www.cpwr.com • www.elcosh.org

CPWR
THE CENTER FOR CONSTRUCTION
RESEARCH AND TRAINING

Applying Prevention through Design (PtD) to Solar Systems in Small Buildings

Hyun Woo Lee
John Gambatese
Chung Ho

University of Washington
Oregon State University

July 2017
CPWR Small Study Final Report

8484 Georgia Avenue
Suite 1000
Silver Spring, MD 20910

PHONE: 301.578.8500
FAX: 301.578.8572

 CPWR is the research and training arm of North America's Building Trades Unions. Production of this document was supported by cooperative agreement OH 009762 from the National Institute for Occupational Safety and Health (NIOSH).

CPWR FINAL REPORT

Applying Prevention through Design (PtD) to Solar Systems in Small Buildings

Researchers

- Dr. Hyun Woo Lee, Assistant Professor, Department of Construction Management, University of Washington.
- Dr. John Gambatese, Professor, School of Civil and Construction Engineering, Oregon State University.
- Chung Ho, PhD Student, Department of Construction Management, University of Washington.

Submitted to

- Center for Construction Research and Training (CPWR)

JULY 2017

PREAMBLE

This protocol provides guidance on applying Prevention through Design (PtD) to the design and installation of solar energy systems for small residential buildings. Seven PtD attributes with related design and installation issues are introduced, including roof materials, roof slopes, panel layouts, roof accessories, fall protection systems, lifting methods, and electrical systems. These attributes should be incorporated into the design documents of solar energy systems to improve the safety of solar workers during the installation processes.

ACKNOWLEDGEMENT

We are grateful for the research grant support of the Center for Construction Research and Training (CPWR). We would also like to express our sincere gratitude toward the companies and individuals that participated in interviews and provided case studies for this research. We also thank and appreciate the Department of Construction Management at the University of Washington and the School of Civil and Construction Engineering at Oregon State University for their support throughout our research progress and the development of this protocol.

TABLE OF CONTENTS

1. ABSTRACT

As a viable, efficient, clean, and renewable energy source, solar installations in the U.S. have drastically increased in recent years due to a reduced payback period. Most future solar installations are expected to take place on the rooftops of existing houses, performed by small- to mid-sized contractors. This type of installation forces workers to face unique safety hazards in terms of existing roof conditions and panel installations. Prevention through Design (PtD) was developed as a proactive method in design processes to eliminate safety hazards in the workplace. However, no identified study has aimed at determining how PtD can be effectively applied to prevent safety hazards during solar installation. To fill this knowledge gap, this research aims to investigate how, during the design process, to address workers' safety concerns during solar installations on small buildings. This document serves as the research's final report, presenting research findings and the objectives that the research team has accomplished.

2. KEY FINDINGS

The key results of this research include:

- Identification of seven PtD attributes for the design and installation of solar systems for small residential buildings, including roofing material, roof slope, roof accessories, panel layout, fall protection system, lifting methods, and electrical system.
- Development of a protocol guiding the implementation of PtD for solar system design and installations. Industry feedback about the protocol indicates that the protocol will contribute to improving the safety performance of solar contractors.

The key findings of this research are:

- Most solar contractors who participated in the interview expressed a positive attitude toward PtD, suggesting that PtD has a potential to improve safety performance in the solar industry. However, some contractors suggested that safety enforcement is more important.
- Although all solar contractors acknowledged the importance of solar installation safety, safety performance varies from contractor to contractor. Some contractors follow safety rules closely, while other contractors still ignore certain safety rules to achieve gains in productivity.
- Small solar contractors may still resist carrying out safety measures as required by regulations, such as the use of lifting equipment to carry solar panels to the rooftop and use of fall protection systems. As per the interviewed solar contractors, this resistance is largely due to cost and time impacts when implementing the safety measures.

3. INTRODUCTION AND LITERATURE REVIEW

Safety in the Solar Industry

Solar installation in the U.S. has significantly increased in recent years. As of 2015, the residential solar sector has achieved more than 50% annual growth for a fourth consecutive year (GTM/SEIA, 2016). The increased utilization of solar energy also creates new business opportunities and generates more jobs for the labor market. According to the Solar Energy Industries Association (SEIA, 2017), California stands as the leading solar market in the U.S. with more than 2,625 solar companies and providing jobs for 100,050 people. While the proliferation of the solar industry indicates positive impacts for the environment and society, its labor intensiveness also raises concerns about the safety of workers involved in solar systems. The safety concerns arise because most solar installations are expected to happen on roof tops, forcing workers to be faced with unique risks and hazards. The U.S. Bureau of Labor Statistics report about Green Jobs (produced by Hamilton, 2011) indicates that safety is a priority consideration during the installation of solar systems, since the installers face the risks of being electrocuted or falling from a roof. Caution is needed during installation because the panels are heavy, fragile, and expensive to replace if broken.

Instructions on safety practices for solar installations have been addressed in some publications. A guideline on safety for solar construction, which complies with Occupational Safety and Health Administration (OSHA) standards and considers the unique conditions of solar energy installations, was published by the Oregon Solar Energy Industries Association (OSEIA). Solar safety information is also included in a guideline for solar electric system design, operations, and installations issued by the Extension Energy Program of Washington State University (WSUEEP 2013). However, few studies investigated how to reduce safety hazards for solar installers during the design process. For example, Bucher's study (1998) about solar modules suggested that a module's safety documents need to include testing information, such as insulation tests, glass breakage tests, edge sharpness tests, and wet leakage current tests. Nevertheless, this study did not address the impact of roof conditions on safety during solar installations.

Although there are few studies addressing safety during the solar design process, attention has been paid to the potential hazards of solar energy systems for fire fighters during fires (Kreis 2009, Paiss 2009). Studies on this aspect have led to specific requirements about the clearance between solar panels and roof edges. Although the influence of solar systems on fire fighters is out of the present research scope, the research does include the regulations regarding clear access pathways and clearance between panel edges and roof ridges that can contribute to improving safety in solar installations.

Prevention through Design and Its Applications

PtD is "*The practice of anticipating and "designing out" potential occupational safety and health hazards and risks associated with new processes, structures, equipment, or tools, and organizing work, such that it takes into consideration the construction, maintenance, decommissioning, and disposal/recycling of waste material, and recognizing the business and social benefits of doing so*" (Schulte 2008). PtD involves all attempts to recognize and design out hazards for workers, from work methods and processes to equipment, tools, materials, and technologies. In 2007, the National Institute for Occupational Safety and Health (NIOSH) launched a PtD initiative aiming to change cultural norms that will achieve designing out occupational hazards. Up to 2014, PtD concepts have been used in over 25 standards, including those issued by American National Standards Institute, American Society of Heating, Refrigerating and Air-Conditioning Engineers, American Society of Safety Engineers, American Industrial Hygiene Association, Underwriters Laboratory, Semiconductor Equipment and Materials International, and the International Organization for Standardization (NIOSH 2014).

Previous studies on construction hazard prevention have shown that almost 50% of construction fatalities and accidents are linked to upstream decisions made during the design process (Behm 2005; Gibb et al. 2004). Behm (2005) reviewed 224 fatality reports and found that 42% of fatalities are linked to design for construction safety. Gambatese and Behm (2008) reviewed the study of Behm (2005) and agreed with 71% of the reviewed cases. Walline (2014) suggested incorporating lessons from proven solutions and past-mishaps into design to prevent hazards and reduce risks. Toole & Gambatese (2008) claimed that although Construction Hazards Prevention through Design (CHPtD) has received much research attention, technical principles supporting this concept are not available to help designers to implement PtD. As proactive methods to eliminate hazards are safer and more cost-effective than reactive methods, Toole and Gambatese (2008) suggested that the long-term application of CHPtD will evolve along four trajectories: (1) increased construction prefabrications, (2) increased use of less hazardous materials and systems, (3) increased applications of construction engineering, and (4) increased spatial investigations and considerations.

Regarding how to apply PtD to construction, especially roof construction, Rajendran and Gambatese (2016) developed a case study focused on the financial impacts and risks of roof fall protection solutions. In this study, the costs for the design and installation of roof anchors and parapets were compared with those of other design options on the same project. Their research indicated that it was more expensive, but safer to install the parapet system than install the roof anchor system. The roof anchor system required additional temporary fall protection measures during construction, leading to more injury risks for workers.

Despite the advancement of PtD and its applications, there is no study addressing the application of PtD to improve safety in solar installations. The present research is expected to bridge this knowledge gap and make a valuable contribution in the effort to prevent safety hazards in solar installations. The research project started in August 2016 and completed in July 2017. The main outcome of the research is a PtD protocol that solar contractors can use to improve their safety practice. This report presents the research findings and research team's accomplishments, including the literature review, industry interviews and case studies, PtD attributes, PtD protocol development, and the organization of a solar PtD seminar.

4. RESEARCH OBJECTIVES

The overall objective of this research is to develop the knowledge and resources that support the application of PtD in solar design and installation, leading to the improved safety performance of construction workers. The study results are expected to show that using PtD to devise proactive measures in the design process can effectively contribute to preventing safety hazards and risks during solar installation while minimally affecting the intended solar production level or the efficiency of field operations.

The specific aims of this study are to: (1) identify the attributes of solar systems and roof conditions that affect safety risk, (2) analyze the identified attributes through case studies, and (3) develop a PtD protocol for solar design and installation. The study targets solar contractors and their safety practices, specifically those who work in small businesses. A solar PtD protocol was created at the final stage of this study to assist solar contractors in effectively implementing PtD for their solar design and installation.

5. RESEARCH METHODS

This research relied on contextual data from actual construction projects and construction industry personnel who install solar systems. The contextual data allowed for the identification of safety hazards and risks associated with roof conditions, roof features, solar panel characteristics, and PtD attributes. The research team used a mixed-methods approach that incorporated experiential data from interviews with solar contractors and observational data from in-depth project case studies. Using mixed methods, this research included the following specific tasks: (1) Investigate safety management practices in solar design and installation, (2) Identify PtD attributes of solar systems, (3) Analyze PtD attributes through case study projects, (4) Develop a PtD protocol for solar design and installation, (5) Obtain industry feedback regarding the PtD protocol, and (6) Develop and submit a final research report and an article for publication on the research study and findings.

6. ACCOMPLISHMENTS

Summary

At this time, all project tasks have been completed as scheduled. In addition, a conference paper is being prepared to disseminate the results of this research. Figure 1 shows research progress, including a comparison between the timeline as planned in the research proposal versus the timeline of our actual progress.

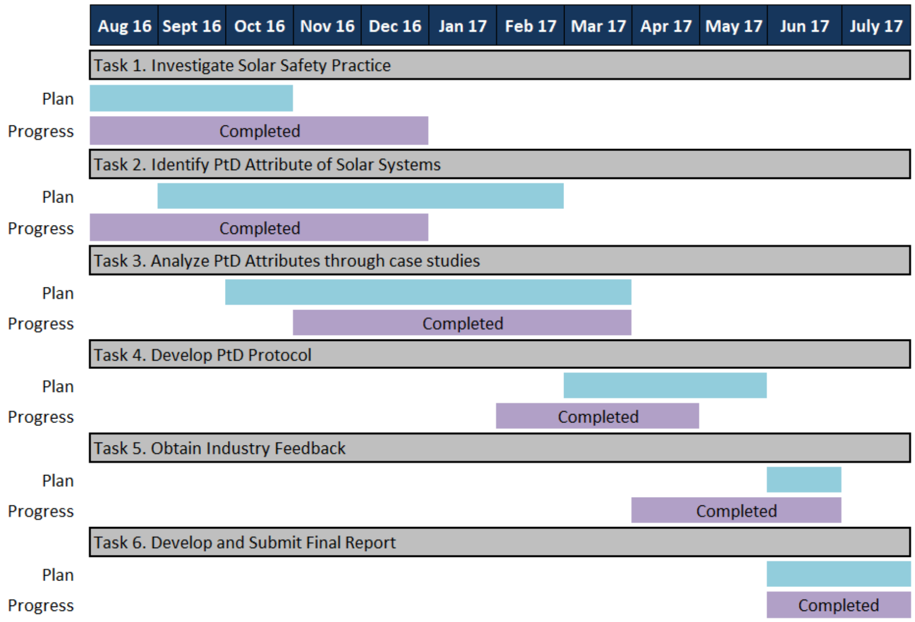


Figure 1. Research Progress Timeline

Details of each task are described hereinafter:

Task 1. Investigate safety management practices in solar design and installation

Task 1 involved determining the current design and installation practices of the solar industry when working on small buildings. To do so, we conducted interviews with solar contractors, targeting small businesses in the State of Washington. Interview invitations were sent out to a list of 36 industry professionals. A total of 13 interviews were conducted with 16 solar professionals, including solar designers, sales persons, site managers, electricians, workers. An interview questionnaire was created prior to the interviews. Appendix 1 presents this interview questionnaire. The performed interviews are summarized in Table 1. Note that due to a confidentiality agreement, company and interviewee names are not reported.

After finishing the interviews, the researchers performed a cross-analysis of the interview results to compare different practices and perspectives of the interviewed contractors. We found that all of the interviewed companies have a similar solar design and installation process in general. However, solar contractor performance and perspectives about safety varied from contractor to contractor. Although all solar contractors acknowledged the importance of safety rules for solar installation and many follow rules closely, some solar contractors still ignored certain rules to gain higher productivity. When an introduction to PtD was provided, most solar contractors expressed a positive attitude toward PtD in solar safety. Solar contractors also suggested that PtD has a potential to improve the overall safety performance of the solar industry and community. Some still suggested that safety enforcement should emphasized more than PtD, while others were neutral, expressing no interest or objection to PtD. While each new interview gave a new perspective and creative ideas about how PtD could be applied, the information provided by the solar contractors was found to be rather consistent regarding safety planning in solar installation and PtD attributes. Interview results served as a basis for the development of PtD attributes in Task 2, and verified through the case studies in Task 3.

Table 1. List of Interviews

No.	Cont-ractor	No. of Interviewees	Interviewee's Position	Interview Date	Interview Duration	Interview Location (WA)
1	A	1	Project Engineer	24-Sep-16	1.5 hours	Coffee shop, Seattle
2	B	1	Company's Founder	14-Oct-16	1 hour	Interviewee's office, Seattle
3	C	1	Project Engineer	30-Sep-16	1 hour	Interviewee's office, Shoreline
4	D	1	Company's Founder	14-Oct-16	1 hour	Interviewee's office, Olympia
5	E	1	Sales Associate	26-Oct-16	-	Via Email
6	A	1	Vice President	21-Oct-16	1 hour	Via Google Call
7	F	2	Sales Engineers	9-Nov-16	1 hour	Interviewee's office, Seattle
8	A	3	Electrician, Roof Workers	18-Nov-16	3 hours	Solar Project, Tacoma
9	A	1	Roof Worker	23-Nov-16	0.5 hour	Solar Project, Tacoma
10	A	1	Site Manager	23-Nov-16	0.5 hour	Solar Project, Tacoma
11	B	1	Electrician	2-Dec-16	1 hour	Solar Project, Seattle
12	B	1	Site Manager	2-Dec-16	1 hour	Solar Project, Seattle
13	A	1	Project Manager	19-Jan-17	1 hour	Coffee shop, Seattle

During Task 1, the research team conducted an extensive literature review to identify solar industry design and construction practices, as well as safety hazards and risk mitigation practices. The summary of the completed literature review is provided in Section 3Introduction and Literature Review.

Lastly, based on the interviews and literature review, the researchers developed a process map representing current practices in solar design and installation (see Appendix 2). The process map incorporates the findings of a master thesis written by Vaishnavi Nevrekar, a former MS student at the University of Washington, who was involved in some of the interviews and case studies in this research.

Task 2. Identify PtD attributes of solar systems

Based on the results captured during Task 1, Task 2 was intended to systematically categorize primary system attributes that solar contractors should consider when implementing PtD. Task 2 first involved developing a comprehensive list of attributes based on the parameters of solar systems identified during Task 1. Approximately 10 PtD attributes were identified, then analyzed, and grouped into seven major attributes as follows: (1) roofing material, (2) roof slope, (3) roof accessories, (4) panel layout, (5) fall protection system, (6) lifting methods, and (7) electrical system. Appendix 3 presents detailed descriptions of these attributes.

Second, to augment the extensiveness of the developed list, Task 2 used publicly available databases to investigate the types of previous accidents that occurred in the solar industry. We reviewed the OSHA database and NIOSH Fatality Assessment and Control Evaluation (FACE) Program reports for accidents that occurred during the past 10 years. After reviewing these incident reports, we identified a list of risk factors, such as falling from roof, falling from ladders, falling from roof opening, falling objects from roof, wind blow, electric shock, being struck by falling objects, tripping, and slipping. These risk factors were used to analyze the risks in the case studies performed in Task 3.

Lastly, 13 workers from the case study projects included in Task 3 participated in a short survey to review and share their opinions on the developed list of attributes in terms of the significance of each attribute. During the evaluation, the participants were asked to evaluate the level of impact of each of the attributes using a 1 to 5 Likert scale (1 = Strongly Disagree; 5 = Strongly Agree). All attributes received ratings higher than 3, ranging from 3.2 to 4.7, equivalent to “Neutral” to “Strongly Agree.” Regarding the level of safety impacts, roof slope and roof material received the highest levels of impact, while roof accessories, electrical system, and installation sequence received the lowest levels of impact. Table 2 presents the survey results.

Table 2. Result of the Survey on the Impact Level of PtD Attributes

FACTORS	Roof Slope	Roof Material	Roof Accessories	Panel Layout	Fall Protection System	Lifting method	Electrical system	Installation sequence	Other
CONTRACTOR A									
Worker 1	3	3	2	2	4	3	4	3	
Worker 2	3	4	1	3	5	4	1	4	
Worker 3	5	2	4	4	3	5	2	3	3
Worker 4	5	5	5	5	4	2	4	3	
Worker 5	5	4	4	2	4	4	3	3	
Worker 6	5	5	1	3	5	5	5	1	
Worker 7	5	5	5	3	3	4	3	3	
Worker 8	5	5	5	3	3	4	3	3	
Worker 9	5	5	4	4	4	4	3	4	
CONTRACTOR B									
Worker 1	5	5	3	5	5	5	4	4	
Worker 2	5	5	2	2	3	2	2	4	
Worker 3	5	5	3	4	5	4	4	3	5
Worker 4	5	5	3	4	4	4	3	4	4
Average	4.7	4.5	3.2	3.4	4.0	3.8	3.2	3.2	

Task 3. Analyze PtD attributes through case study projects

Task 3 involved field-analyzing the applicability and significance of the developed attributes by observing case study projects that were performed by small-business solar contractors. This research task was carried out on four case study projects that were selected while working with interviewees participating in Tasks 1 and 2. The case study projects represent the roof conditions, roof features, and solar panel characteristics of typical single-family houses in Washington. Table 3 summarizes the case study information.

Table 3. Summary of Case Study Projects

No.	Solar Contractor	Project Location	Project Start	Project Finish	Crew Size (person)	No. of Story	Roof Material	Roof Type
1	A	Tacoma, WA	18-Nov-16	23-Nov-16	5	1	Composite	Gable roof and dormer
2	A	Tacoma, WA	17-Nov-16	23-Nov-16	4	1	Composite	Gable roof and dormer
3	B	Seattle, WA	1-Dec-16	2-Dec-16	4	2	Composite	Crossed gable roof and dormer
4	C	Rochester, WA	13-Mar-17	15-Mar-17	4	1	Composite	Crossed gable roof

The first two case studies are two houses in Tacoma, WA, which are located next to each other. These projects were completed by one solar contractor (Contractor A) at the same time, but using two separate installation teams. The third case study is a house located in Seattle, WA and the installation was performed by Contractor B. The forth case study is another house located in Rochester, WA. The solar installation on the fourth case study was carried out by Contractor C.

Both case studies 1 and 2 are single-story houses with a gable roof and dormer. The roof slope on both houses is approximately 25 to 27 degrees and roofing material is composite shingles. The solar panels were placed on the southwest-facing sections of the roofs. The solar system of case study 1 was installed in four working days, from November 18 to 23, 2016. On case study 2, installation work started one day earlier and was completed on the same day as case study 1. The installation crew on case study 1 included one electrician and three roofers, while the crew for case study 2 consisted of one electrician and two roofers.

Case study 3 is a two-story house with a crossed gable roof and dormer. This house has a composite shingle roof with a slope of approximately 30 to 35 degrees. The solar panels are located on the south-facing and west-facing sections of the roof. The solar system was installed within two working days, on December 1 and 2, 2016. The installation crew on case study 3 consisted of one electrician and three roofers.

Case study 4 is a one-story house with a crossed gable roof. The roof is made of composite shingles and has a slope of 30 degrees. The solar system on this house comprised of two solar arrays, both located on the south-facing section of the roof. It took only three days to install the solar system for this house, from March 13 to 15, 2017. The installation team included three roofers and one electrician.

Figure 2 shows satellite photos of the four case study projects before solar installations.

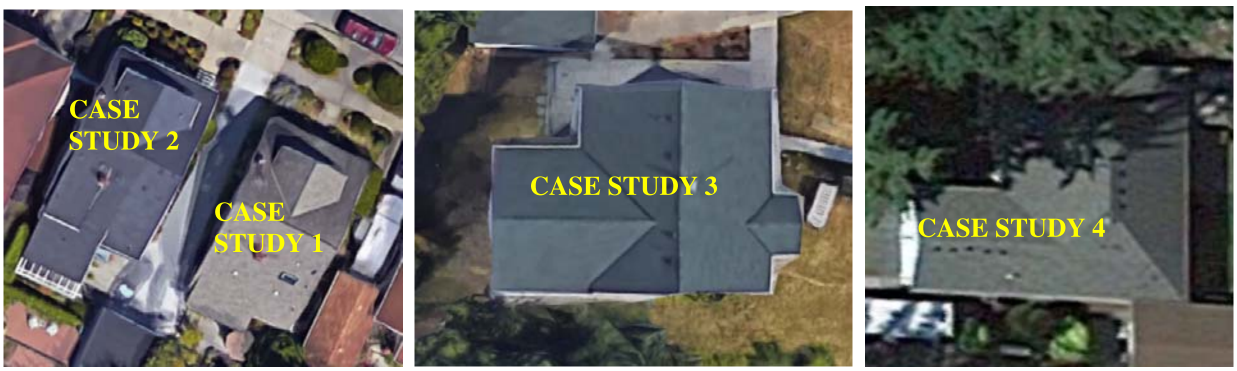


Figure 2. Case Study Projects (Google Map 2017)

As stated previously, the PtD attributes under consideration in the case studies included roofing material, roof slope, roof accessories, panel layout, fall protection system, lifting method, and electrical system. The site observations performed by the researchers focused on identifying the link between the identified PtD attributes and installation activities/roof characteristics. The implications of the identified attributes within the context of the case study projects are presented herein.

Roofing Material

The roofs in these projects are all made of composite shingles, which are less slippery than metal or wood roofs. In particular, composite shingles make it easier for the installation of mounting systems because to install a mounting system, roof tiles at connection locations should be lifted up to insert connection plates. Composite shingles are thin and easy to lift, compared to metal, concrete, or wood tiles, which are thicker and heavier. The age of roofing materials can also create a difference in safety. The composite shingles in case study 4 were newer than those in the other case studies. Newer shingles have more granularity and are less slippery. Aged composite shingles tend to adhere with each other, making it harder to lift up the shingles to insert the connections for solar systems. Compared with other projects, the newer composite shingles in case study 4 made it easier and safer for the installation process.

Roof Slope

The roof slopes in case studies 1 and 2 were about 25 to 27 degrees, while the slopes were 30 to 35 degrees in case studies 3 and 4. Since the roof slopes are not very steep, the workers could move around on the roofs with no specific problems, and did not need any special working platform for rooftop operation. Nevertheless, it should be noted that these roofs are classified as "steep roofs" per the OSHA standards and must adhere to the following OSHA regulation: "*1926.501(b)(11): Each employee on a steep roof with unprotected sides and edges 6 feet (1.8 m) or more above lower levels shall* *be protected from falling by guardrail systems with toeboards, safety net systems, or personal fall arrest systems.*" (OSHA, 2017a).

Roof Accessory

There was one skylight and a few roof vents on case study 1. The panel layout was designed to avoid the skylight location. The skylight and roof vents posed a tripping hazard to the workers. The skylight opening was covered by a fixed glazing panel, and the safety hazard of falling through the skylight opening did not appear significant in this case. As a result, no barricade or covering was installed for the skylight. It was interesting to note that the crew actually took advantage of the skylight by placing tools and materials against the side of the skylight to prevent them from sliding down the roof.

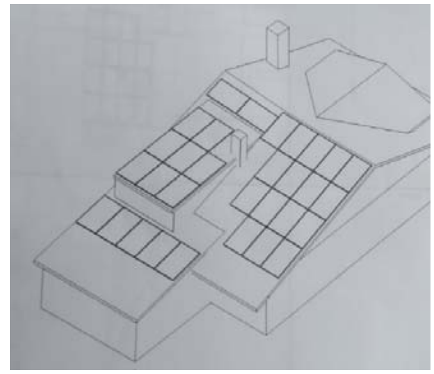


Figure 2. Panel Layout in Case Study 2 (*courtesy of Contractor A, Picture taken by Chung Ho on Nov. 18, 2016 at Case Study 2*)

No skylights were present on case study 2. However, a chimney, dormer, and a few roof vents were present on its southwest facing section of the roof where the solar panels were installed. The panel layout was significantly impacted by the existing roof accessories on this project. Because of the limited roof area, some solar panels were installed on the dormer's roof. In addition, a small space at the roof area adjacent to the dormer was also utilized for solar panels. Two solar panels were placed horizontally to fit into this space (Figure 3). From a safety perspective, the chimney and dormer sometimes blocked the lanyards used by the workers and hindered the workers' movements. The safety lanyard was occasionally trapped by installed rackings, forcing the workers to stop to untangle it.

Different from case studies 1 and 2, case study 3 had no skylight, dormer, or chimney present at the south-facing and west-facing sections of the roof where the solar panels were installed. However, some roof vents were present, posing tripping hazards for workers.

No skylight was present on case study 4, yet a chimney was at the middle of the south-facing roof section that caused a need to separate the solar system into two arrays. Although this separation was due to the chimney, clearance between these arrays made it more convenient for the workers to move around on the roof. Some roof vents on the south-facing roof section posed tripping hazards. However, the workers could still take advantage of these accessories by leaving tools and materials resting against the vents, using the vents as the backing objects to prevent materials from sliding down the roof.

Panel Layout

Through the interviews conducted during Task 1, the research team determined that the clearance between panel edge and roof edge can have a significant impact on safety. The clearance between panel edges and roof edges on case study 1 was relatively small, approximately 12 inches. The limited space caused a relatively higher level of falling hazard for the workers when moving along the roof edge, requiring them to take great caution.

The solar panels were extended to the roof edge in case study 2, leaving no clearance from the panel edge to the roof edge (see Figure 3). As a result, although the workers could move along the roof edge during the installation of the mounting system, no access to the installation area was possible after the panels had been installed. Then, the roof valley along the dormer became the only egress for the workers. The unoccupied area along this valley appeared to help facilitate the safe movement of workers, and reduced the shading impact of the chimney on the panels. Nevertheless, the installation sequence had to start from the space with limited access and end at the space with ample access. The sequence was needed in order to secure an exit point for the workers after installing all of the panels.

The layout of panels in case study 3 included an 18-inch clearance between panel edge and roof edge. This clearance allowed the workers to move easily along the roof edge, although the roof slope on this project was steeper than that on case studies 1 and 2. In addition, the movement of the workers on the roof was also easier because of the valley along the crossed gamble roof. Similar to case study 3, case study 4 also has an 18-inch clearance between panel edge and roof edge. This ample clearance—plus the clearance between the two solar arrays—allowed the workers to move around on the roof easily.

Fall Protection System

The crew installed two anchors for case study 1 in addition to the two existing safety anchors on the rooftop. Three safety anchors were installed in case study 2, since it had no existing safety anchor. In both case studies 1 and 2, all workers were equipped with personal fall arrest systems (see Figure 3), including safety harness, lanyard, and life line. It took time to install a personal fall arrest system and additional time to hook and unhook safety anchors during the operation. It was also observed that the usage of the system slowed down the movements of workers. Nevertheless, it is an utmost important safety measure, since it protects the workers from falling.

Figure 3. Fall Protection System (*Picture taken by Chung Ho on Nov. 17, 2016 at Case Study 1*)

In case study 3, the workers did not wear any personal fall arrest systems, which appeared to make the workers move faster and be more productive. The workers also mentioned that no safety anchor installation shortens the installation duration. The installation duration on this project was two days, relatively fast compared with case studies 1 and 2. However, this lack of fall protection was a violation of the safety regulation in section 1926.501(b)(11) of the OSHA standards for steep roofs (OSHA, 2017a), and could lead to significant injuries for workers if they should fall from the rooftop.

No existing safety anchor was available in case study 4, so the workers installed two safety anchors for this project. Although the workers used personal fall protection systems with the safety anchors during our first visit, none of the workers used any fall protection methods during our second visit. It appeared that the workers did not prefer using the system even if it was available onsite.

Lifting Method

On all four of the case studies, the workers used ladders to lift panels and other materials to the rooftop. It was observed in the first three cases that when lifting up panels through a ladder, the workers used one hand to hold up a solar panel or other material while their other hand was used to hold onto the ladder. When getting close to the roof, the worker stayed on the ladder and handed the panel or other material to another worker who was waiting to take it on the rooftop. Regarding safety regulations on ladder handling, OSHA section 1926.1053(b)(22) (OSHA, 2017a) requires that "*An employee shall not carry any object or load that could cause the employee to lose balance and fall.*" More specifically, OSHA's article, Green Job Hazards (OSHA, 2017b), states that "*Workers should never be allowed to climb ladders while carrying solar panels.*" Although the workers said that it was more convenient for them to carry panels to the roof by climbing the ladder, this was apparently a violation of the safety rule and could lead to injury incidents, such as tripping and falling from the ladder.

In case study 4, the workers did not carry solar panels. Instead, the workers pushed panels along the ladder while climbing. A worker rested a solar panel on the ladder first, then pushed the panel up to the rooftop. Both of the worker's hands held and pushed the solar panel, concurrently leaning on the ladder's side rails while he was climbing. When getting close to the roof, the worker still stayed on the ladder and another worker on the roof took the panel. Although no specific regulation in the OSHA standards prohibits pushing solar panels up the ladder to the rooftop, this action is still a violation per Washington Administration Code: "*WAC - 296-876-40025 Climbing and Descending: (1) You must have both hands free to hold on to the ladder*" (WAC, 2016).

Electrical System

Each project had one electrician who was in charge of the electrical installation for the solar system. As informed by the interviewees, all electricians are required to participate in extensive safety training designed specifically for their work. Since electrical hazards can cause serious injuries, electricians in solar installations are required to follow strict safety rules for electrical work (OSHA, 2017c).

It is a requirement to include a rapid shutdown function in solar systems. Centralized rapid shutdown systems were installed in case studies 1 and 4 for safety during the operation as required by the National Electrical Code. An optimizer was installed at each solar panel in case study 2 instead of a centralized rapid shutdown. The optimizers functioned as rapid shutdowns as well as devices to balance the electricity generation among panels and make the system more productive. Case study 3 complied with the requirement for rapid shutdown by including the installation of a micro inverter at each solar panel.

In addition to the above-listed PtD attributes, the researchers identified other safety factors, such as weather conditions and unique working conditions at the beginning and end of installation processes. The additional safety concerns are described below.

Weather Conditions

The interviews revealed that weather conditions have a significant impact on safety performance. Specific to the state of Washington, the rainy, cold winter makes the installation work hard and dangerous. The rain makes the roof wet and slippery, and the cold weather makes workers' movements clumsy, causing them to often drop tools and hurt their hands or feet.

The impact of cold and rainy weather to safety was apparent during the site visits. In case studies 1 and 2, the weather was cold and dry during the first visit, while it was rainy during the second visit. The air temperature was approximately 45 degrees Fahrenheit. The weather at the first visit did not cause a significant issue to the workers since it was dry and activities could warm up the workers at that moderate winter temperature. However, the rain during the second visit worsened the coldness and impeded workers' movements. It was rainy and much colder during the site visit for case study 3. The air temperature dropped to around 40 degrees Fahrenheit.

Despite the unfavorable weather, the crews in the case studies still performed their work as planned. Although the rain made the roofs more slippery, it did not cause any serious issues on the projects because all of the houses contained composite roofs. However, the cold weather made it harder for the workers in case study 3 to perform the work; their hands were very cold and their movements slowed down. The workers were also getting tired easily and took more breaks to warm up. It is interesting to note that one of the workers dressed in a battery heated jacket. The heated jacket kept the worker warm and made him comfortable while working in the chilly weather. This observation showed that proper protective clothing is important to protect the workers in unfavorable weather and would improve their safety.

Unique Working Conditions

While the crew can follow safety rules for most parts of the installation, it is hard to follow the rules entirely at some particular times, especially at the beginning and the end of the job. At the beginning, the workers have to climb up without a fall protection system to install safety anchors. Similarly, at the end of the job, they have to climb up to unhook the anchor and climb down without a fall protection system. It is also more difficult to climb down after finishing solar installations since almost all of the available roof space has been occupied by the newly-installed panels.

Other

The electrician in case study 2 expressed his concerns about safety in solar installations that the researchers found worthy to be included in this report. The electrician claimed that there are many houses that have poor roofing quality and uneven roof surfaces. These problems render additional safety hazards to workers involved in roof maintenance or solar installation. The electrician suggested that more inspections are needed on roofing construction to ensure safety for future rooftop activities. In addition, many solar contractors in the market do not follow safety rules since they believe that ignoring safety rules can help them work faster and reduce installation costs. This practice is not only dangerous to installation crews, but also may help contractors without well-established safety practices outbid contractors with strong safety practices. Thus, it can hurt the bottom line of contractors who follow safety rules closely because homeowners often make their decision based on bid prices, not a contractors' safety performance. The electrician suggested that stronger safety enforcement is needed to make solar installations safer and to encourage fair competition in the solar industry.

Task 4. Develop PtD protocol for solar design and installation.

The purpose of Task 4 was to develop a PtD protocol that small businesses can apply to improve the safety of their workers. By using this guideline, solar contractors can identify potential safety hazards based on various types of existing roof conditions and can develop optimal solar panel layouts and installation methods that proactively eliminate or prevent safety hazards.

The research team developed the protocol based on the attributes that were verified through the case studies, including roofing materials, roof slope, roof accessories, panel layout, fall protection system, lifting methods, and electrical system. We also incorporated the lessons learned from the extensive literature review into the protocol. The protocol is comprised of two main sections. The first section provides a brief explanation about the application of the protocol, the PtD concept, and solar PtD implementation procedure. The second section describes the influence of each PtD attribute to safety in solar installations and how to incorporate these attributes into the design process to proactively improve worker safety during the installation.

Task 5. Obtain industry feedback regarding the PtD protocol

Task 5 consisted of validating the effectiveness and applicability of the protocol, identifying improvement opportunities, and promoting the dissemination of the PtD principles to small-business solar contractors. Task 5 was centered around a seminar organized on May 12, 2017, in which the researchers introduced the PtD concept, presented the PtD protocol, and gathered feedback from participating solar contractors. The activities that were implemented in Task 5 include: developing a list of potential guests for the seminar, preparing a list of survey questions, sending out the invitation to the guests together with a survey request, organizing the seminar, and collecting and analyzing feedback.

The list of potential guests for the seminar included the interviewees and contractors who participated in Tasks 1 through 3, the member companies of the Solar Energy Industries Associations (SEIA) in the Pacific Northwest, the Solar Installers of Washington, and Solar Washington. In addition to these solar contractors, the researchers also invited other guests from academia including the members of UW Solar and some PhD students and researchers in the University of Washington's Department of Construction Management.

The researchers prepared a seminar flyer to inform guests of the time, location, and the content of the event. The seminar invitation and the flyer was sent out via email to over 40 people and/or companies included in the guest list. The seminar flyer is included in Appendix 4. A web-based Google Form survey was sent to the solar contractors two weeks prior to the seminar to inform the participants of the protocol and gather feedback in advance. The draft version of the PtD protocol was provided to the solar contractors in advance through a link included in the online survey. Appendix 5 shows a copy of the survey and Appendix 6 summarizes the survey's results. After sending the electronic invitations to approximately 40 people/solar companies, the researchers followed up with direct phone calls and reminder emails. Eleven people confirmed their participation. However, only seven of them attended the event, including four solar contractors and three observers.

The seminar took place from 1:00pm to 4:00pm at a construction education building in Seattle, WA. The seminar started with a presentation about the PtD concept and the content of the protocol. Based on feedbacks received from the seminar discussion and online survey, the PtD protocol was updated (see Appendix 7). The content of the seminar discussion and the responses to the online survey are described below.

Seminar Discussion

The seminar discussion lasted for one and half hours, and the discussion covered diverse topics regarding safety in solar energy installation. The discussion around each topic is summarized below.

<u>*The difference between federal and local safety regulations*</u>

The discussion started with a claim from a solar contractor that for 40% to 50% of the jobs they have done, they would never have been able to meet the clearing requirement because they may lose a significant portion of available roof area if the requirement was followed. This claim was raised because the protocol refers to the national IFC (International Fire Code) codes, while the local code governs over the national code. The local code for clearances is less stringent than the national code.

Similarly, safety requirements are also governed by local regulations. However, OSHA sets a higher standard for local laws regarding safety as it requires that local laws be "*at least as effective*" as OSHA (OSHA, 2017d). That is why when addressing ladder usages, OSHA section 1926.1053(b)(22) only states, "*An employee shall not carry any object or load that could cause the employee to lose balance and fall*", while the Washington Administrative Code - WAC-296-876-40025 sets forth a more stringent requirement, "*You must have both hands free to hold on to the ladder*" (WAC, 2016).

The differences between federal and local laws, codes, and standards make it difficult and confusing for solar contractors when implementing the safety requirements into their work. Furthermore, each state, city, or county may have different versions of laws, codes, and standards. As one solar contractor said, "*It is tricky, even for us to look at different codes and figure it out.*" Addressing each local regulation is out of the scope of the PtD protocol. The protocol is designed for the national level and readers are encouraged to refer to corresponding local regulations for implementation on their specific projects.

<u>*How to balance safety with other criteria in decision making*</u>

The researchers found a general resistance toward safety requirements from the solar contractors, although the contractors are still trying to follow the safety regulations at certain levels. To explore the reason behind this objection, the researchers asked the solar contractors how they balance safety with other criteria in decision making and received varying responses. While one solar contractor said that he would not mind designing less panels on a rooftop to make it safer while ensuring an effective solar system, while another solar contractor stated that strictly following safety regulations will increase labor costs. The latter contractor provided an example that a ladder lift takes two hours to install and two hours to take down. Therefore, using a ladder lift would turn a one-day job into a two-day job. The contractor added, "*There is not enough profit in the solar industry to double the hours to take to do the work.*" Other contractors also complained about the inefficiency of a ladder lift. Despite these concerns, all of the contractors believed that technology should be improved to support safety in solar installation. For example, a ladder lift should be more convenient for the solar industry, and solar panels should be more efficient so that a smaller footprint is needed for the same electrical output to provide solar contractors more room to follow clearance requirements.

Whether a sloped roof or a flat roof is better for the safety in solar installations

Sloped and flat roofs render different impacts on worker safety. In term of production, sloped roofs may be better to orient solar panels because sloped roofs do not require additional frames that are needed for flat roofs to achieve the desirable slope of the solar panels. In addition, it was found that workers would need to kneel down more to work on flat roofs than sloped roofs. When asked if it was more convenient for workers to work on sloped roofs than flat roofs, the contractors responded that even though flat roofs require more kneeling, they are still preferred over sloped roofs since workers do not need to stand on a sloped surface for a long time.

Safety hazards and incidents in solar installations

The solar contractors listed tripping, slipping, and heat exhaustion as common safety hazards. Tripping hazards can be caused by roof projections, and even the round ropes of a fall protection system. Slipping hazards are often present when working on metal roofs, composite roofs with low granularity, or roofs containing moss. Heat exhaustion is serious when working on metal roofs in the middle of the summer. When it gets hot, suddenly standing up can make a worker lose his/her balance. Regarding injuries during solar installations, one contractor said that his company had one incident of falling from a roof in eight years. One contractor said that his company have not had any falls from roofs yet, but has had workers trip on the roof because of slippery conditions. Another contractor said that his company had two workers fall from roofs.

Electrical issues in solar safety

Although solar panels can generate energy when exposed to the sun, electrical hazards are not a big concern to solar contractors since the electricity would not flow until the crew completed the circuit, which does not happen until the workers have finished installing the solar panels. Electrical connectors that connect the solar panels with others are "*fully enclosed, fully wrapped, fully insulated …. have to have a special tool to even take them apart.*" In addition, the electrical components have been fully tested from the manufacturing side before reaching the market. Furthermore, in Washington a solar contractor must have a licensed electrician on site, and all electrical works are carried out by a licensed electrician.

PtD in the manufacturing side versus construction side

PtD on the manufacturing side received positive feedback from the solar contractors. However, the contractors were not very interested in PtD on the construction side. The manufacturing side was preferred by the solar contractors since "*It is standardized for everybody,*" "*We don't have anything to do with that, with electrical thing. That was enforced by OSHA and all those people on the manufacturing side of that. They come to us already that way*."

On the other hand, PtD on the construction side somehow does not seem very practical to the solar contractors. For example, strictly following IFC's clearance requirements may mean losing a significant roof area for solar panels and may not meet the needed solar capacity. The requirement in using ladder lifts for carrying solar panels up to the roof also caused difficulties for solar contractors because of the long setup time of a ladder lift. These solar contractors also argued that the personal fall arrest system was too heavy and could cause further tripping hazards, with one contractor stating "*I think that the safety devices that are out there are very impractical in installing the solar.*"

PtD for solar installations for new building constructions

To explore further ideas about PtD for solar installations in new building construction, solar contractors were asked to state what they would want if a house could be designed for a solar system. Responses from the contractors indicated a number of PtD opportunities, including:

- "*Nothing extruding the roof from the south side of the house*"
- "*No shake roof, no tile roof;*" "*Having anchor points ready to install*"
- "*Making the roof at least 4 feet more between the top and bottom and 6 feet more on each side*" for the usage of roof area for solar panels
- "*The house is made solar ready by putting in wiring, it has to be pre-wired*"
- "*Single story house*" - Easy access to the roof less than 2:12 slope
- "*Build a flat surface over here up on the roof and I would bring my material over and setting up there, then I could just carry over and knock it out.*"

It is interesting to note that the Seattle Department of Construction and Inspections has issued Tip 422 for Seattle Permits named "Renewable Energy and Solar-Ready Roofs for Commercial Buildings" for designing solar-ready buildings (SDCI, 2017).

Application of the protocol

During the discussion, the researchers informed the participants that since there is no standard on how to implement PtD in solar installations, the research project aimed at collecting and documenting the knowledge from solar experts. The protocol can be used as a training tool for the people who want to enter the solar industry for the first time. Although there is a hesitance in fully implementing safety regulations from some small solar contractors, they all agree that this protocol is of necessity and will facilitate a learning process regarding safety for the solar industry.

Feedback to improve the protocol

Valuable feedbacks from the solar contractors to improve the protocol were collected, including:

- Conflicting information about the usage of ladders in the protocol should be revised
- The protocol should be consistent by referring to national regulations
- The protocol should add the content about providing hydration, sunscreen, and hats for workers when working in a hot weather
- "*Making sure that the accesses are accessible during the construction*"
- Adding the influence of materials on flat roofs such as "Flat PVC, plastic roofs can have more dust, mud."

The researchers revised the protocol accordingly to incorporate the feedback from the contractors.

Survey Responses about the PtD Protocol

Out of approximately 40 online survey requests that were sent out for the protocol, the researchers obtained seven responses. The overall feedback for the first section about the level of importance of the protocol was positive. The average scores for all questions in this section are equal to or higher than 4.0 (4.0 is equivalent to agree, while 5.0 is equivalent to strongly agree). Feedback was provided in the second section of the survey in order to improve the protocol. The research team has considered and/or incorporated the feedback obtained from the online survey and the seminar discussion into the final version of the protocol (Appendix 7). The survey results are summarized in Appendix 6.

7. CHANGES/PROBLEMS THAT RESULTED IN DEVIATIONS

During the performance of the research, the researchers encountered difficulties in finding case study projects and receiving feedback from solar contractors about the protocol. However, the researchers were still able to perform the study as per the planned methods without any changes.

8. LIST OF PRESENTATIONS, PUBLICATIONS

The research findings have been presented in two conferences and one seminar including:

- March 2017: Oral presentation at New Frontiers in Construction Conference 2017, sponsored by the Center for Education and Research in Construction (CERC), Seattle, WA.
- April 2017: Poster presentation at the Associated Schools of Construction (ASC) 53rd Annual Conference, Seattle, WA.
- May 2017: Solar PtD Seminar, Seattle, WA.

9. DISSEMINATION PLAN

The researchers submitted an abstract to the ASCE Construction Research Congress 2018, one of the largest construction conferences in the world. The abstract has been accepted and the researchers are in the process of preparing a full paper for the conference. The researchers also plan to develop a couple of journal papers on the study to be submitted to top academic journals.

10. CONCLUSION

The researchers successfully completed all tasks planned for the research project. Seven PtD attributes have been identified including: (1) roofing material, (2) roof slope, (3) roof accessary, (4) panel layout, (5) fall protection system, (6) lifting method, and (7) electrical system. These attributes were verified and ranked through four case study projects and the surveys onsite. Each attribute poses varying levels of safety impacts to solar installation. The researchers developed a solar PtD protocol based on the findings from the interviews and case studies. The protocol includes instructions for implementing PtD in solar design and installation, and detailed guidance on addressing each PtD attribute. The content of the protocol has been verified and improved based on industry feedbacks through an online survey and a seminar discussion. Solar designers must address the potential safety hazards associated with the PtD attributes and documented in the protocol in order to reduce safety hazards from the design process.

Throughout the implementation of this research project, the researchers encountered significant resistance about meeting safety regulations from small solar contractors. This resistance focused on areas such as (1) IFC clearance requirements that can significantly reduce available roof areas for placing solar panels, (2) ladder lifts or other lifting equipment that involves a lengthy setup, and (3) personal fall protection systems that feel too heavy or could lead to tripping hazards. These problems should be addressed in future research in order to devise a solution to facilitate and improve safety performance and increase chances of implementing PtD in solar design and installations.

11. REFERENCES

Behm, M. (2005). "Linking Construction Fatalities to the Design for Construction Safety Concept." *Safety Science.* Volume 43, Issue 8. 589-611.

Bucher, K.; Kleiss, G., Batzner, D. (1998). "Photovoltaic Modules in Buildings: Performance and safety." *Renewable Energy.* Volume 15, Issues 1-4, 545-551.

Gambatese, J. A. (2008). "Rapporteur's Report: Research issues in Prevention through Design." *Journal of Safety Research.* Volume 39. 153-156.

Google Map (2017). https://www.google.com/maps/

GTM/SEIA (2016). "GTM Research/SEIA U.S. Solar Market Insight – 2015 Year in Review." *GTM Research and Solar Energy Industries Association.*

Hamilton, J. (2011). "Careers in Solar Power." *U.S. Bureau of labor statistics.*

Kreis, T. (2009). "The Impact of Solar Energy on Firefighting." *Fire Engineering*. Volume 79.

NIOSH (2014). "The State of National Initiative on Prevention through Design." Progress report 2014. *Department of Health and Human Services. Centers for Disease Control and Prevention. National Institute for Occupational Safety and Health*. Publication No. 2014-123.

OSEIA. "Solar Construction Safety." *Oregon Solar Energy Industries Association. Oregon Occupational Safety and Health Division, Department of Consumer and Business Services.*

OSHA (2017a). "PART 1926 Safety and Health Regulations for Construction." *Occupational Safety & Health Administration.* https://www.osha.gov/pls/oshaweb/owasrch.search_form?p_doc_type=STANDARDS&p_toc_level=1&p_keyvalue=1926

OSHA (2017b). "Green Job Hazards: Solar Energy – Falls." *Occupational Safety & Health Administration.* https://www.osha.gov/dep/greenjobs/solar_falls.html.

OSHA (2017c). "Green Job Hazards: Solar Energy – Electrical." *Occupational Safety & Health Administration.* https://www.osha.gov/dep/greenjobs/solar_electrical.html.

OSHA (2017d). "OSHA Act of 1970 – Section 19 – State Jurisdiction and State Plans." *Occupational Safety & Health Administration.* https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=3372&p_table=OSHACT

Paiss, M. (2009). "Solar Electric Systems and Firefighter Safety." *Fire Engineering.* Page 83-88.

Rajendran, S.; Gambatese, J. (2016). "Risk and Financial Impacts of Prevention through Design Solutions." *Practice Periodical on Construction Design and Construction.* Vol. 18, Issue 1.

Schulte P, Rinehart R, Okun A, Geraci C, Heidel D [2008]. "National Prevention through Design (PtD) Initiative." *Journal of Safety Research 39:*115–121. www.cdc.gov/niosh/topics/ptd/pdfs/Schulte.pdf

SDCI (2017). "Tip 422 – Seattle Permits – Renewable Energy and Solar-Ready Roofs for Commercial Buildings." *Seattle Department of Construction and Inspections*. http://www.seattle.gov/DPD/Publications/CAM/Tip422.pdf

SEIA (2017). "Washington Solar." *Solar Energy Industries Association.* http://www.seia.org/state-solar-policy/washington

SEIA (2017). "California Solar." *Solar Energy Industries Association.* http://www.seia.org/state-solar-policy/california

Toole, T. M.; Gambatese, J. (2008). "The Trajectories of Prevention through Design in Construction." *Journal of Safety Research 39.* 225-230.

USCD (2017). "Climate Seattle – Washington." *U.S. Climate Data.* http://www.usclimatedata.com/climate/seattle/washington/united-states/uswa0395.

WAC (Washington Administrative Codes). 2016. "Ladders, Portable and Fixed." Safety and Health Core Rules, 296-876 WAC. http://apps.leg.wa.gov/wac/default.aspx?cite=296-876

Walline, D. (2014). "Prevention through Design – Proven Solutions from the Field." American Society of Safety Engineers. *Professional Safety*. Volume 59, Issue 11.

WSUEEP (2013). "Solar Electric System Design, Operation and Installation – An Overview for Builders in the U.S. Pacific Northwest". *Washington State University. Extension Energy Program.*

12. APPENDIX 1 – INTERVIEW QUESTIONAIRE

INTERVIEW QUESTIONAIRE

Applying Prevention Through Design (PtD) to Solar Systems on Small Buildings

INTRODUCTION

We are a research team from the Department of Construction Management at the University of Washington. Federally funded through the Center for Construction Research and Training (CPWR), we are conducting a research project aimed at investigating how, during design process, to address safety concerns related to existing roof condition, accessary features, and solar panel characteristics during solar installation on small buildings.

As the start of the project, this open-ended interview targets to capture the current safety practices of the solar industry and the common safety hazards to which solar installers are exposed. Based on the captured current practices, various attributes of solar systems will be identified and then analyzed through case study projects. This research will end with the development of a design protocol for solar systems that small businesses can apply to improve their safety practices. Your participation in this interview will greatly contribute to the successful completion of the research project. Thanks for your support.

Please share your experience in solar design and installation on residential or commercial buildings as follows.

Current Solar Design and Installation Process

1. Explain your role in solar design and installation process.

2. Explain steps for solar design process.

3. Explain steps for installation process of solar system.

Safety Planning for Solar Installation

4. What field issues have you observed in terms of occupational safety and health?
   - Fall hazards
   - Electrical hazards
   - Heat stress hazards
   - Other (please explain)

5. What safety code/regulation do you apply in solar installation?

6. What safety planning do you apply to protect workers from:
   - Falling from the roof or ladder?
   - Injury due to falling objects?
   - Openings on the roof?
   - Injury due to heavy lifting?
   - Heat stress?
   - Electric shock?

Design Attributes in Solar Design and Construction

7. Briefly explain types of buildings and roofs that you typically deal with for your installation.

8. How does the roof shapes and types affect your safe operations?
   - Roof types
   - Roof layouts
   - Roof accessory structures
   - Other (please explain)

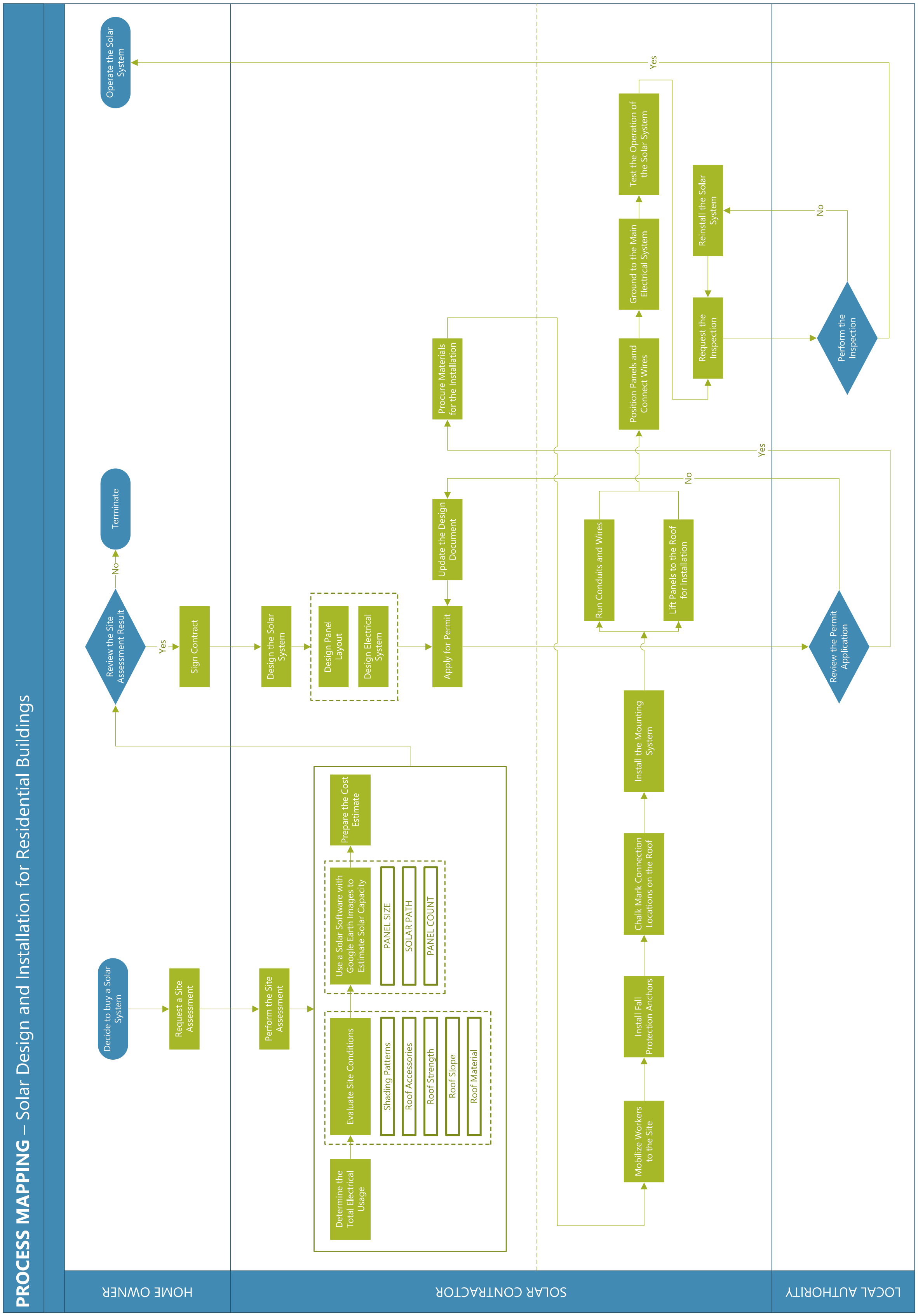
9. What elements of solar systems affect your safe operations?
   - Panel sizes or types
   - Location
   - Layout
   - Support structure sizes or types
   - Other (please explain)

10. What should be specified in solar design document to improve the safety of solar system installation?

11. Please explain, in the current practice, what information is communicated between project parties to improve occupational safety and health during solar design and installation?
    - Information flow during pre-construction
    - Information flow during construction

Lastly, we are looking for case study opportunities. Please let us know if you have an upcoming project where solar systems are installed on the rooftop of a small building, and if we can have a field observation on the project.
Thank you so much for your participation.

13. APPENDIX 2 – PROCESS MAPPING



14. APPENDIX 3 – PtD ATTRIBUTES

By analyzing the data collected from the 13 interviews and four case study projects, the researchers identified seven major PtD attributes including (1) roofing material, (2) roof slope, (3) roof accessary, (4) panel layout, (5) fall protection system, (6) lifting method, and (7) electrical system. Each attribute is described in further detail in this section.

1. Roofing Material

As most solar installation activities are performed on the rooftop, roofing materials have a significant impact on the safety performance of solar contractors. Composite shingle roofs are most convenient for the installation crew because they are not very slippery, even when raining. Figure 4 shows an example of a composite shingle roof. Wood roofs, tile roofs, metal roofs, and roofs losing granules are more slippery, especially when wet, making them more dangerous for the crew. The researchers found that installation crews still work even when raining. However, for safety reasons, solar installation on metal and wood roofs when raining should be carefully considered and if possible, not performed.

Figure 4. Composite Shingle Roof (*Picture taken by Chung Ho on 11/17/2016 at Case Study 1*)

There are a few more unique issues for metal roofs and wood roofs. First, besides being slippery, metal roofs create glare on sunny days, causing workers to feel dizzy if they work for a long time and potentially causing visibility concerns. Second, it is more difficult to drive nails on wood roofs when attaching mounting systems to the roof. Without pre-drilling, it is hard to determine whether the nail has gone through the wood tiles and has reached the roof frame. As a result, there is an increased chance of having a mounting system not fully attached to the roof frame. Third, certain types of roofs, such as shake roofs, require wearing special footwear to gain more traction and avoid breaking the roofing materials. However, wearing this footwear hampers the workers' movement, causing other tripping hazards.

The strength of a roof structure is a factor that solar contractors have to consider when performing a site assessment. The roof structure must be strong enough to support the intended solar system. Reinforcement is required if the roof structure is not strong enough. In addition, since the lifespan of a typical solar system is approximately 25 years, roofing materials should be able to last over that period. Before installing solar panels, the homeowner should consider replacing the roofing materials if the remaining life of the roofing materials is determined to be relatively short; after solar panel installation, it will be complicated to replace the roofing.

2. Roof Slope

Roof slope has a significant impact on safety performance. Simply put, the steeper the roof slope, the more dangerous the solar installation. Roof slope can affect decision making on lifting methods and installation sequences. In most cases with moderately-sloped roofs, the installation crew can use a ladder to climb up and stand on the roof surface to perform the installation. For steep roofs, the crew often needs to use a scissor lift as a working platform to perform the work. The bottom (lowest) rack is always installed first for steep roofs so that workers can face downward as the installation progresses upward. Each anchor point is typically used for one worker as a fall arrest system for usual cases, while for steep roofs, two anchor points for each worker may be needed to ensure safety.

Figure 5 shows the workers' positioning when installing connections for a mounting system on a moderately-sloped roof.

Figure 5. Installing Connections for Mounting System (Picture taken by Chung Ho on 11/17/2016 at Case Study 1)

3. Roof Accessory

Roof accessories may present both advantages and disadvantages for solar installations. First, shading from chimneys can significantly impact the efficiency of solar systems. Thus, solar contractors need to design the location of solar panels around chimneys. From a safety perspective, the installation crew may use chimneys as an anchor point for a temporary fall protection system. However, most solar contractors do not prefer using a chimney as a support for a fall protection system unless the chimney is structurally robust and can support the load from the fall protection system.

Roof accessories, especially small features such as roof vents, can create tripping hazards for workers. Solar panel layouts are designed to account for these accessories. Figure 6 shows how the solar panel layout was altered to avoid a skylight. A temporary barricade or cover should be installed to protect workers from stepping on or falling through a skylight or other openings on the roof.

Figure 6. Solar Panels on Roof with Skylight (Picture taken by Chris Lee on 11/23/2016 at Case Study 1)

Besides the safety hazard issues mentioned above, sometimes solar workers can take advantage of the accessories, such as a chimney or skylight, to hold up tools and materials, preventing them from sliding down along a sloped roof. Figure 7 shows how the workers were taking advantage of the skylight for holding up installation materials.

Figure 7. Using Skylight to Hold up Installation Tools and Materials (Picture taken by Chung Ho on 11/17/2016 at Case Study 1)

4. Panel Layout

To achieve the desired electrical generation output, solar designers may need to include as many solar panels as possible in a system. However, the layout and maximum number of panels are largely determined by considering available roof space, roof layout, roof direction, roof accessories, required clearance between panel edge and roof edge, and voltage limit set for residential buildings.

Section 605.11 of the International Fire Code (IFC) sets a clear access pathway for panel layout, and a clearance between the panel edge and roof ridge to assist the operation of fire fighters in case of fire. Although the requirement regarding clear access pathways is applied only to residential buildings with a roof slope that is 2:12 or steeper, no limitation on slope ranges is applied for the clearance requirement between the panel edge and roof ridge. The pathway requirement is summarized in Table 4.

Table 4. Pathway Requirments Based on Roof Types

Roof Types	IFC Requirements
Hip Roof	A clear access pathway that is 3 feet wide or larger extending from the eave to the ridge should be provided on each roof slope where the panels are located.
Single Ridge	At least two clear access pathways
Roof Hips and Valleys	A clear access pathway should be more than 1.5 feet wide if there will be panels on both sides of the valley. On the other hand, if panels will only be on one side of the hip or valley that is of equal length, no clearance is required.

Specific to residential buildings, the panel should be located no higher than 3 feet from the roof ridge to allow for smoke ventilation operations. Although these clearance requirements are for fire fighters, they can also help the installation crew move up and down on the roof by providing more space, and hence improve overall safety in solar installation. The clearance between the panel edge and roof ridge also makes it convenient for the installation and usage of safety anchors, which are usually installed at the roof ridge. The interviews revealed that a 1 foot clearance between panel edge and roof ridge is preferred for the installation of safety anchors.

Figure 8 shows the panel layout of a house with a single ridge. However, the panel layout provides neither two clear access pathways from the eave to the roof ridge, nor the clearance between panel edge and roof ridge as required by the International Fire Code.

Figure 8. Panel Layout on a Gable Roof with Dormer (Picture taken by Hyun Woo Lee on 11/23/2016 at Case Study 2)

Besides the clearance requirements, the layout of panels should be carefully designed to allow for a convenient loading point for material hoisting as well as an access point for workers on a ladder.

5. Fall Protection System

OSHA requires that workers be protected from falls when working on an unprotected side or edge that is more than 6 feet higher than the lower level. Per OSHA standards, Sections 1926.501(b)(10), and 1926.501(b)(11), multiple fall protection options can be used when working on sloped roofs, such as guardrail systems, safety net systems, or personal fall arrest systems. It is important to note that guardrail systems should include toeboards for steep roofs.

The interviews reveal that personal fall arrest systems are commonly used for solar installation. Either life lines or individual anchor points can be used for a personal fall arrest system. The location of anchor points should be considered as part of roof construction so that the anchors can be used for window cleaning or building maintenance during the use of the building. For residential buildings, a minimum of two anchor points per roof should be installed. The maximum distance between two anchor points should be determined to ensure the movement of the worker within the lanyard length. Anchor points should be installed on both sides of any obstructions on the roof, such as a dormer, chimney, or skylight, because these obstructions can hinder the movement of workers wearing a fall arrest system. Section II.m in Subpart M Appendix C of the OSHA standards also suggests considering obstructions when deciding on tie-off locations. Figure 9 shows examples of anchors that solar contractors typically use for a fall arrest system.

Figure 9. Safety Anchors for Personal Arrest System (Source: roofingcontractor.com; us.msasafety.com)

6. Lifting Method

Standard solar modules that are commonly used on residential buildings are 40"x66" or 40"x78". Each solar panel weighs between 30 and 40 pounds, which is within OSHA's manual lifting limit of 50 lbs. However, to lift panels and system components to the roof, OSHA (2017b) suggests using lifting equipment such as ladder hoists, swing hoists, or truck-mounted cranes/conveyors whenever possible. If using a ladder is unavoidable, sections 1926.1053(b)(21) and (22) of the OSHA standards (2017a) require using at least one hand to hold onto the ladder while progressing up and down the ladder, and workers shall not carry an object or load that could cause a loss of balance or a fall. Nevertheless, the interviews showed that for residential buildings, most solar contractors still prefer manual lifting by a ladder since it takes less time than using mechanical lifting equipment that requires additional time to set up. For manual lifting, three methods are identified that solar contractors commonly use: (1) one worker carrying panels up to the roof; (2) two workers carrying panels together; and (3) after tying off panels, having one worker lifting the panels by using a rope. The researchers found that the first method is most commonly used by solar contractors who were interviewed, yet it is a violation of the OSHA standards.

Figure 10 shows a hydraulic ladder and manual ladder used for solar installation.


Figure 10. Hydraulic Ladder and Manual Ladder (Pictures taken by Chung Ho on 9/28/2016 during interview, and on 11/23/2016 at Project 1)

7. Electrical System

Electrical work for solar installation must be performed by qualified electricians and follow the rules and regulations established for electrical safety. While the scope of the present research is not fully focused on electrical safety hazards, it is worth noting that solar installation indeed involves electrical safety concerns. IFC 605.11.1.2 requires that "*Conduit, wiring systems, raceways for photovoltaic circuits shall be located as close as possible to the ridge or hip or valley, and from the hip or valley as directly as possible to outside wall as direct as possible to reduce trip hazard and maximize ventilation opportunity.*" In addition, the National Electrical Code 2014 NEC 690.12 requires installing a rapid shutdown device to quickly de-energize the conductor associated with a solar system. Figure 11 depicts the wire installation of case study 3.

Figure 11. Running the Wire for Solar System (Picture taken by Chung Ho on 12/02/2016 at Project 3)

8. Other Factors Affecting Safety

In addition to the above-listed PtD attributes, other factors, such as installation sequence and weather conditions, influence safety during solar installation.

Installation sequence can play an important role in reducing safety hazards. Installation should begin from the bottom (lowest) racks of the mounting system and move upwards toward upper racks. The racks should be installed horizontally rather than vertically. This installation sequence makes it safer for solar workers since the bottom rack can serve as a backup for the installation of the upper components. For access points, it is suggested that solar panels are installed from the point with limited access to the point with ample access so that workers can easily exit the roof after finishing the installation.

Since most solar installation work is performed outside, weather conditions can have a significant impact on safety operations. Sun can create glare on metal roofs and may also result in heat stress to solar workers. Big wind gusts may knock over solar panels, leading to falling and striking hazards. Rain can cause slips and falls, and cold temperatures can cause freezing and fatigue. Safety plans should consider potential hazards caused by weather conditions. In the case of unfavorable weather conditions, postponing or rescheduling the installation should be considered.

15. APPENDIX 4 – SEMINAR FLYER

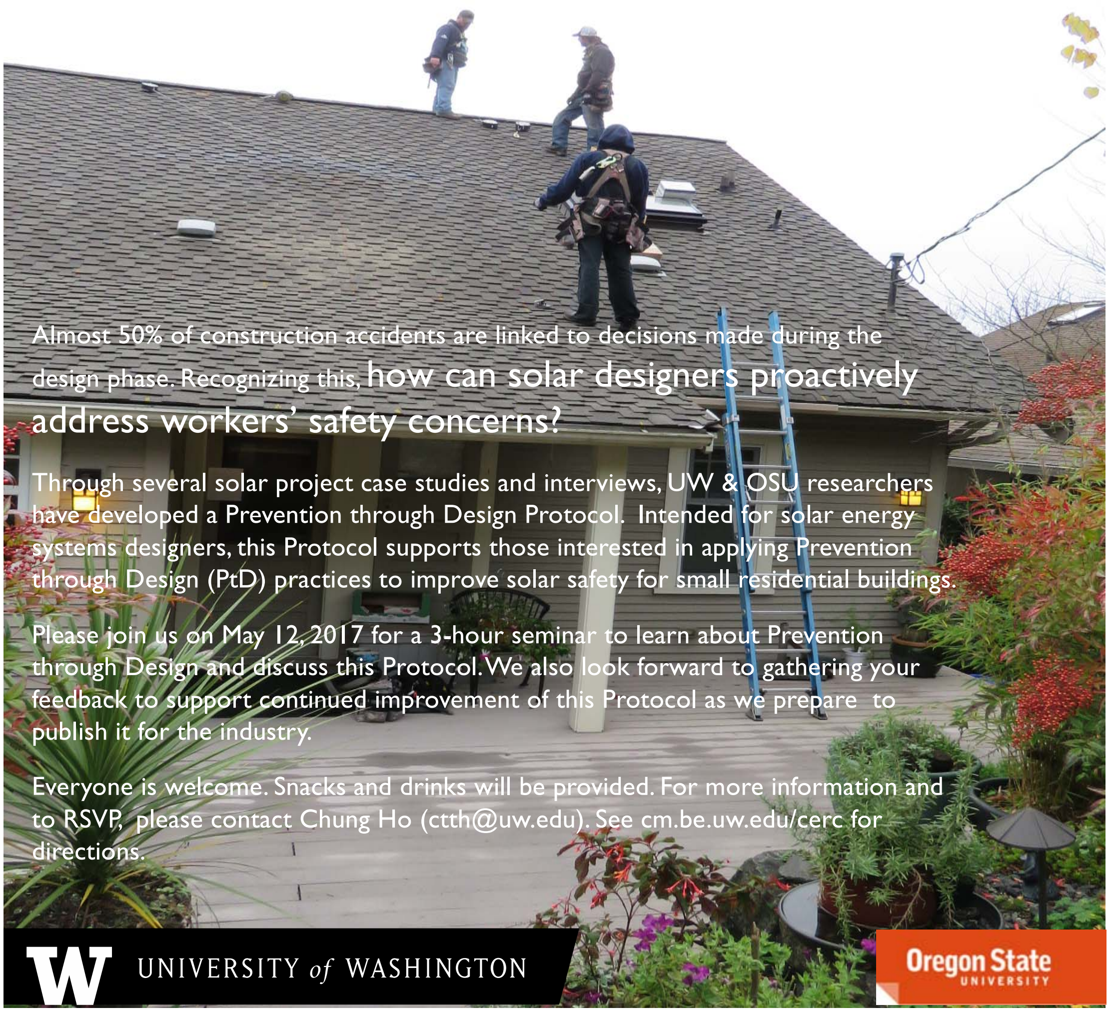
PREVENTION THROUGH DESIGN FOR SOLAR SAFETY

SOLAR PtD

FRIDAY, MAY 12, 2017 1:00pm-4:00pm

CERC/Sandpoint

PD Koon Room @ Building 5B, 7543 63rd Ave NE, Seattle, WA 98115



16. APPENDIX 5 – SURVEY QUESTIONAIRE FOR THE PROTOCOL

SURVEY QUESTIONAIRE
Prevention through Design (PtD) Protocol
to Improve Safety in Solar Designs and Installations

PART A: To what extent do you agree or disagree with the following statements?

1. It is practical to apply this protocol into the design and installation of solar systems for small residential buildings.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
☐	☐	☐	☐	☐

We will appreciate it if you can provide the reason for your response.

2. The information provided in this protocol is sufficient for me to implement prevention through design (PtD) on solar designs and installations.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
☐	☐	☐	☐	☐

We will appreciate it if you can provide the reason for your response.

3. The protocol is clear and easy to understand.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
☐	☐	☐	☐	☐

We will appreciate it if you can provide the reason for your response.

4. The information provided in the protocol is helpful for the solar industry in general.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
☐	☐	☐	☐	☐

We will appreciate it if you can provide the reason for your response.

5. Implementing the PtD protocol will help to improve worker safety during solar installations.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
☐	☐	☐	☐	☐

We will appreciate it if you can provide the reason for your response.

6. I will apply this protocol to my current practice.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
☐	☐	☐	☐	☐

We will appreciate it if you can provide the reason for your response.

7. Do you think the application of the protocol can impact the cost, schedule, or quality of your work? Please explain why or why not.

PART B: Please provide your comments about the content of the protocol, and any suggestions to improve it.

Section	Comment
Introduction	
PtD application procedure	
PtD Attributes	
1. Roofing material	
2. Roof slope	
3. Roof accessary	
4. Panel layout	
5. Fall protection system	
6. Lifting method	
7. Electrical system	

End of the survey. Thank you very much for your support!

17. APPENDIX 6 – RESULTS OF THE ONLINE SURVEY ABOUT THE PROTOCOL

PART A: To what extent do you agree or disagree with the following statements?

STATEMENT	Responder 1		Responder 2		Responder 3		Responder 4		Responder 5		Responder 6		Responder 7		Average Score
	Score	Comment	Score	Comment	Score	Comment	Score	Comment	Score	Comment	Score	Comment	Score	Comment	
1. It is practical to apply this protocol into the design and installation of solar systems for small residential buildings.	5	Essential to properly install a solar system.	4	Most of everything in the protocol is practical to apply to all solar installations.	4		3	Depends on how small the array is. There is a limit of how many hours we can add to the installation to accommodate "safety".	4		4	Basic ideas to keep systems safe	5	It is practical to implement.	4.1
2. The information provided in this protocol is sufficient for me to implement prevention through design (PtD) on solar designs and installations.	4	I think you need more discussion about actions required during the design to provide existing conditions, i.e. as-builts documents, comprehensive site visit. Suggest you include a checklist of considerations and documents as a basis of design and installation method statement.	4		4	Most of its already in practice	4	It is enough information to include the notes and instructions in the design drawings.	3		4		5		4.0
3. The protocol is clear and easy to understand.	4	I like the inclusion of applicable OHSA/WISHA rules.	5	The protocol was written very well and is easy to understand and follow.	4	Couple of area need clarification such as Set-back requirement need to be modified	4		5		4		5		4.4
4. The information provided in the protocol is helpful for the solar industry in general.	5	Having a protocol/checklists simplifies the whole process. Hopefully it will lead to greater safety and efficiency.	5	The information will be a benefit to people entering the industry with little or no experience.	4		4		3		5		5		4.4
5. Implementing the PtD protocol will help to improve worker safety during solar installations.	5	Provides consideration of safety during the design phase and will hopefully include the installation team input and lessons learned during the design phase.	4		4		4		5		4		5		4.4
6. I will apply this protocol to my current practice.	5	I will if the occasion arises?	4	We already use the majority of what is in the protocol on all jobs.	4		3		3		5		5		4.1

18. APPENDIX 7 – SOLAR PTD PROTOCOL

CPWR
Center for Construction Research and Training

SAFETY PROTOCOL

Prevention through Design for Safety in Solar Installations

Hyun Woo Lee
John Gambatese
Chung Ho

July 2017

UNIVERSITY *of* WASHINGTON

Oregon State UNIVERSITY

TABLE OF CONTENTS

A - INTRODUCTION

THIS PROTOCOL:

Provides	A guidance for application of Prevention through Design (PtD) into the design and installation of solar energy systems.
Applies	To existing residential buildings.
Addresses	Safety hazards and risk in the installation of solar energy systems.
Considers	Roof materials, roof slopes, roof accessories, roof layouts, fall protection systems, lifting methods, and electrical systems.

PREVENTION THROUGH DESIGN (PtD)

- Eliminates or reduces occupational safety and health hazards during the design process.
- Can be incorporated into the design of new processes, structures, equipment, tools, and work methods.

SAFETY FACTS

- Falls account for 35% of fatalities in construction (Wang et al. 2015).
- Almost 50% of construction fatalities and accidents are linked to design decisions (Behm 2005)

Prevention through Design (PtD) is "*the practice of **anticipating** and '**designing out**' potential occupational safety and health hazards and risks associated with **new processes, structures, equipment, or tools, and organizing work**, such that it takes into consideration the construction, maintenance, decommissioning, and disposal/recycling of waste material, and recognizing the business and social benefits of doing so*" (Schulte et al. 2008).

A - INTRODUCTION (cont.)

PtD APPLICATION PROCEDURE

Involved parties:	Project managers, designers, contractors, and safety personnel
Safety conditions:	Addressed in design documents (e.g. drawings, specs)
Safety enforcement:	Applied during installation processes

Basic steps

Step 1 Define the expected solar energy system.

Step 2 Review the design of the existing roof, evaluating how it impacts the solar panel layout and safety in solar installations (e.g. roof structures, roofing materials, roof accessories, roof layout).

Step 3 Review the solar energy system (e.g. panel layouts, roof access points, installation methods), including safety issues.

Step 4 Prepare initial design documents.

Step 5 Review the design and incorporate safety into the design and the design documents.

Step 6 Finalize the design documents.

Step 7 Safety personnel backcheck the design documents.

Step 8 Develop a safety implementation plan and enforce safety rules.

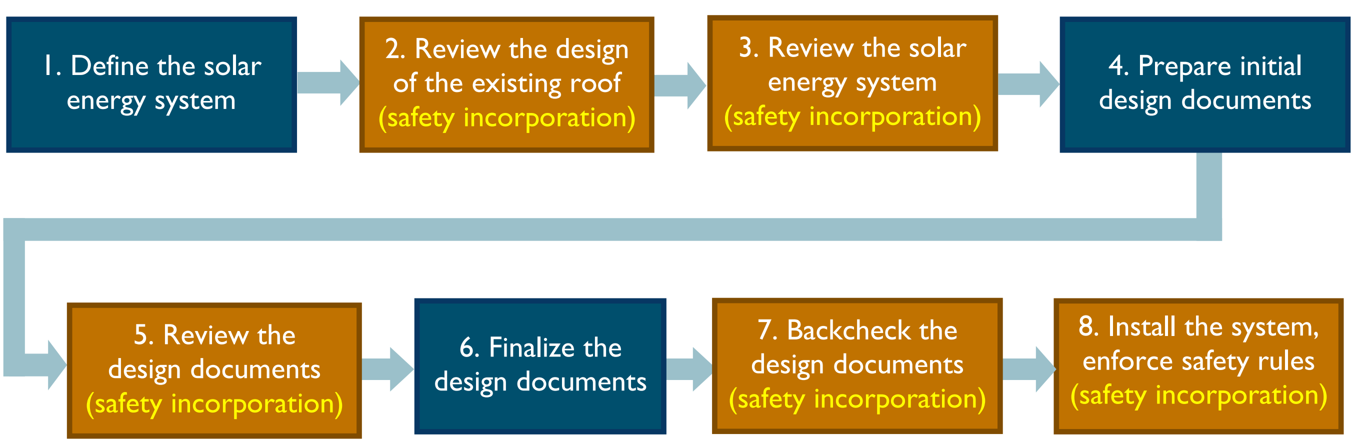


Fig. 1 PtD Implementation Procedure (adapted from Anderson & Galecka 2014)

B - PtD ATTRIBUTES

1. ROOFING MATERIAL

Roofing materials influence solar safety in different ways. While composite shingles present convenient installation conditions, metal roofs and cedar shakes pose high safety risks and hazards.

- Metal roofs, wood roofs, and roofs losing granular particles are slippery, especially when raining.
- Metal roofs increase the heat stress on hot days and glare under sunlight.
- Cedar shakes can crack or split when workers step on them.
- Concrete tiles are heavy, making it difficult to install connections for mounting systems.

Consider the following factors for roofing materials when designing solar panel layouts and installation methods.

Factors	Design suggestions
Roof Structures	Only install solar panels on structurally sound roofs that are unlikely to be damaged during the lifecycle of the solar energy systems. Structurally unsound roofs or damaged roofs should be upgraded before installing solar energy systems. If possible, include the layout of roof structures in the solar design documents.
Safety Anchors	Locate safety anchors along roof ridges whenever possible. *Composite shingle roofs:* Safety anchors should be located at any suitable areas in addition to roof ridges. *Metal roofs:* Safety anchors should be located only along metal roof ridge caps (if possible) to avoid roof leaks caused by connection holes.

B - PtD ATTRIBUTES

1. ROOFING MATERIAL (cont.)

Consider the following factors for roofing materials when designing solar panel layouts and installation methods.

Factors	Design suggestions
Installation Methods	*Wood roofs:* Include a recommendation in the design documents to use predrills to create pilot holes when connecting safety anchors and mounting systems with wood roof structures.
Personal Protective Equipment	*Wood roofs:* Include a recommendation in the design documents to use special working boots to avoid cracking wood tiles. *Roofs losing granular material:* Include a recommendation in the design documents to use special working boots with high slip resistance capacity. *Metal roofs:* Provide sunglasses and sufficient hydration for workers when working on sunny days.

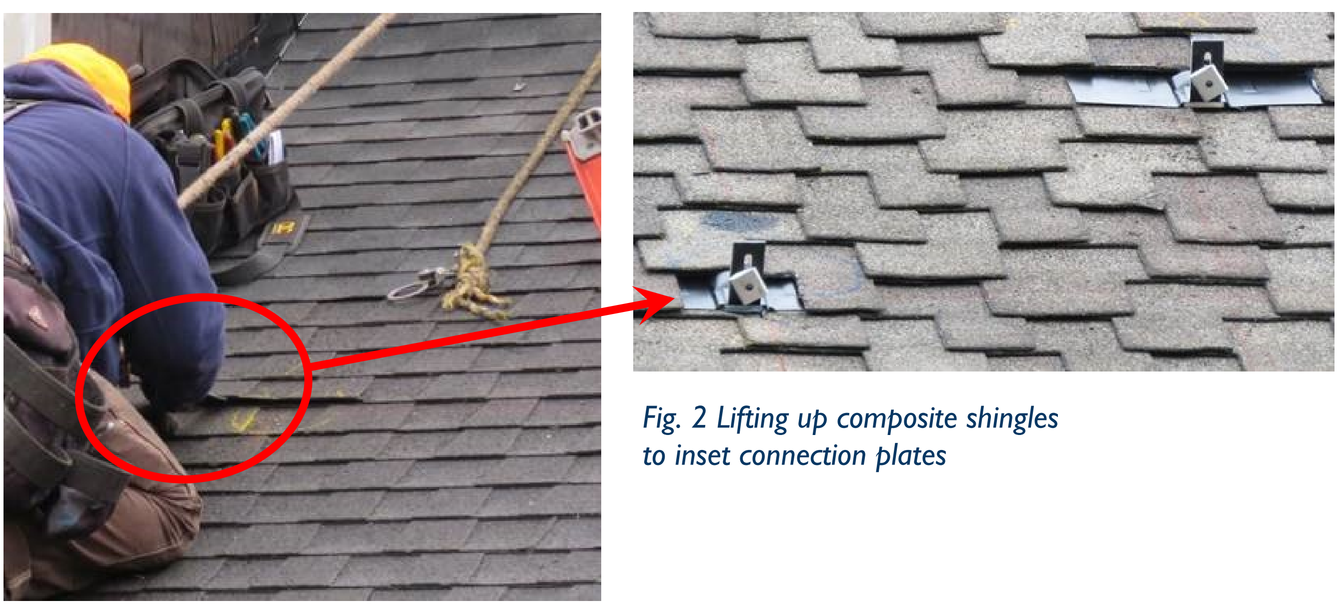


Fig. 2 Lifting up composite shingles to inset connection plates

B - PtD ATTRIBUTES

2. ROOF SLOPE

Roof slope has a significant impact on solar safety. The steeper the roof, the more dangerous it is to install solar systems.

- Steeper roofs are more slippery, especially in the rain.
- Flat roofs can be slippery with the development of ponding and mosses
- Standing on steep roofs increases stress and pain in workers' ankles.
- Tools or materials slide along and drop from steep roofs more frequently.

Fig. 3 Installing connection brackets on a sloped roof.

B - PtD ATTRIBUTES

2. ROOF SLOPE

Consider the following factors regarding roof slope when designing solar panel layouts and installation methods.

Factors	Design suggestions
Safety Systems	*Steep roofs (slope > 4:12)*: Use either a guardrail system with toeboards, safety net system, or personal fall arrest system. *Low-slope roofs (slope ≤ 4:12)*: Use either a guardrail system, safety net system, personal fall arrest system, or a combination of warning line system and safety monitoring system.
Safety Anchors	More than 1 safety anchor should be installed for each worker for high steep roofs.
Working Platforms	*Low-slope roof and moderately-steep roofs:* Use the roof surface as a working platform. *High-slope roofs:* Use mechanical lifts as a working platform.
Installation Sequences	*Steep roof:* Install bottom racks first to serve as a support point for installing other racks.

OSHA 1926.500(b)(2): *Steep roof* means a roof having a slope greater than 4 in 12 (vertical to horizontal).

B - PtD ATTRIBUTES

3. ROOF ACCESSORIES

Roof accessories may present both advantages and disadvantages for solar safety. Solar designers should be fully aware of existing roof accessories and their impacts to safety during solar installations.

- Unprotected skylight openings may cause falling hazards.
- Roof accessories may cause tripping hazards, but can also serve as a backing object to keep materials from sliding along roof slopes.
- Chimneys may obstruct the movement of workers, but can also serve as an anchor point if they are structurally able to support a worker in a fall.

Fig. 4 This chimney obstructs the movement of the workers and reduces resistance capacity of the safety line

Fig. 5 This skylight and exhaust vent prevent installation materials from sliding, while the small drain vents pose high tripping hazards for the worker

B - PtD ATTRIBUTES

3. ROOF ACCESSORIES (cont.)

Consider the following factors regarding roof accessories when designing solar energy systems.

Factors	Design suggestions
Safety anchors	Chimneys should not be used as a safety anchor unless they are structurally attached to the building's structure and can support a worker in a fall. Locate safety anchors on both sides of dormers and chimneys in case these accessories obstruct the movement of the workers.
Fall from openings	Equip the workers with personal fall arrest systems, or install covers or guardrail systems for the openings. If using covers, ensure that they can support twice the load that may be imposed on them.
Solar panel layouts	Do not place solar panels on the top of skylights or chimneys.

Fig. 6 This solar energy system is divided into two arrays to avoid the existing chimney

OSHA 1926.501(b)(4)(i): Each employee on walking/working surfaces shall be protected from falling through holes (**including skylights**) more than 6 feet (1.8 m) above lower levels, by personal fall arrest systems, covers, or guardrail systems erected around such holes.

When cover is used, OSHA requires that:
OSHA 1926.502(i): ... covers shall be capable of supporting, without failure, at least twice the weight of employees, equipment, and materials that may be imposed on the cover at any one time.

B - PtD ATTRIBUTES

4. PANEL LOCATION

Choices about solar panel locations influence solar installation safety. Solar panel locations determine worker access areas, and decisions that facilitate or impede the movement of the workers.

- Locating solar panels over the entire roof and to the roof ridge makes it difficult to install safety anchors and to unhook from safety anchors.
- Covering the entirety of a roof with solar panels also impedes the ability of workers to perform maintenance after installation.

To allow access for fire fighters in case of an emergency, the International Fire Code (IFC 2012) requires clear access pathways and the clearances between solar panel edges and roof ridges.

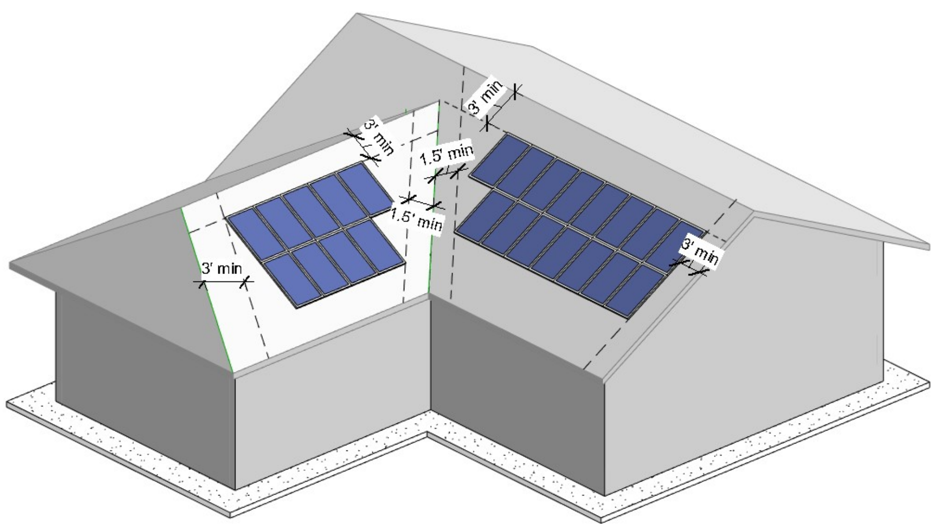


Fig. 7 Minimum clear access pathways and clearances between panels and roof ridges for residential building with roof hips and valleys

IFC 605.11.3.2.3 Residential buildings with roof hips and valleys. Panels/modules installed on residential buildings with roof hips and valleys shall be located no closer than 18 inches (457 mm) to a hip or valley where panels/modules are to be placed on both sides of a hip or valley. Where panels are to be located on only one side of a hip or valley that is of equal length, the panels shall be permitted to be placed directly adjacent to the hip or valley. (Exception: roof slopes ≤ 2:12).

IFC 605.11.3.2.4 Residential buildings with smoke ventilation. Panels/modules installed on residential buildings shall be located no higher than 3 feet (914 mm) below the ridge in order to allow for fire department smoke ventilation operations.

B - PtD ATTRIBUTES

4. PANEL LOCATION (cont.)

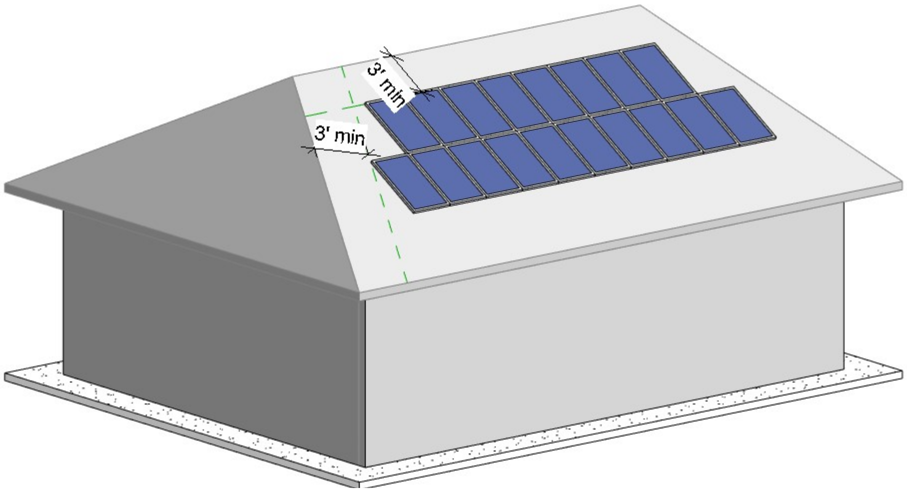


Fig. 8 Minimum clear access pathways and clearances between panels and roof ridges for a residential building with a hip roof

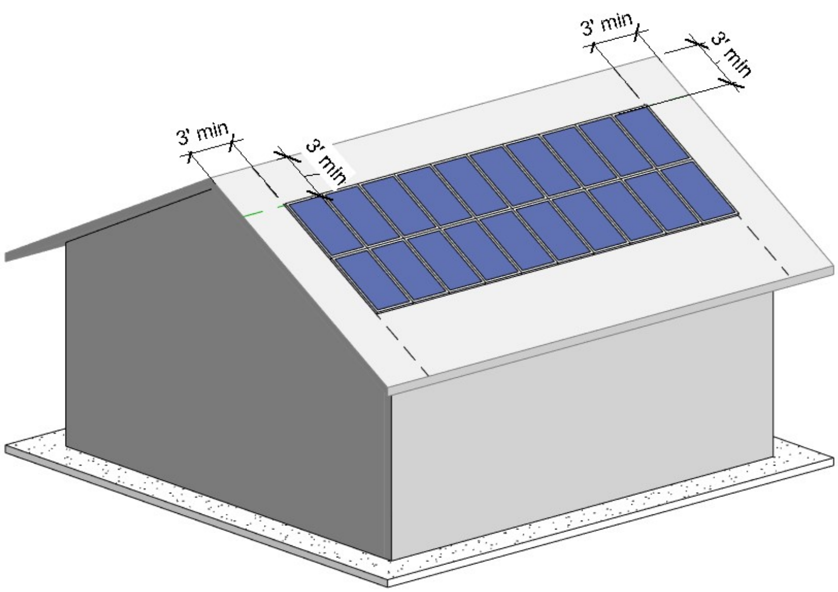


Fig. 9 Minimum clear access pathways and clearances between panels and roof ridges for a residential building with a single ridge

IFC 605.11.3.1 Roof access point. Roof access points shall be located in areas that do not require the placement of ground ladders over openings such as windows or doors, and located at strong points of building construction in locations where the access point does not conflict with overhead obstructions such as tree limbs, wires, or signs.

IFC 605.11.3.2.1 Residential buildings with hip roof layouts. Panels/modules installed on residential buildings with hip roof layouts shall be located in a manner that provides **a 3-foot-wide (914 mm) clear access pathway** from the eave to the ridge on each roof slope where the panels/modules are located. The access pathway shall be located at a structurally strong location on the building capable of supporting the live load of fire fighters accessing the roof. (Exception: roof slopes ≤ 2:12).

IFC 605.11.3.2.2 Residential buildings with a single ridge. Panels/modules installed on residential buildings with a single ridge shall be located in a manner that provides **two, 3-foot-wide (914 mm) access pathways** from the eave to the ridge on each roof slope where panels/modules are located (Exception: roof slopes ≤ 2:12).

B - PtD ATTRIBUTES

4. PANEL LOCATION (cont.)

Consider the following factors regarding solar panel locations when designing solar energy systems.

Factors	Design suggestions
Clear access pathways (for roof slopes > 2:12)	*Buildings with hip roofs:* Allow **a 3-feet-wide clear access pathway** from the eave to the ridge of each roof slope where panels are located. *Buildings with a single ridge:* Allow **two, 3-feet-wide clear access pathways** from the eave to the ridge of each roof slope where panels are located. *Buildings with hip roofs and valleys:* ♦ If panels are located on both sides of a hip or valley, locate the panels no closer than 18 inches from the hip or valley. ♦ If panels are located on only one side of a hip or valley that is of equal length, locate the panels directly adjacent to the hip or valley.
Clearances between panels and roof ridges	Do not place the panels higher than 3 feet below roof ridges, unless approved by the fire chief (for smoke ventilation).
Roof access points	Locate roof access points on the areas that do not require placing ground ladders over openings, such as windows and doors. Locate roof access points on areas that are structurally sufficient to support access.
Roof access areas	Allow sufficient areas for roof access and hoisting materials during installation.

IFC 605.11.3.1 Roof access point. Roof access points shall be located in areas that do not require the placement of ground ladders over openings such as windows or doors, and located at strong points of building construction in locations where the access point does not conflict with overhead obstructions such as tree limbs, wires, or signs.

B - PtD ATTRIBUTES

5. FALL PROTECTION SYSTEM

Multiple options can be used for fall protection, such as guardrail systems, safety net systems, and personal fall arrest systems. Panel layout design should facilitate the use of proper fall protection methods.

Figures 9 and 10 show examples of safety anchors that can be used for personal fall arrest systems. The maximum number of personal fall arrest systems attached to each safety anchor must be within the limit stated by the manufacturer.

Fig. 10 This project installed Hitchclips along the roof ridge to serve as safety anchors.

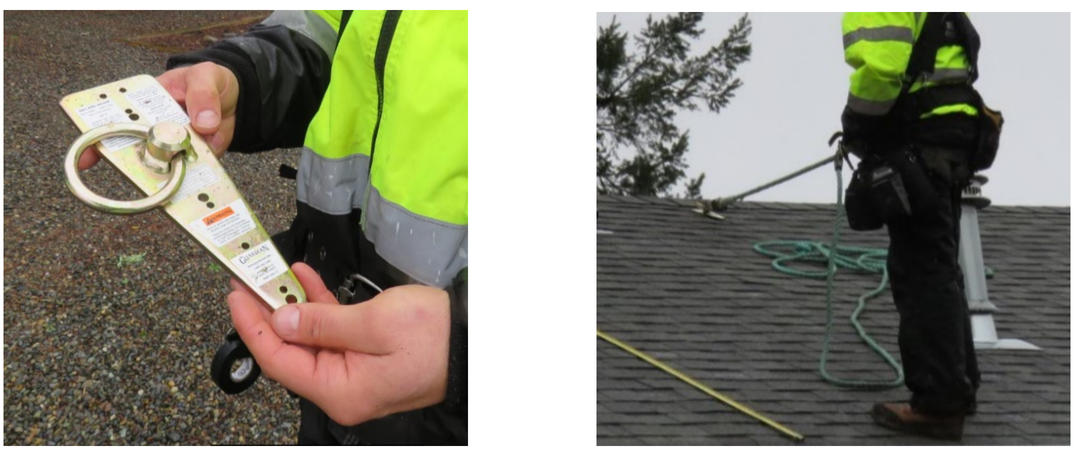


Fig. 11 This project installed Guardian bull ring anchors along the roof ridge.

OSHA 1926.501(b)(10): … each employee engaged in roofing activities on low-slope roofs, with unprotected sides and edges 6 feet (1.8 m) or more above lower levels shall be protected from falling by guardrail systems, safety net systems, personal fall arrest systems, or a combination of warning line system and guardrail system, warning line system and safety net system, or warning line system and personal fall arrest system, or warning line system and safety monitoring system. Or, on roofs 50-feet (15.25 m) or less in width (see Appendix A to subpart M of this part), the use of a safety monitoring system alone [i.e. without the warning line system] is permitted.

OSHA 1926.501(b)(11): … Each employee on a steep roof with unprotected sides and edges 6 feet (1.8 m) or more above lower levels shall be protected from falling by guardrail systems with toeboards, safety net systems, or personal fall arrest systems.

B - PtD ATTRIBUTES

5. FALL PROTECTION SYSTEM (cont.)

Consider the following factors regarding fall protection systems when designing solar energy systems

Factors	Design suggestions
Safety anchors	Safety anchors are normally located along roof ridges. Solar panels should not extend to roof ridges in order to comply with the International Fire Code (see Panel Layout Section) and allow for the installation of safety anchors. The maximum distance between two safety anchors should allow for the movement of workers within lanyard lengths. Install safety anchors on both sides of any obstruction on the roof, such as dormers, chimneys, and skylights. The obstruction can hinder the movement of workers who are wearing a fall arrest system.
Guardrail systems	For fall protection systems on a steep roof, guardrail systems must include toeboards.
Safety monitoring systems	Use a combination of safety monitoring systems and warning line systems for fall protection on low-sloped roofs. These can be in addition to using guardrail systems, safety net systems, and personal fall arrest systems. Low-sloped roofs having ≤ 50-foot width are permitted to use only a safety monitoring system for a fall protection system.

B - PtD ATTRIBUTES

6. LIFTING METHODS

Roof heights and panel sizes influence lifting methods. Consider the size and design of panel layouts when choosing a lifting method.

- The standard solar panel size for residential projects is 65”x39”. The standard panel weight is about 40 lbs, within OSHA’s manual lifting limit.
- OSHA regulations do not allow workers to carry solar panels while climbing on a ladder.
- OSHA regulations require workers to use at least one hand to grasp the ladder when progressing up and down the ladder
- Local codes may have stricter requirements. For example, Washington Administrative Codes requires that both hands must be free to hold on to the ladder while climbing or descending.

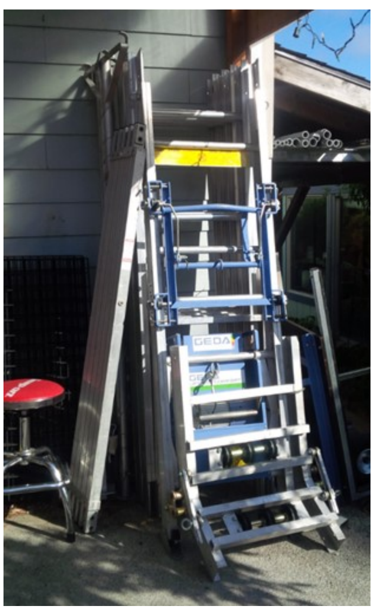


Fig. 12 Ladder hoists are recommended for panel lifting

Fig. 13 Ladder stabilization device

Fig. 14 Ladder with a ladder safety device

OSHA - Green Job: Solar panels should be lifted safely to the rooftops. Workers should never be allowed to climb ladders while carrying solar panels. Lifting equipment, such as ladder hoists, swing hoists, or truck-mounted cranes/conveyors, should be used wherever possible.

WAC - 296-876-40025 Climbing and Descending: (1) You must have both hands free to hold on to the ladder.

B - PtD ATTRIBUTES

6. LIFTING METHODS (cont.)

Consider the following factors for lifting solar panels when designing solar panel layouts and installation methods.

Factors	Design suggestions
Panel sizes	Design documents should include information about panel weights in relation to OSHA's manual lifting limit. Standard solar panels for residential projects should be selected whenever possible.
Panel layouts	Panel layouts should be designed to locate ladder access points at structurally strong areas and avoid the need to place ladders over openings, such as windows or doors.
Lifting methods	Use lifting equipment to lift solar panels to rooftops whenever possible. Do not climb the ladder while carrying solar panels.

Fig. 15 Use of a ladder extension can make it safer to step off a ladder onto the elevated surface (Source of the picture: Amazon.com)

OSHA 1926.1052(b)(21): Each employee shall use at least one hand to grasp the ladder when progressing up and/or down the ladder

OSHA 1926.1052(b)(22): An employee shall not carry any object or load that could cause the employee to lose balance and fall.

B - PtD ATTRIBUTES

7. ELECTRICAL SYSTEM

Electrical systems can create several safety hazards for workers. First and foremost, the power generated from solar energy systems can cause shock hazards for workers. In addition, electrical wires or conduits can create tripping hazards during installation.

Consider the following factors for electrical systems during the design phase:

Factors	Design suggestions
For safety during installation	Locate conduits, wiring systems, and raceways as close as possible to the ridge, hip, or valley, and from the hip or valley as directly as possible to the outside wall. Cautions is needed to ensure minimum clearance distances with existing overhead electrical lines
For safety during operation	Design the system to include rapid shutdown devices as required by the National Fire Code

IFC 605.11.1.2: Conduit, wiring systems, raceways for photovoltaic circuits shall be located as close as possible to the ridge or hip or valley, and from the hip or valley as directly as possible to outside wall to reduce trip hazard and maximize ventilation opportunity.

Fig. 16 Rapid shutdown device for a residential project

National Electrical Code 2017 NEC 690.12 : Rapid Shutdown of PV Systems on Buildings. PV system circuits installed on or in buildings shall include a rapid shutdown function to reduce shock hazard for emergency responders in accordance with 690.12(A) through (D).

C - REFERENCES

- Anderson, Marjory, and Craig Galecka. 2014. "Getting Started with Prevention through Design." *Professional Safety* 59(3): 63--65.
- Behm, Michael. 2005. "Linking Construction Fatalities to the Design for Construction Safety Concept". *Safety Science* 43(8): 589--611.
- ICC (International Code Council). 2012. *International Fire Code (IFC)*. Country Club Hills, Illinois: International Code Council, Inc. .
- NFPA (National Fire Protection Association). 2016. *NFPA 70: National Electrical Code (NEC)*. Quincy, Massachusetts: National Fire Protection Association.
- OSHA (Occupational Safety & Health Administration). 2017. "Green Job Hazards: Solar Energy – Falls." *Occupational Safety & Health Administration.* https://www.osha.gov/dep/greenjobs/solar_falls.html
- OSHA (Occupational Safety & Health Administration). 2017. "Safety and Health Regulations for Construction." Construction, *Standards 29-CFR Code of Regulations, Part 1926.* https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10593
- Schulte Paul, Richard Rinehart, Andrea Okun, Charles Geraci, and Donna Heidel. 2008. "National Prevention through Design (PtD) Initiative." *Journal of Safety Research* 39(2):115–121. www.cdc.gov/niosh/topics/ptd/pdfs/Schulte.pdf
- WAC (Washington Administrative Codes). 2016. "Ladders, Portable and Fixed. " Safety and Health Core Rules, *296-876 WAC.* http://apps.leg.wa.gov/wac/default.aspx?cite=296-876
- Wang, Xuanwen, Julie A. Largay, and Xiuwen Sue Dong. 2015. "Fatal and Nonfatal Injuries Among Construction Trades between 2003 and 2014." *CPWR Quarterly Data Report*. Silver Spring, MD: CPWR – The Center for Construction Research and Training. http://www.cpwr.com/sites/default/files/publications/Third%20Quarter%20QDR%20final_2.pdf