 with the conditions below, meet points 2, 3 and 4 of the provision.

For exterior walls to buildings with up to eight storeys if the test shows that

a) no major parts of the façade fall down, for example, large pieces of plaster, panels or glass panes, which could cause danger to people evacuating or to rescue personnel,

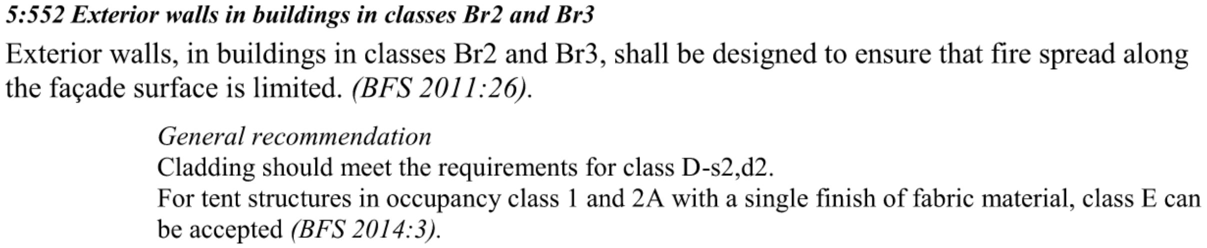
b) fire spread on the surface finish and inside the wall is limited to the bottom edge of the window two floors above the fire room, and

c) no exterior flames occur which could ignite the eaves located above the window two floors above the fire room. As an equivalent criterion, the gas temperature just below the eaves must not exceed 500 °C for a continuous period longer than 2 minutes or 450 °C for longer than 10 minutes.

For exterior walls in buildings with more than eight storeys, in addition to criteria a–c in the test, the exterior wall must not increase the risk of fire spreading to another fire compartment in a floor above the fire room. As an equivalent criterion when testing according to SP FIRE 105, the total heat flow into the façade in the centre of the window in the storey above the fire room must not exceed 80 kW/m^2. *(BFS 2014:3).*

Figure 10: BBR 5:551 Exterior walls in building class Br1 (Boverket, 2018)

C - BBR 5:552 Exterior walls in buildings in classes Br2 och Br3



5:552 Exterior walls in buildings in classes Br2 and Br3

Exterior walls, in buildings in classes Br2 and Br3, shall be designed to ensure that fire spread along the façade surface is limited. *(BFS 2011:26).*

> *General recommendation*
> Cladding should meet the requirements for class D-s2,d2.
> For tent structures in occupancy class 1 and 2A with a single finish of fabric material, class E can be accepted *(BFS 2014:3).*

Figure 11: BBR 5:552 Exterior walls in buildings in classes Br2 och Br3 (Boverket, 2018)

D - Interview Questions

Introduction: *(same for everyone)*

- Presentation of myself and the thesis. Specify that it relates to BIPV's in residential and office buildings.
- Explain that the interview will be recorded and not anonymous, unless them wishes to be. A summary of the Q&A will be sent back to them for review and approval before being used in the thesis.
- Recording starts.
- *Could you give a description of your professional role, please?*

D1 - Manufacturers

1) *Have you been in contact with BIPV's in your professional role? If so, how?*

2) *The interest of BIPV's is growing globally. What is your knowledge about this technology?*
   i. *What is your attitude towards it? Pros / cons?*
   ii. *How does BIPV's differ from the traditional solar panels or BAPV's previously used?*

3) *From your perspective. How does a BIPV-façade differ from glass walls/curtain walls that they typically replace?*

4) *When it comes to fire initiation. From your perspective, what is the main reason / risk for fires in BIPV-facades?*
   i. *Any ideas how to mitigate these risks?*

5) *When it comes to testing of the façade. What tests do you prefer to use? Why have you chosen to go with this test?*
   i. *Do your clients request specific tests? If so, what kind of test are usually requested?*

6) *What is your opinion on the AFCI's (Arc Fault Circuit Interrupter), BMS (Battery Management System) or other automatic suppression system? Is that something that is being implemented in your products?*
   i. *Why/why not?*
   ii. *How effective are they?*

7) *Are there any recurring worries and questions from clients before implementing your products in their buildings?*

8) *What countries do you believe are using BIPV's the most?*
   i. *Are there any countries with more concerns and questions while in contact with you? Are you aware of countries that makes it hard to implement these systems because of rules and legislation?*

9) *To stop fire spread through a BIPV-façade, what parameter or component do you believe is the most important one to focus on?*
   i. *Any lessons learned from real projects where they implemented your products?*

10) *If you had all the power, what changes or improvements would you like to see regarding BIPVs for the future?*
    i. *Do you believe this is feasible?*

11) *Is there anything else you would like to discuss? Any other thoughts or concerns associated with the future of BIPV's, or maybe something about your product that you would like to highlight?*

D2 - Fire Brigades

1) *Have you been in contact with BIPV's in your professional role? If so, how?*

2) *The interest of BIPV's is growing globally. What is your knowledge about this technology?*
    i. *What is your attitude towards it? Pros / cons?*

3) *From the brigades perspective. How does a BIPV-façade differ from glass walls/curtain walls that they typically replace?*

4) *I understand you have BIPV buildings in your area. Do you have any procedures in place to handle a fire in a BIPV-façade for example? Any lessons learned from fires in similar buildings around the world?*
    i. *Any differences in handling a BIPV fire compared to a fire in "regular" solar panels, or BAPV's?*
    ii. *PVStop. Heard of it? Interesting or not interesting? Why / why not?*

5) *When it comes to fire initiation. From your perspective, what is the main reasons for fires in BIPV-facades?*
    i. *Any ideas how to mitigate these risks?*

6) *Are there any specific tests or standards that you would prefer being used when these systems are being implemented in projects?*

7) *Swedish fire and rescue services have highlighted the problem with BIPV-façades when evacuating from a high rise. Understand evacuation through windows with turntable ladder is being used. BIPV-façade could possibly complicate this. Any thoughts on this? Possible solutions?*

8) *To stop fire spread through a BIPV-façade, what parameter or component do you believe is the most important one to focus on?*
    i. *Any lessons learned or solutions that you can share from buildings in your area?*

9) *What are the brigades biggest concerns when it comes to BIPV's?*

10) *If you had all the power, what would be the minimal requirements when it comes to fire safety for a BIPV façade?*
    i. *What brought you to this conclusion?*

11) *What changes or improvements would you like to see regarding BIPVs for the future?*
    i. *Do you believe this is feasible?*

12) *Is there anything else you would like to highlight? Any other thoughts or concerns associated with the future of BIPV's?*

D3 - Fire Engineers

1) *Have you been in contact with BIPV's in your professional role? If so, how?*
   i. *How many different projects have you been involved with? Different countries?*

2) *The interest of BIPV's is growing globally. What is your knowledge about this technology?*
   i. *What is your attitude towards it? Pros / cons?*
   ii. *How does BIPV's differ from the traditional solar panels or BAPV's previously used?*

3) *From your perspective. How does a BIPV-façade differ from glass walls/curtain walls that they typically replace?*

4) *Are there any lessons learned that you could share from real projects? Obstacles that occurred along the way or other issues that you are aware of that are common in BIPV-projects?*
   i. *Is there anything you wished you considered at an earlier stage and that might came up as a surprise in the end and delayed the project?*

5) *To stop fire spread through a BIPV-façade, what parameter or component do you believe is the most important one to focus on?*
   i. *Any solutions from real projects that you could share when it comes to mitigate fire spread?*

6) *When it comes to fire initiation. From your perspective, what is the main reasons for fires in BIPV-facades?*
   i. *Any ideas how to mitigate these risks?*

7) *If you had all the power, what would be the minimal requirements when it comes to fire safety for a BIPV façade?*
   i. *What brought you to this conclusion?*

8) *What changes or improvements would you like to see regarding BIPVs for the future?*
   i. *Do you believe this is feasible?*

9) *Is there anything else you would like to highlight? Any other thoughts or concerns associated with the future of BIPV's?*

E – Summary of Interviews

Appendix E1

Date: 17/04/2024

Name: John Rakic

Company: Trafalgar Group (Australia)

Professional roll: Owner of Trafalgar Group - Manufacturers & Supplier of specialty building products

Questions as presented in D1 - Manufacturers.

1) John and his colleagues are currently working on two building products that can be used for BIPV's. One is siderise cavity fire barriers, and the other one is called bilda framing.

2) John is aware of the technology and its potential of generating energy for the building. He does not have enough experience from these systems to know the differences compared to the older more traditional PVs.

3) John does not see many differences except that the panels needs maintenance, so access needs to be considered when designing these facades.

4) John assumes that the inverters could be a potential fire initiator. If we had more knowledge in that area, we could help develop enclosures to mitigate that potential issue.

5) John only believes in full scale testing when it comes to testing of BIPV facades.

6) No. Trafalgar focus on passive fire safety measures.

7) He believes it is too early to say at this point.

8) John and his colleagues are mainly focused on Australia.

9) John believes cavity fire barriers is the way to go to mitigate fire spread in a BIPV-façade.

10) John would like to see NCC provide a DtS pathway for compliance when it comes to BIPV-facades.

11) No.

Appendix E2

Date: 09/04/2024

Name: Marc Wendorf

Company: Avancis (Manufacturer based in Torgau, Germany)

Professional roll: Sales Manager / BIPV Consultant

- Notable that question number 5, 6, and 9 were passed on to Avancis product management with more knowledge in these areas. Their answers were sent to Marc, and he presented them during the interview.

Questions as presented in D1 - Manufacturers.

1) Been assisting architects, planners, other actors to implement Avancis BIPV's globally. Avancis products was used in both 550 Spencer Street, Melbourne and Sara Kulturhus, Skellefteå. However, Marc was not involved personally in these projects. BIPV's in bigger buildings like Offices, Residential, and multistorey Carparks are Avancis main focus nowadays and something they work with daily. Many other PV producers focus on regular PV's, often applied on the roof.

2) Facades will always be built regardless. Would make a lot of sense to use these areas to produce energy where it is needed. Marc identifies two main differences compared to BAPV's. First one being the design of the façade. Architects and planners obviously want good looking panels. The newer BIPV's is therefore a popular choice compared to the older / cheaper monocrystalline modules that has been used in the past. The second one being all the rules, legislations, and testing related to BIPV's. Marc highlights that it is a lot more difficult to implement BIPV's compared to the older BAPV's.

3) Not that big of a difference. The BIPV is implemented in ventilated façades. The areas behind the panel looks identical to a regular ventilated façade. The biggest difference would be all the wiring and cables that is needed in a BIPV-façade.

4) Marc states that luckily no fires in BIPV’s have occurred yet so they have no qualified experience in fire initiation. Can only guess, do research, and test. Marc mentions the possibility of external fire spread to the façade from fires in close proximity, like wastebins or other buildings. Another scenario highlighted was spread from a major fire inside the building spreading outside and into the ventilated façade somehow, starting a fire in the façade. However, this is only speculations and there has been no lessons learned in this area.
   Marc highlights the possibility of horizontal barriers made of metal between panels to prevent these risks. The façade can also be divided into different parts. BIPV-panels can be used, then a gap of 2-3 m with "normal façade", and then continue the BIPV-panels. This to get a distance between the panels if one would catch fire. A popular choice among Avancis clients.

5) Avancis have tested their modules in several ways. They need to proof safety standards for PV modules as well as quality issues for the panel being a building material. Tests include mechanical load tests, load-bearing capacity of the foil among others. For facade-testing we've conducted fire classification tests based on DIN EN 13501 and DIN 4102-20 and BS 8414, the last one was requested by clients in Australia. Another test which is conducted soon is a soft-body impact test. Wind-load testing of the module in a facade assembly was also tested as requested by their Dutch partner. Results from these tests was later used to obtain the BDA Agreement. Some clients, depending on which countries they operate in, could need several tests to be done before using the BIPV-façade. Can get expensive.

6) Avancis have been using AFCI's in different projects since they were requested by local fire authorities to ensure safe operation of firemen. Both AFCI and BMS are implemented by whoever does the electrical installation. Avancis do not implement them into our product.
   Hard to say how effective they are. They are state of the art, whilst reports from Switzerland states that they are not using them anymore since most inverters have introduced functionalities that make them obsolete.

7) Worries mostly come from clients that has never used BIPV's before. Avancis believes it is roughly the same as constructing a normal curtain wall, except for all the wiring and electrical components. The only worry the clients really have, is to install the products and components in the wrong way. With a qualified electrician, this is believed to not be a problem.

8) Europe market is the biggest one, also where Avancis has most of their clients. US and China growing a little bit as well. South America and Africa is not a market yet, as they have not really implemented regular PVs on the roof yet. All the countries are rather complicated when it comes to the legislation related to BIPV’s.

9) Glass-glass BIPV modules do not have any impact on the spread of flame in a facade. They are certified flame retardant. Often the modules are built into a ventilated curtain wall. Here, if not properly conducted, the ventilation has the biggest effect on fire spread. Construction and façade system must include fire barriers, and the cabling is not allowed to be installed through these barriers. Avancis biggest lessons learned is to have clear and consistent communication between the planners, architects, fire engineers, etc, to avoid failures. Most of them have never built a BIPV-facade and has a lot of worries and questions.

10) More harmonized legislation globally. Every country has their own set of rules, requirements, and tests. An approved BIPV-façade in Germany, could not be implemented in, for example, Saudi Arabia or Dubai. They are requesting different testing and are not open to look at other tests that has been done. Instead, they are now looking at a 3-4 year process to get the façade approved through their tests and requirements. This is a very common issue, and it is also very expensive. Governmental support would also help the process of implementing BIPV's. In Germany this is not the case. Lately the executors have taken bad decisions for the PV industry, slowing down the German market significantly. This also happened 10 years ago, resulting in an almost complete shutdown of the German PV market.

11) The difference from Avancis compared to their competitors is that Avancis have a design object and focusing more on high appearing buildings like Offices, Residential, and multistory Carparks. Most other manufacturers focus on PVs on the roof.

Appendix E3

Date: 11/04/2024

Name: Daniel Haarala

Fire Brigade: Skellefteå, Sweden

Professional roll:
Head of Unit, Fire Protection & Hazardous Areas, Fire Brigade Skellefteå
Regional & Local Operations Leader for Rescue Collaboration North (Räddningssamverkan Nord)

Questions as presented in D2 - Fire Brigades

1) No not really. A lot of focus on timber constructions in the area. Sara Kulturhus is one of them. Mostly been in contact with PVs on the roof.

2) This technology is new to Daniel. He believes it could be a little bit riskier with building integrated PVs compared to the older PVs located on the roof. Fire on the roof feels like a better scenario, compared to fire initiation in a ventilated façade where the fire can spread into the building more easily and possibly to multiple stories. Daniel also highlights that the brigade intervention can get tricky when PVs are involved, with experience from fires involving houses with PVs on the roof. The building integrated ones could mean that the brigade intervention is even more limited.

3) All the electrical components and cabling. It is one more aspect to keep in mind when conducting operations. The risk of falling debris was also highlighted.

4) No special procedures. The brigade was not really aware about the BIPV facade implemented in Sara Kulturhus. Hard with lessons learned as there has not been a fire in a BIPV façade yet.
One difference with BIPV's compared to PV's located on the roof is the risk of panels falling down and hurting people around the building, that can not happen with PV's located on the roof.
Possibly more risks to consider compared to the older PVs because of the cabling and electrical components being integrated in the façade.
PVStop is not being used or discussed. Have not really made it to Sweden yet.

5) Faulty electrical components or installation.
Regardless if it is the PV that started the fire or not. If the panels are involved in the fire, it will complicate operation and make the situation worse.

6) Not really. SP Fire 105 is common for facades in Sweden, could potentially be an option. As long as the test say something about the fire behaviour of the façade, then it can be useful.

7) This should be considered when designing these facades as this is sometimes necessary for evacuation. Every residential apartment should have the option of evacuation through on of the windows to not get stuck.

8) Daniel suggests having non-combustible material behind the panel to mitigate spread into the building. Another idea is where glass-glass facades are being used, the glass closest to the building should be stronger than the glass on the outside. This means that if the glass closest to the building breaks, the glass on the outside will break shortly after. This means that the possible risk of spreading through the façade cavities goes away as the glass breaks, and the hot gases ends

up in the atmosphere instead of causing a chimney effect. Some kind of fire barrier should also be used to avoid potential fire spread between different levels. Combustible material to be avoided as much as possible, especially in these cavities.
Fire brigade intervention must also be considered so they can conduct an effective and safe operation.

9) One concern is the fact that the panels can be hard to see as they are integrated in the façade. If not adequate information comes out beforehand, for example the location of all these PV's, it could lead to catastrophic consequences if brigades start fighting the façade fire without being informed about all the risks. The electrical aspect and how it can limit their operation would be the short answer.

10) Fire barriers to prevent fire spread to different levels, which also should make sense when looking at the buildings fire compartmentation. This feels like an important aspect to consider.

11) More testing to get more knowledge about these facades and how they behave. Clear signage should be in place when these façade systems are implemented.

12) Always hard when new innovations are ahead of the legislation. This is what the situation feels like at the moment.

Appendix E4

Date: 15/04/2024

Name: Fredrik Nilsson

Fire Brigade: Uppsala, Sweden

Professional roll: Fire Engineer, Fire Brigade Uppsala (Sweden)

- 10 years of experience. Parts of Fredriks daily work would be managing different construction works, accident investigations, and operate as regional operations manager. Got interested in PVs a couple of years ago as the team needed someone to get some extra knowledge in that area. Since then, Fredrik has been chosen as the "expert". A word he does not like to use himself.

Questions as presented in D2 - Fire Brigades

1) Mostly been in contact with regular PVs on the roof. However, Fredrik is aware of the two buildings with BIPV's in the area and has been trying to get ahead to learn about this new technology.

2) Fredrik understands the technology is pretty similar to the older more traditional PVs, but in this case, it is integrated. He believes more guidance would be very useful as the situation in Sweden is not that good at the moment when it comes to BIPV's and fire engineering. Fredrik believes there are not many, if any at all, that are really addressing all the clauses that are being highlighted in BBR relating to PVs. It is also obvious right now that the control system in Sweden is not working. There are major flaws in this, something that Fredrik and his colleagues anticipated beforehand, but they have now also seen it in real projects where these controls are not conducted in a proper way.
   This is not ideal and a control system should be properly in place before we even start thinking about implementing BIPV's into our buildings, as it presents even more questions and insecurities compared to the older generation of PVs. Fredrik has also read the reports from Germany stating that the risk of fire is 20x bigger with BIPVs compared to BAPVs. He believes this statistic sound a bit worrying.

3) Fredrik highlights that you are integrating a potential fire initiator into the façade, something that is not being addressed in the current Swedish building code. All the cables and electrical components are also a big difference. The risk of electrocution is also worrying as it is not clear what parts of the façade that could possibly be electrically energised. Evacuation from high-rises could also be a problem as the ladder sometimes needs to be leaned against the façade. Can this be done on a BIPV façade? Could it potentially electrocute the personnel if in contact? Fredrik has heard of situations in Sweden where a turntable ladder has been leaned against a sheet metal roof with PV's all over it. In this case the car died straight away. Luckily no personnel were injured. The brigades safety is something that need to be considered, as stated in the Swedish BBR. However, Fredrik is of the opinion that this has not been a priority when implementing PVs in Sweden, and there is a lot to be done in this area.

4) Nothing specific for BIPV facades. It also took some time before the brigade in Uppsala realized that Frodeparken was equipped with BIPVs. There are differences between BIPVs and regular solar panels, but Fredrik believes the fire brigade intervention could be pretty similar. One thing to consider is a safe distance to the fire when electrical components are involved, this to not get electrocuted. Guidelines like that would be very useful. If there are no guidance and info on, for example, where the DC cabling is installed in the façade. This will result in a much more

defensive operation to make sure Fredrik is not putting any of his colleagues in danger. The problem with evacuation from high-rises with BIPV facades was also highlighted. At the moment there are no detailed procedures in place more than to keep a safe distance, to contact an expert, and conduct a defensive operation because of the current that is involved. In some cases, like in Frodeparken, it is really hard to see what part is a "regular façade" and what is BIPVs. Clear info is needed for these types of buildings. Fredrik also highlights the risk of external fire spread in the façade. Can it spread between different levels for example? Fredrik believes a lot of builders is happy with hearing that the panels are "non-combustible” and does not think further than that. That is not the full truth as it does have combustible components in the design. Fredrik believes a performance solution must be used for these types of facades to get a good end result.
Fredrik is aware of PVStop, even though it has not really made it to Sweden yet. He thinks it sounds interesting but feels like he wants to get more info, as it right now sounds a little bit too good to be true. Also questions how effective PVStop would be on a huge façade, as it only looks like a normal extinguisher. Can PVStop be used on bigger scales? Fredrik also highlights that he believes it is possible to conduct an effective operation without this invention.

5) Fredrik has more knowledge in BAPVs than BIPVs but speculates that it could be the same risks for fire initiation. For example, one of the electrical components like inverters, junction box, and DC isolator switch. All the cabling, especially if faulty, could also initiate a fire. Fredrik also highlights the importance of installation and maintenance to avoid fires. In Sweden you have to have the proper education to be able to install PVs. Requirements for maintenance could be one idea to mitigate this risk, possibly where a third part comes in every now and then and checks so the system is functioning as it should and is not damaged in any way.

6) SP Fire 105 would make sense to see how the fire can spread in the façade. One problem could be that all the manufacturers have slightly different designs, and you have to test every design as they may differ. If a component is changed, you have to test the design again, and so on. This might lead to a huge amount of tests and that might not be feasible. Fredrik believes it is hard to say what test would be the most effective one, but believes a test has to be done. Guidance from Boverket would be very much appreciated when it comes to testing of BIPV-facades, that does not exist at the moment.

7) Very hard to say. The consultants should consider this bit when designing the façade to make this possible. Adequate info and signage would also be very helpful for the brigades safety. Can the façade lead electricity? If that is the case, Fredrik believes this kind of evacuation should not be allowed for everyones safety.

8) Important to do a performance solution on these types of facades. To say its non-combustible and that is all good, is not the right way to go as it is not that easy. Fredrik also proposes some kind of fire barrier behind the panels to mitigate fire spread from the façade to the inside and vice versa. Some kind of break or barrier is also proposed between the panels to avoid fire spread vertically to different levels. A proper control system should also be in place, where you control the installation and maintenance to make sure it is done correct, and to identify problems before it is too late. Regular check-ups on the system would also be great. The control system in Sweden at the moment is not working very well according to Fredrik. He also believes the fire engineer has a very important role in this process to design a safe BIPV façade, as the other actors does not see the same risks with this as we do.

9) Fredrik and his colleagues would like to see a change and more guidance before there is a major accident connected to BIPVs. Unfortunately, that is sometimes the case, that an accident has to happen before changes are being implemented. That is a scenario that Fredrik and his team wants

to avoid by any means necessary. A functioning control system should be in place before we even start thinking about implementing BIPV's into our buildings, as it presents even more questions and insecurities compared to the older generation of PVs. The risk of electrocution is also a big worry for Fredrik, one of the areas that needs more guidance in relation to BIPV's. What parts can become electrically energised on these facades? The brigade needs info on all of this to conduct a safe operation.

10) Fredrik wants to see requirements on signage and a plan for fire brigade intervention in place beforehand. Performance solution must be the way to go, instead of using the DtS provisions. Some kind of standardization on how the cables should be installed so the brigade knows what to expect and what to look out for.

11) Guidance from Boverket on how to handle PVs in general, but also BIPV's. Since BIPV's are now getting introduced and will be more common, we should get some kind of guidance to implement this in a safe way. However, for now it does not look like this is going to happen.
Fredrik wants to avoid the situation where a major fire takes place before we react and do something about this. Similar to the combustible cladding issue.
A test designed for these types of facades could also be a good idea and would erase some of the issues we have today. Hard to say if it is feasible or not.

12) See previous questions.

Appendix E5

Date: 08/04/2024

Name: Reidar Stølen

Company: RISE (Norway)

Professional roll: Researcher, RISE Fire Research

- Been a researcher at RISE Fire Research since 2008. Been doing research on sprinkler systems, material testing, fire testing, just to mention a few. A small part of this has also been connected to PV's. Right now involved in research regarding Fire Safety for buildings with PVs, in a research centre called FRIC where RISE is one of the research partners.

Questions as presented in D3 - Fire Engineers

1) Not that much. Right now involved in research regarding Fire Safety for buildings with PVs, in the FRIC centre. Also used a few cases of BIPV buildings that was used in one of his research articles a few years back. Recently conducted an SP Fire 105 full scale test of a BIPV façade.

2) Reidar highlights that BIPV has been a small market in Norway, but now when PVs are getting more common, BIPV is also getting more interest. BIPV's feels like the next step for PVs in projects where the aesthetics are important. He found interest in BIPV because of research from Germany in 2012/2013 that concluded that BIPV's represented 20% of the damages done by PV fires in Germany, while BIPV's only represented 1% of the PV's installed in the country. He would like to see new similar research to see if it differs now, highlighting that the statistics could be different now compared to back then. A lot has happened during that time when it comes to product development for BIPVs and its components.
   The main difference from BAPV's would be the high complexity that relates to BIPV's. As the panels are integrated into the wall there are more parameters and components to consider and how they affect each other. It is a way more tailor-made product as standardized solutions for these facades does not exist yet. Standard components does not really exist either. The variation between the different manufacturers is also highlighted. The BIPV module is usually smaller than the more traditional BAPV, it also has more cables, connections, etc. When you integrate the panels in the façade you will therefore have more potential weak spots in a BIPV module compared to BAPV's. People involved in these projects also wants a good-looking façade. All these things needs to be considered as it can affect the fire safety.

3) The high complexity that relates to BIPV's. As the panels are integrated into the wall there are more parameters and components to consider and how they affect each other. It can also be differences between BIPV-facades from different manufacturers.

4) Reidar believes the costs connected to BIPV's could be a big obstacle in many cases, as it is way more expensive than traditional BAPV's. A lot more tailor-made solutions must be used as standard components does not really exist, the design and components can also differ between BIPV manufacturers. The fact that is has been so expensive could be one of the reasons that is has not really exploded in Norway yet. Reidar believes standardized modules and components will be more and more common with time, as they want to compete on prize with the more standardized BAPV's that already exists.

5) This is a question that Reidar believes is very important. He will start conducting a series of medium-scale tests later this year where they want to look closer on these parameters and what actually contributes to fire spread the most. He believes one of the more important and logical things would be to make sure all the electrical cabling and components are properly installed and maintained to avoid any fire initiation from electrical faults. To inspect the system every now and then is also important to identify these issues before it is too late. Fire could potentially also spread to the façade from external areas. Fire barriers could be a good option to stop fire spread in this situation. However, it was concluded from the SP Fire 105 test that fire spread is very much possible even when fire barriers are being used. The façade in RISE fire test had a very small amount of combustible material in the cavities. Plasterboard was used in the back with 6 cm cavity with fire barriers installed in them. The backsheet of the BIPV module was made of polymer material. The encapsulants on either side of the solar cells was also made of plastic material. In the end, this resulted in enough combustible material for the fire to spread along the façade, where the encapsulants contributed way more to fire spread than the backsheet. Reidar highlights the importance of keeping the amount combustible material in these cavities as low as possible. He speculates that if glass was used on the backsheet instead, the fire initiation in the cavities and solar cells/encapsulants would not have started as easy. Reidar also believes it is possible to design the cavities in such a way that heat is not allowed to grow in there. It should be able to release the heat. To have some distance between modules in the façade could also be a good idea to mitigate fire spread.

6) Electrical faults. It has been concluded that the installation made by the electrical engineer or similar is often not adequate. That could be faulty connections, components, or maybe damaged cables. Another possible initiator could be internal fire spread through a window or similar, or an external fire in close proximity to the façade.
   Possible improvements could be that the person that is installing, inspects, and approves a façade like this must have the proper experience and knowledge. To educate people on the electrical side on BIPV's would be very useful, this to make them aware of all the possible risks that can occur from a bad installation. Higher requirements for the final inspection should also be implemented to make sure everything is in order. Reidar is skeptical when it comes to AFCI's, BMS, as an automatic suppression system. This because it is hard to say how effective they are. Furthermore, when the AFCI would warn for an arc fault. It might already be too late as it already around 1000 degrees in these connections. Systems that could identify irregularities in an earlier stage would be much more useful.

7) Requirements on commissioning. For example, before you are allowed to actually use your façade you have to get it approved that all the electrical components and installations has been done correct. One idea could also be to have a non-combustible material on the inside of the panels to make it less likely for the fire to spread into the building, even if the fire would start to spread along the façade. The consequence of this would be a destroyed solar cell system, but the people in the building would be safe. Requirements should also be in place for the prevention of falling panels or debris, as this could possibly put the people evacuating in danger. Spread from the façade to neighbouring buildings must also be prevented. Once we know more what parameters is the most important to mitigate fire spread, then we could implement requirements for this. That could for example be requirements on how these cavities needs to be designed, or similar.

8) To demand BIPV-facades to go through full-scale fire test like SP Fire 105, would be a good idea. However, this will lead to expensive projects. These facades differs between manufacturers, what kind of building it is, and are very often tailor made for their specific use. This could possibly mean that every BIPV-façade will have to go through full scale

testing, as one is not similar to another. It is not certain that this is even feasible because of the high costs. Reidar hope to see in the future that research has come so far that they can define a parameter and an interval that is acceptable, and that can be tested through a small-scale test. If your façade is in that interval, you are allowed to use your façade.

9) Sometimes difficult to say if it should count as BIPV or BAPV. For example, in some cases you will have the panel integrated, but not all the technical components. The requirements will differ a lot if you call it BIPV rather than BAPV. A clearer line should be drawn so builders can not call a BIPV for a BAPV, and through that avoid the tougher requirements that applies.

Appendix E6

Date: 12/04/2024

Name: Tobias Salomonsson

Company: RED Fire Engineers (Swede based in Australia)

Professional roll: Managing Director of RED Fire Engineers

- Been doing fire engineering in Australia for over 15 years. Also been working in US and Sweden.

Questions as presented in D3 - Fire Engineers

1) RED and Tobias was the first in the state of Victoria to get building approval to use a BIPV facade. Other projects might have used it, but they are calling it DtS by comparing it to laminated glazing or similar. In this case RED pushed hard for a full large scale fire test to be done. Passing the test was not expected, instead the most important thing was to understand the burning / non-burning behaviour of the façade, and to use that in the following assessment.

2) Tobias is very pro. He believes it is a free hit for reduced energy costs and sustainability. BIPV’s will be very useful and it is important to allow these products for the future, but in a correct and safe way. He continues with the cons, or maybe more of a risk this time. Many manufacturers and other actors believes small scale tests can be used to get away from the more expensive full large-scale testing. This could lead to a similar dilemma as for the combustible cladding issue. That some people might think that one product is the same as all. Which can be very dangerous. Just because one panel has been tested, does not mean that the next one will have the exact same fire behaviour.
   Tobias believes BIPVs differ quite a lot from the more traditional PVs located on the roof for example. There is enough data and research to say that fire risks exist with the older more traditional PVs. These older versions also have more combustible elements to it. BIPVs should not be compared to regular PVs as they are two different things and used differently.

3) You are introducing something that creates energy, kind of like an active system instead of a passive one. Those risks needs to be addressed, and in REDs view you do that through a full large scale fire test to see how they behave. So, they do differ, but it does not mean that it can not be used. What type of panels that are being used needs to be considered, and not just assume or guess that it is going to be the same as another one.

4) See previous question. We are not at a point where we can rely on small scale testing yet. Full large scale fire tests should be the way to go when implementing BIPV's.

5) What they learnt through the testing of their specific façade for 550 Spencer was that if you are able to control the internal fire, the panels does not contribute to the fire spread. Instead, it will self-extinguish. With that said, it has combustible elements, and if there is a fire close by it could potentially burn. Sprinkler protection is obviously a good idea and will be common in these types of buildings to avoid internal fires spreading to the facade. Some kind of fire barriers in the façade can potentially also be used if needed. Tobias does not consider external fire spread on the facade as a big risk, but also highlighting the importance of a large-scale test to fully understand the behaviour of the panel that is being used.

6) This is speculations as there has not been a fire in a BIPV façade yet. Have heard that the inverters could potentially short circuit, but also understands that it is very unlikely. Based on the large-scale test that Tobias has been involved in, he does not believe it would cause a continuous fire spread issue on the external façade, even if the inverters would ignite. To mitigate these risks, Tobias once again highlights the importance of a large-scale test to fully understand the behaviour of the panel you are using.

7) A large-scale test should be a minimal requirement. Potentially, if there is enough data available, a small-scale test could be enough. With that said, the industry is not at that point just yet. It does not have to be a specific test, e.g. AS5113, BS8414, the important part is that it is a large-scale test with a documented test procedure that is being done.
The combustible cladding issue started from this kind of issue. Where one product got approved from the small-scale testing, let us not do the same mistake again.

8) Hard to say. Tobias just hopes that consultants that are being in contact with BIPV's does not go down the road where they try to compare it to something that is DtS. BIPV's did not even exist when the latest DtS provisions was made, so that does not make any sense at all. We can gain a lot by handling this new technology in a correct way. Let us not destroy this opportunity because of cheapness or greed because we think testing is expensive.

9) See previous answer.

Appendix E7

Date: 12/04/2024

Name: Kjetil Pedersen

Company: STRATEG Consulting (Norwegian based in Australia)

Professional roll:
Director of STRATEG Consulting & Board Member of the Building Appeals Board Victoria

- Fire engineer with over two decades of experience in fire engineering. Graduated in Norway and started working there as a fire engineer. Later moved to UK to complete masters and work for a number of years, before relocating to Singapore and subsequently Malaysia heading up fire and risk engineering for WSP in Asia. Later ended up in Australia where he is now operating. Also been actively involved in IFE since UK days, and SFS (and Engineers Australia) since moving to Australia. He is the current Deputy Chair for SFS.

Questions as presented in D3 - Fire Engineers

1) Was on the Building Appeals Board for 550 Spencer Street, the first BIPV building in Australia. RED Fire did the design for the building while Kjetil was one of the board members who reviewed the design, and in the end concluded that the building complied.
   He has not been involved in BIPV projects outside of Australia. While working in Asia there was a lot of conversations in design stages about BIPV's. However, the development in Asia has grown a lot since then, especially the last decade. It was not as interesting at that point in time.

2) Depends on the efficiency of the panel, as they differ between different producers. Kjetil believes it makes perfect sense to change to BIPV-facades from the older PV's used on the roof. By doing this, the space on the roof can be used as a terrace or similar. The façade will be there anyway, using it to create electricity feels like a smart and effective move.
   One difference that Kjetil highlights compared to the older versions of PV's, is the fact that additional real estate or areas is not needed. For example, in typical PV installations panels would be placed next to or on top of building. As it is being integrated in the building, these spaces can instead be used for something else. Have to be mindful on what is being used and where it is being used.

3) One mistake that is pretty common is the fact that people say it is just laminated glass, so there is no difference from what has been used before. This is an oversimplification, and not correct. A BIPV façade will have a current that is being continuously generated, while a normal glass wall is just sitting there to hold the weather out. There are uncertainties based on the lack of testing. Often the fire engineers want to create a break in the façade, and the cabling should be installed in a certain way, etc. But where do the cables go? Cables might be led through the stair to a switchboard that is located on your only, or one of two escape routes. Could become an issue. Another difference that needs to be considered is the risk of falling debris from a BIPV façade. Being conservative here is a good idea, especially if you are not sure. The location of the panels needs to be considered, are there any evacuation routes below? Are there a canopy or anything that protects the evacuating occupants?
   On the other side, some people overreact and think BIPV's are scary because it is combustible and sitting in the façade. Kjetil believes this comes from the trouble the fire engineering business had with combustible cladding. Kjetil believes this situation is very different.

4) Holistic engineering is important for a smooth project. The fire engineers should be involved as early as possible. Getting on board early and understand what the design outcome should look like is important. This means that we can provide solutions, variations, and options to facilitate that outcome in an early stage. Otherwise, the other actors involved might plan everything in their way, without understanding the risks a fire engineer would identify.
In 550 Spencer Street it was pure panels on the back of a non-combustible wall. Kjetil also refers to the determination of the building that is available online.
Most of these projects gets delayed because there is a lot of hesitation, and actors just wait to press that play button. Most of it coming from the old uncertainties and worries we've had with combustible cladding. The financials and payback period are also always considered as well before implementing a BIVP-façade. Kjetil highlights that it can be hard to estimate the payback period as it can change with the labor prices and solar converted energy prices going up or down.

5) Hard to say, and this is where more fire testing would be very useful. A holistic approach needs to be used to understand how all these things come together. The idea is that a little bit of combustible elements could be OK, but how to quantify it? At this time it is just numbers with no reference point really. More testing from around the world would be very useful to get a better understanding of this and to compare from case to case. This is something that Kjetil hopes to continue working on with Rebecca Yang and the rest of the RMIT team.
The cavities in the wall could potentially contribute to spread of fire in the façade if there is enough fuel. Which there should not be.

6) A damaged component because of external influence could hypothetically be a fire initiator. Question still remains if that would cause a big enough fire. If it does, the main problem lands on the brigade and their intervention, as the panels are still alive while they would try and extinguish the fire. It is a lot of talk about different foams and this new invention called PVStop. However, Kjetil is not convinced about using any of these on something that is vertically aligned as it will only slide off. There has been scenarios where fire men are on the roof, using foam on the panels. After a while the foams starts sliding off the panels and that will put the fire men in a dangerous situation, often without them even noticing.

7) Kjetil would not recommend minimal requirements. He instead suggests getting the relevant people in the project involved in an early stage and let them work it out. Have them sit down and go through the process and what exact panels they are using to get a better understanding of what is really needed. In some cases, we do not know beforehand what panel is going to be used. In those cases, the team should take a more conservative approach and provide additional precautions.
Kjetil believes there is no solution that fits all BIPV-projects as they will differ between different manufacturers, building designs, etc. If we are starting to describe it through minimal requirements, we have gone down the wrong path.

8) To get the relevant people with the right knowledge into the design team in an early stage. Kjetil believes the fire engineer is the appropriate actor to look at BIPVs. Similar to the EV guidelines here in Australia regarding the EV chargers. Because it is a special hazard, you must get a fire engineer to look at it. Something similar could be implemented for BIPVs. Kjetil also highlights that he does not want to worry people and say that BIPVs are a major issue. The point is that it is a new technology and there is a lot of uncertainties in some cases. The architect, building surveyor, supplier, or electrical engineers will not have fire risks in their scope, so having a fire engineer involved makes a lot of sense to mitigate these potential

risks.

9) See previous questions.

F – IEA PVPS Task 15 – Analysis of the Technological Innovation System for BIPV in Sweden

- **Increase diversity and focus of BIPV actors:**

1) Initiate partnerships between PV and construction companies, either voluntary or through requirements in tenders or funding calls;
2) Develop and provide trainings on BIPV for professionals, preferably in multi-disciplinary groups;
3) Collaborative road-mapping initiatives;
4) Develop and demonstrate reproducible BIPV concepts (with extensive knowledge dissemination);
5) Innovation procurement for mass-customized BIPV-solutions;
6) Implement collaboration and mobility schemes for industry experts and researchers;
7) Market potential reports;
8) Joint campaign, by BIPV-actors, to highlight the technology's benefits;

- **Improve technical guidance and assurance for BIPV installations:**
    - Recommendation 2) also included;

9) Organize technical and scientific workshops on BIPV;
10) Establish harmonized (EU) standards or production certifications for (non-glass) BIPV (preferably based on the European Construction Products Regulation)
11) Increase the use of grants/loans for product tests & verification;
12) Clarify requirements in, and possible exceptions to, building and electrical code requirements for BIPV;
13) Develop LCA reports or Environmental Product Declarations for BIPV products and systems;

- **Level the playing field between BAPV and BIPV:**

14) Investigate which building product-originated requirements also are relevant to (some) BAPV;
15) Report and campaign on disadvantages by current institutions;
16) Investigate economic incentives (or bonuses) for BIPV installations, e.g. Feed-In Tariff (FIT) or tax reduction;
17) Investigate building permit exceptions for BIPV (or ending exceptions for BAPV);

- **Promote cultural change in construction and real-estate sectors:**
    - Recommendation 1), 2), 4), 6), and 9) also included;

18) Develop (and communicate) an industry-bridging perspective on BIPV in the implementation of upcoming EU regulations (Solar Strategy, EPBD,…);
19) Encourage (or demand) BIPV solutions in municipal planning (e.g. detailed development plans, land allocation agreements), wherever a significant interest from real-estate developers makes this feasible;
20) Organise BIPV networking events aimed at (BI)PV, construction, and real-estate industries.

- **Enhance social networking:**

Recommendations 1), 2), 3), 4), 6), 9), 19), and 20)

G - Redovisning av användning av generativ AI

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