Recommended Model Permitting Processes and Structural Review Guidance for Rooftop Solar PV in Massachusetts

Prepared for:
Massachusetts Department of Energy Resources

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1. Executive Summary

As the Commonwealth of Massachusetts works towards achieving the renewable energy goals set out by the administration, increasing attention is being paid to the role that the permitting process plays in the overall costs of rooftop solar energy systems. As an awardee of the U.S. Department of Energy's SunShot Initiative Rooftop Solar Challenge, the Commonwealth of Massachusetts has the opportunity to position itself as a leader in the rapidly growing solar market.

The U.S. Department of Energy SunShot Initiative Rooftop Solar Challenge incentivizes 22 regional awardees to make it easier for Americans to go solar. By streamlining permit processes, updating planning and zoning codes, improving standards for connecting solar power to the electric grid, and increasing access to financing, teams will clear a path for rapid expansion of solar energy and serve as models for other communities across the nation. The Rooftop Solar Challenge is part of the SunShot Initiative, which strives to make solar energy cost-competitive with other forms of energy by the end of the decade.

One of DOER's tasks as part of the Rooftop Solar Challenge grant focuses on streamlining the solar permitting process in Massachusetts; specifically the permitting process for rooftop systems based on two size categories; residential rooftop systems sized 10 kW or less and any rooftop system sized 300 kW or less.

Permitting can increase the installed cost of solar and deter firms and individuals from pursuing solar projects. In fact, a recent study found that about 1 in 3 installers avoid selling solar in an average of 3.5 areas because of associated permitting difficulties[1]. Finding ways to decrease the cost of permitting will allow for more deployment of solar in Massachusetts.

This report includes an assessment of current solar permitting practices throughout the Commonwealth and presents a recommended model permitting process for potential adoption by municipalities in the Commonwealth.

This report also includes structural review guidance. There is a section on the team's early approach to developing the structural review guidance and how we arrived at the concept of a prescriptive process. This is followed by an assessment of the Massachusetts housing stock, particularly as it relates to the prescriptive process. Finally the report refers to the prescriptive process that will be posted on the Department of Public Safety's FAQ (Frequently Asked Questions) website that instructs building inspectors and other knowledgeable parties on the use of the process.

Massachusetts has a long tradition of honoring and respecting the institutions of local government. The model permitting processes and structural review guidance described in this report are not intended to

[1] Clean Power Finance. "Nationwide Analysis of Solar Permitting and the Implications for Soft Costs." December 2012.

erode that tradition, but rather to demonstrate ways in which local governments can enhance the services they provide to their residents while advancing statewide economic development objectives and improving the governance of land use in their communities.

In Massachusetts, 351 municipalities currently regulate development through numerous boards and departments with permit granting authority. Permitting processes differ markedly from one municipality to another. This report strives to assist municipal officials and permit applicants through the solar permit process by offering ways in which applications may be analyzed and considered more efficiently and effectively. By standardizing the solar permitting process, permit applicants will spend less time and money on permitting.

2. Model Permitting Process – Summary of Interview Program

2.1 Approach to Interview Program

Twenty-five municipalities were interviewed to assess how permitting for solar photovoltaics (PV) is currently handled in Massachusetts. A variety of criteria were considered in selecting the 25 municipalities including region, population, whether the town was a participant in the Solarize Mass program, whether the town is a Green Community, and the amount of solar deployed to date. A diverse group of municipalities was selected by DOER with input from and review by Navigant and Borrego. Navigant and Borrego developed the questionnaire, which was adapted from DOE's SunShot Initiative Rooftop Solar Challenge Market Assessment. The questionnaire was reviewed and approved by DOER.

The questionnaire and a list of the municipalities surveyed are contained in Appendix A. In addition to interviewing the municipalities (normally the municipal building inspector), we also reviewed the town websites to examine how information about obtaining building and electrical permits is presented, and whether the information provided is specific to solar PV.

A summary of the results of the interviews and website reviews are below.

2.2 Accessible Solar Permitting Information

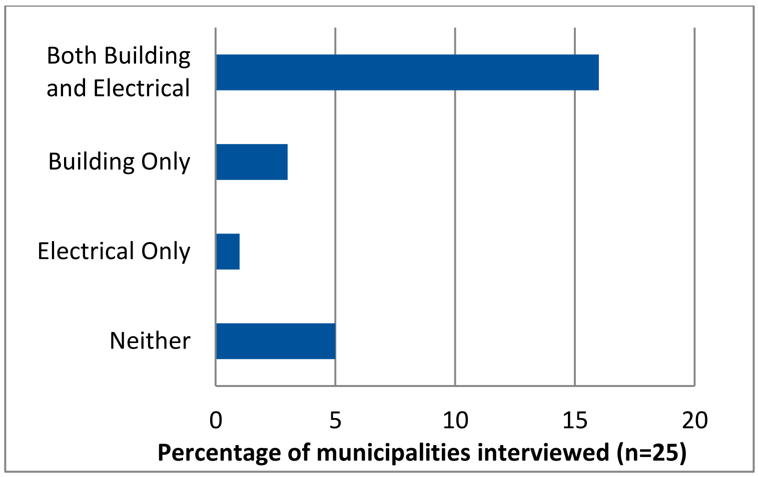
2.2.1 General Permitting Process Information

All 25 municipalities interviewed have websites for the building inspection and electrical inspection departments with contact information for the offices. Some include helpful information, such as the hours that the office is open and when the inspectors are available by phone. Sixteen of the 25 municipalities include online applications for both the building and electric permits, while three municipalities only have an application available online for the building permit and one municipality only has an application available online for the electrical permit. Twenty-two of the 25 municipalities have information available online about both the building and electrical permit fees, while one municipality only has building permit fee information online and one municipality only has electrical permit fee information online. Most often though, the information is general and does not specify by project type or size. Only two of the municipalities have information on their website about the inspection requirements. Generally, there is not any information on the municipal websites specific to solar PV permitting.

2.2.2 Obtaining and Submitting an Application

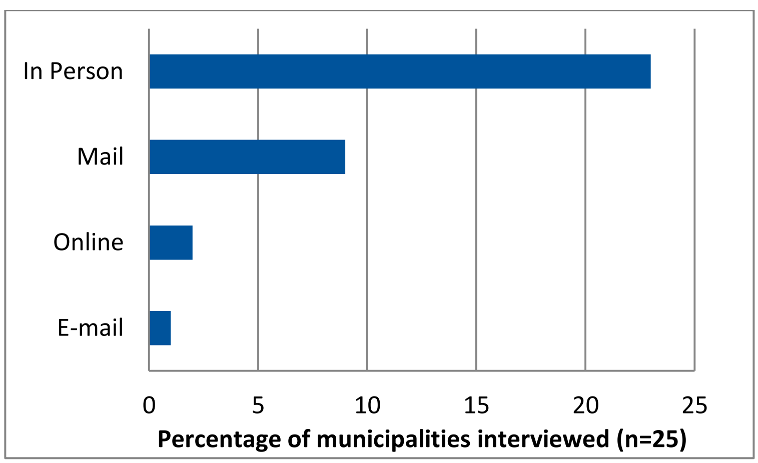
Most municipalities (16 of the 25 interviewed) make the building and electrical permit applications available for download online, as seen in Figure 1. The five municipalities that do not make any permit applications available online require that the application be picked up in person. As seen in Figure 2, the most common mode for permit application submittal is in person. Fifteen of the 25 municipalities require that both building and electrical permit applications be submitted in person, while seven municipalities give the option of submittal by mail or in person. Only three of the municipalities allow permit applications to be submitted online. Municipalities generally want people to submit permit applications in person so that they have the opportunity to check if the application includes all the necessary information before accepting it.

Figure 1. Permit Applications Available Online



Note: Some municipalities offered multiple options for obtaining an application.

Figure 2. Options for Submitting Building and Electrical Permit Applications



Note: Some municipalities offered multiple submission options.

2.2.3 Building and Electrical Permit Fees

Both building and electrical permit fees vary widely from municipality to municipality. For both building and electrical permits, fee structures can include either a flat fee, a valuation fee to account for the size of the project, or a combination of the two. A minimum fee is also used in some cases. Figure 3 shows how the permit fees vary across municipalities and system sizes. Fees were compared across three different system sizes as follows: a 3 kW residential system valued at about $15,000, a 10 kW commercial system valued at about $50,000 and a 100 kW commercial system valued at about $400,000. The average total permit fees for these systems across the 25 municipalities were $208, $749 and $4,139, respectively. However, for all three system sizes, the variation in fee was significant. For residential systems, the highest fee charged among the 25 municipalities was more than double the lowest fee charged. And for commercial systems, the highest fee was more than 10 times the lowest fee charged.

All 25 municipalities require both a building permit and an electrical permit – Figure 4 includes a breakdown of the fees for each type of permit. The building permit fee is generally larger than the electrical permit fee. On an overall basis, the building permit fee makes up 68% of the total permit fees for a 3 kW residential system, 66% for a 10 kW commercial system, and 84% for a 100 kW commercial system.

Generally speaking, expedited permit processing for an additional fee was not offered by the municipalities. Only two municipalities out of 25 offered expedited permit processing for building permits.

Permit fee information for PV projects is generally available online. However, the information is usually lumped into sections on general retrofits or roof alterations and is not specifically called out.

Figure 3. Building and Electrical Permit Fees for Different Sized PV Projects[2]

Total Permit Fees					
	System Type and Value				
	Residential		Commercial		
Municipality	$15,000 3 kW	Permit Fee Type	$50,000 10 kW	$400,000 100 kW	Permit Fee Type
Belchertown	$130	Flat	$255	$1,305	Flat + $/k of cost
Boston	$162	Flat + $/k of cost	$500	$3,775	Flat + $/k of cost
Cambridge	$325	Flat + $/k of cost	$850	$6,100	Flat + $/k of cost
Falmouth	$155	Flat + $/k of cost	$500	$3,300	Flat + $/k of cost
Gloucester	$245	Flat + $/k of cost	$750	$5,650	Flat + $/k of cost
Greenfield	$290	Flat + $/k of cost	$670	$4,345	Flat + $/k of cost
Harvard	$161	Flat	$700	$5,600	$/k of cost
Hatfield	$225	Flat	$2,250	$2,250	Flat
Hingham	$185	Flat + $/k of cost	$800	$6,050	Flat + $/k of cost
Hudson	$155	$/k of cost	$930	$4,080	$/k of cost
Lowell	$200	Flat + $/k of cost	$400	$400	Flat + $/k of cost
Middleborough	$300	Flat + $/k of cost	$618	$4,555	$/k of cost
Natick	$275	Flat + $/k of cost	$1,300	$1,328	Flat + $/k of cost
New Bedford	$175	Flat	$425	$425	Flat
Northampton	$145	Flat + $/k of cost	$380	$2,480	Flat + $/k of cost
Pittsfield	$135	Flat + $/k of cost	$400	$2,500	Flat + $/k of cost
Quincy	$238	Flat + $/k of cost	$683	$4,883	Flat + $/k of cost
Rutland	$160	Flat + $/k of cost	$785	$6,035	Flat + $/k of cost
Scituate	$190	Flat + $/k of cost	$650	$4,150	Flat + $/k of cost
Sutton	$240	Flat + $/k of cost	$450	$2,550	Flat + $/k of cost
Tisbury	$190	Flat + $/k of cost	$600	$4,100	Flat + $/k of cost
Waltham	$230	Flat + $/k of cost	$1,150	$8,850	Flat + $/k of cost
Wellesley	$200	Flat + $/k of cost	$1,350	$10,100	Flat + $/k of cost
Williamsburg	$155	Flat + $/k of cost	$375	$2,475	Flat + $/k of cost
Winchester	$325	Flat + $/k of cost	$950	$6,200	Flat + $/k of cost
Average	**$208**	-	**$749**	**$4,139**	-

Range

Min	**$130**	-	**$255**	**$400**	-
Max	**$325**	-	**$2,250**	**$10,100**	-

[2] These fees are calculated as per the municipalities' permit fee schedules. Installers will often negotiate lower fees (e.g., excluding the module costs from the project value), especially for large commercial projects. In addition, they will negotiate lower fees when doing large volumes of PV in one municipality (number of projects and megawatts).

Figure 4. Building and Electrical Permit Fees[2]

Building and Electrical Permit Fees									
	Residential			Commercial					
	$15,000, 3kW			$50,000, 10kW			$400,000, 100kW		
Municipality	Building Permit Fees	Electrical Permit Fees	Total	Building Permit Fees	Electrical Permit Fees	Total	Building Permit Fees	Electrical Permit Fees	Total
Belchertown	$100	$30	$130	$225	$30	$255	$1,275	$30	$1,305
Boston	$162	Included in building fee	$162	$500	Included in building fee	$500	$3,775	Included in building fee	$3,775
Cambridge	$225	$100	$325	$750	$100	$850	$6,000	$100	$6,100
Falmouth	$120	$35	$155	$400	$100	$500	$3,200	$100	$3,300
Gloucester	$200	$45	$245	$550	$200	$750	$4,050	$1,600	$5,650
Greenfield	$190	$100	$290	$575	$95	$670	$4,075	$270	$4,345
Harvard	$125	$36	$161	$600	$100	$700	$4,800	$800	$5,600
Hatfield	$100	$125	$225	$250	$2,000	$2,250	$250	$2,000	$2,250
Hingham	$150	$35	$185	$750	$50	$800	$6,000	$50	$6,050
Hudson	$105	$50	$155	$350	$580	$930	$2,800	$1,280	$4,080
Lowell	None	$200	$200	None	$400	$400	None	$400	$400
Middleborough	$150	$150	$300	$500	$118	$618	$4,000	$555	$4,555
Natick	$225	$50	$275	$750	$550	$1,300	$545	$783	$1,328
New Bedford	$50	$125	$175	$300	$125	$425	$300	$125	$425
Northampton	$90	$55	$145	$300	$80	$380	$2,400	$80	$2,480
Pittsfield	$90	$45	$135	$300	$100	$400	$2,400	$100	$2,500
Quincy	$188	$50	$238	$608	$75	$683	$4,808	$75	$4,883
Rutland	$110	$50	$160	$285	$500	$785	$2,035	$4,000	$6,035
Scituate	$150	$40	$190	$500	$150	$650	$4,000	$150	$4,150
Sutton	$190	$50	$240	$400	$50	$450	$2,500	$50	$2,550
Tisbury	$140	$50	$190	$550	$50	$600	$4,050	$50	$4,100
Waltham	$180	$50	$230	$1,100	$50	$1,150	$8,800	$50	$8,850
Wellesley	$150	$50	$200	$750	$600	$1,350	$6,000	$4,100	$10,100
Williamsburg	$90	$65	$155	$300	$75	$375	$2,400	$75	$2,475
Winchester	$225	$100	$325	$750	$200	$950	$6,000	$200	$6,200
Average	**$140**	**$67**	**$208**	**$494**	**$255**	**$749**	**$3,459**	**$681**	**$4,139**

Range

Min	**$50**	**$30**	**$130**	**$225**	**$30**	**$255**	**$250**	**$30**	**$400**
Max	**$225**	**$200**	**$325**	**$1,100**	**$2,000**	**$2,250**	**$8,800**	**$4,100**	**$10,100**

Figure 5 shows current permit fees from major solar cities across the US. The average permit fee for a residential 3 kW solar PV system is $100 higher for the major solar cities than the average for the 25 municipalities in Massachusetts. While the average permit fee for a commercial 10 kW system is about the same ($749 for Massachusetts vs. $687 for major solar cities), the average permit fee for a larger 100 kW commercial project is $1,212 higher for the Massachusetts municipalities.

Figure 5. Total Permit Fees from Major Solar Cities Across the US

Total Permit Fees					
	System Type and Value				
	Residential		Commercial		
Municipality	$15,000 3 kW	Permit Fee Type	$50,000 10 kW	$400,000 100 kW	Permit Fee Type
San Diego, CA	$445	Flat	$819	$819	Flat
Los Angeles, CA	$404	Flat	$737	$6,644	Flat
San Jose, CA	$206	Flat	$412	$412	Flat
Bakersfield, CA	$127	Flat + $/k of cost	$407	$2,892	Flat + $/k of cost
Fresno, CA	$320	Flat	$762	$2,637	Flat + $/k of cost
San Francisco, CA	$180	Flat	$180	$1,080	Flat
Sacramento, CA	$280	Flat	$1,330	$2,450	Flat
Portland, OR	$256	Flat + $/k of cost	$527	$2,154	Flat + $/k of cost
Phoenix, AZ	$375	Flat	$551	$3,001	Flat + $/k of cost
Newark, NJ	$490	Flat + $/k of cost	$1,148	$7,178	Flat + $/k of cost
Average	**$308**	-	**$687**	**$2,927**	-

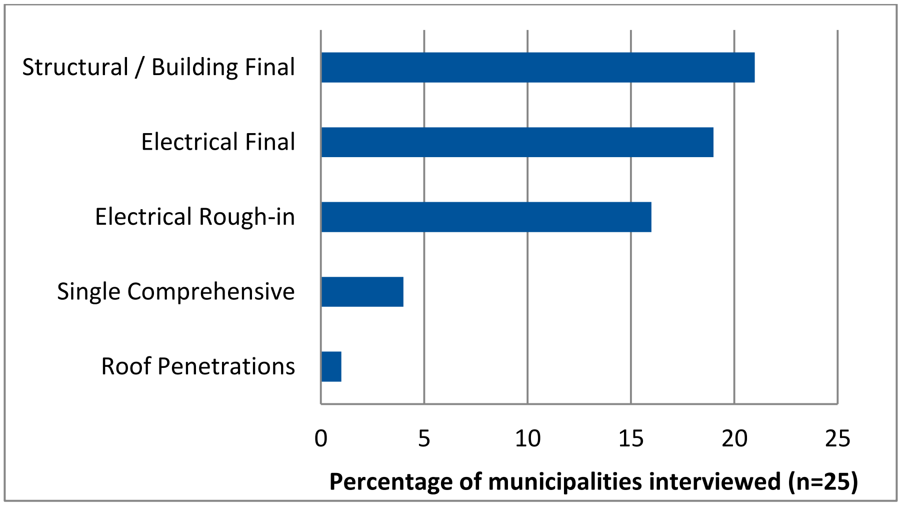
Range

Min	**$127**	-	**$180**	**$412**	-
Max	**$490**	-	**$1,330**	**$7,178**	-

2.2.4 Inspection Requirements

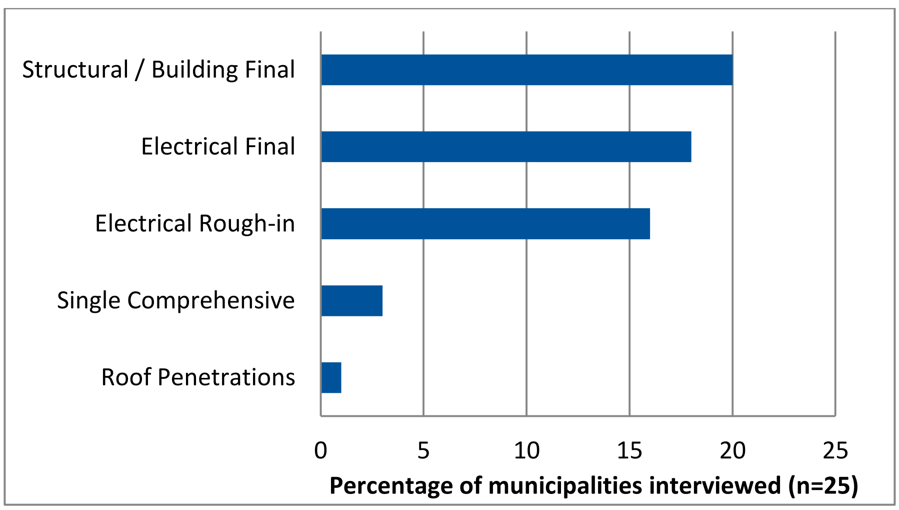
The Navigant team found that inspection requirements for PV permitting are not typically available online. Our team obtained information on the inspections required by calling the building inspection office or the electrical inspection office, or both. The majority of municipalities (13 of the 25 interviewed) require three inspections for both residential and commercial PV permitting: electrical rough, electrical final, and a structural final. Almost all municipalities (21 of the 25 interviewed) require at least one structural/building inspection and at least one electrical inspection for both residential and commercial installations. As seen in Figure 6 and Figure 7, few municipalities offer a single comprehensive inspection – four municipalities for residential installations and three municipalities for commercial installations. It is rare for municipalities to require a roof inspection in addition to electrical and/or structural inspections for commercial installations – only one municipality for residential installations and two municipalities for commercial installations.

Figure 6. Inspections Required for Residential Installations



Note: Most municipalities require multiple inspections.

Figure 7. Inspections Required for Commercial Installations



Note: Most municipalities require multiple inspections.

Nationally, the inspection requirements also vary by jurisdiction. Nearly all jurisdictions require at least one inspection by the electric utility (84%) and at least one inspection by the city (81%).[1] While the utility and city planning office are the two most common authorities involved, other authorities may also be involved, such as the county planning office (35% of the time), the city fire department (13%), and the county fire department (10%).[1]

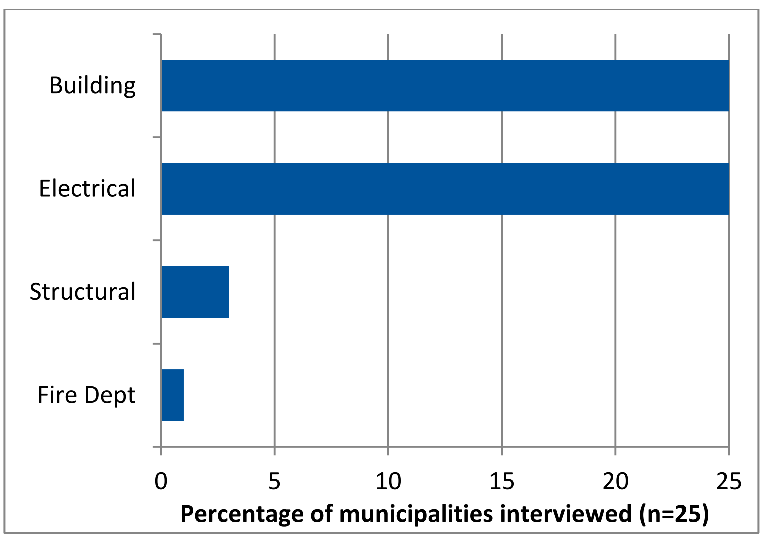
It is important to note that the number of inspections matters to the permit applicant because there is a fee associated with each inspection; therefore the more inspections, the higher the cost to the permit applicant. Thus, having one single inspection is most desirable from the standpoint of the permit applicant.

2.3 *Application Contents and Review Process*

2.3.1 Departmental and Professional Engineer Approvals

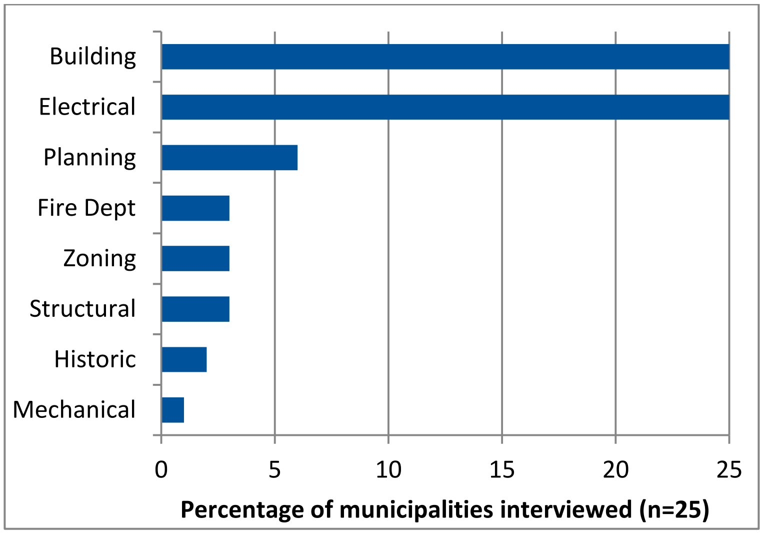
All 25 Massachusetts municipalities interviewed require building inspection and electrical inspection department approval for PV permitting, as shown in Figure 8 and Figure 9. Six municipalities require additional approvals for residential installations from other departments, including structural and fire. Thirteen municipalities require additional approvals for commercial installations from other departments, such as planning, fire, zoning, and structural. The vast majority of municipalities (24 of the 25 interviewed) require two separate applications to be submitted – one for the building permit and one for the electrical permit. Notably, one municipality, Harvard, has a single solar permitting application for both the building electrical permits. The single application form does include the standard Massachusetts electrical permit application form, but it is combined into one document with the building permit application information. None of the municipalities require separate copies for departments besides building inspection and electrical.

Figure 8. Departmental Approvals Required for Residential Installations



Note: Most municipalities require multiple departmental approvals.

Figure 9. Departmental Approvals Required for Commercial Installations



Note: Most municipalities require multiple departmental approvals.

Nationally, the two main reviews are: a building/structural design review (required by 77% of jurisdictions) and an electrical review (required by 67% of jurisdictions).[1] In addition, a fire code review is required by 36% of jurisdictions.[1]

For residential installations in Massachusetts, most commonly there are either no professional engineer approvals required (11 of the 25 municipalities interviewed) or only a structural engineer approval required (10 municipalities), as seen in Figure 10. For commercial installations, most commonly there is a structural engineer approval required (11 municipalities) or no professional engineer approvals required (nine municipalities), as seen in Figure 11. Only four municipalities require an electrical engineer's approval for residential installations, and only five municipalities require the same for commercial installations.

Figure 10. Professional Engineer Approvals Required for Residential Installations

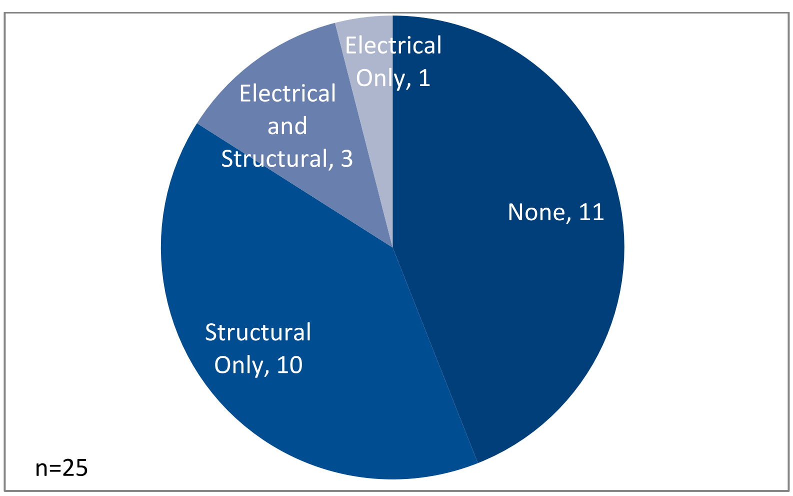
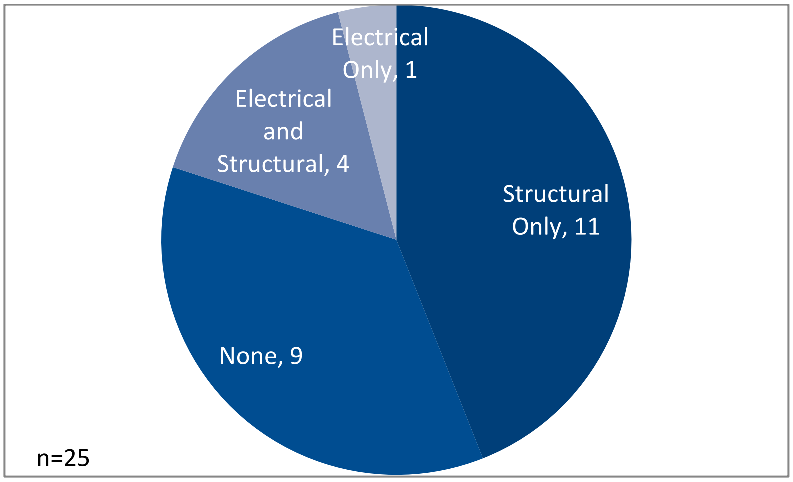


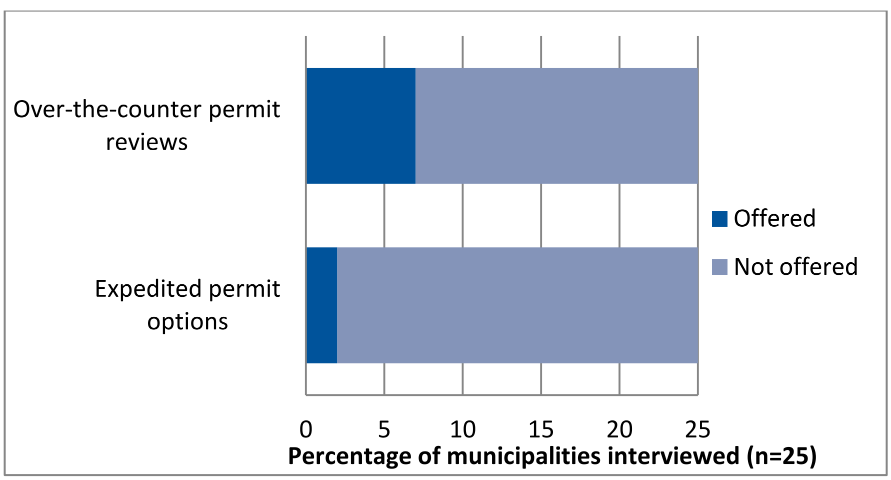
Figure 11. Professional Engineer Approvals Required for Commercial Installations



2.3.2 Application Review Timeline and Options

Municipalities have a maximum of 30 calendar days in which to issue or deny a building permit. Work can begin as long as the electrical permit application is submitted within five days. Generally, a building permit for PV is issued much quicker than 30 days. The average time needed for permit review is eight business days. Municipalities do not usually offer over-the-counter or expedited permit reviews, as seen in Figure 12. Only seven of the 25 municipalities offer over-the-counter building permit reviews and only two offer expedited permit options.

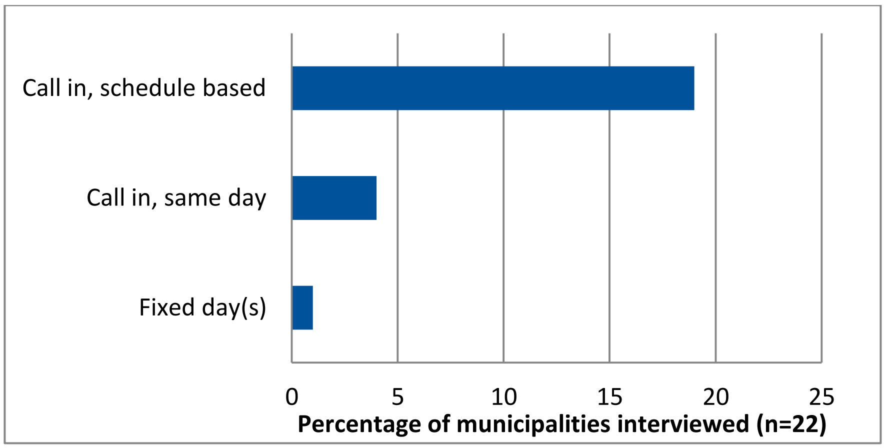
Figure 12. Over-the-Counter and Expedited Building Permit Options



The work can start on a PV project as long as the electrical permit application is submitted within 5 days.

Most municipalities (19 of the 25 interviewed) require applicants to call in and schedule their building and electrical inspections based on the inspector's availability, as seen in Figure 13. The building inspection appointment time generally ranges from same day to five days later, but the average scheduled time amongst the municipalities is sometime the next day. Electrical inspectors can usually meet within a similar time frame as building inspectors, 24-48 hours. It is most often no more than 2 days from the time of the request.

Figure 13. Process for Requesting Building Inspections



As noted earlier in this section, the permit review process takes an average of eight business days. In Section 2.2.4, it was explained that the majority of municipalities require three inspections for both residential and commercial solar PV permitting (electrical rough, electrical final, and a structural final). Accordingly, the typical permit timeline is 11 business days, as seen in Figure 14.

Figure 14. Typical Permit Timeline for PV

Nationally, the average permit timeline is much longer – 38 business days from initial building permit application submission to final inspecion.[1] This includes the following actions, which can overlap to some extent: 11 days for the electric code review, 13 days for the structural/building design review, eight days for the fire code review, 10 days for plan resubmittal, 14 days for the utility site inspection, and five days for the city site inspection. [1] Note that the national average of 38 days is not exactly comparable to the Massachusetts analysis because the Massachusetts analysis does not include time for fire code review and utility site inspection.

2.3.3 Permitting Checklist for Solar

Few building inspectors maintain general or solar-specific permitting checklists, as seen in Figure 15. Typically, building inspectors responded that they have a mental checklist, but have never written down an official checklist.

Figure 15. Permitting Checklists Maintained by Building Inspectors

Permitting Checklist (n=25)	Yes	No
General	6	19
Electrical	0	25
Solar-Specific	2	23

2.4 *Feedback from Municipal Building Inspectors*

Municipal building inspectors in Massachusetts reported that there are little to no challenges associated with their solar permitting process. The few minor challenges mentioned were:

- "The inadequacy of roof structures of houses built in the 1960s."
- Ensuring that "there are qualified [licensed] personnel actually doing the install work."

In addition, municipalities agreed that the quality of the plans submitted by solar contractors relative to other contractors was very good. The submitted plans are generally clear and complete. The only minor issue cited by one municipality was that they "have noticed a lot of structural stamps coming from engineers that are out-of-state; it is obvious they are not personally reviewing the structures."

Municipal building inspectors are "most concerned about structural because rooftop PV is generally a retrofit project"; however, this can mean that some "projects come in too focused on structural and not enough on electrical." Both structural and electrical should be the focus, "particularly in the inspection process."

When asked if they would be willing to adopt a standard statewide permitting process, reactions from municipalities were mixed. Some were in favor, citing that it "would make the process even more streamlined." Others were more skeptical, saying that they "feel like they are already up to code" and "their application is comprehensive enough" in its current state. A standard statewide permitting process "would have to fit into the existing building requirements, electrical requirements, and local zoning ordinances."

Many municipalities have received training on solar code, mostly in seminars and online training courses. Those who had taken solar-specific courses had a positive experience and would "definitely be interested in taking more".

Lastly, municipalities report that they generally have adequate staff and budget to process permits for PV projects.

2.5 *Navigant's Recommended Best Practices*

Based on the input that Navigant received in the interview program and the Navigant team's own knowledge of the permitting process, a summary of Navigant's recommended best practices for solar PV permitting are contained in the "Suggested Procedural Guidelines" document within the

Commonwealth of Massachusetts's Solar PV Permitting Toolkit for Municipalities (described in Section 3 of this report).

3. Model Permitting Process – Toolkit for Municipalities

3.1 Recommended Permitting Toolkit

Based on national best practices for solar permitting and taking into account the results of the information that we collected in the interview program of the 25 municipalities, we developed a recommended Solar PV Permitting Toolkit for Municipalities. The toolkit was designed to make the permitting process more efficient for municipalities in Massachusetts. The toolkit is presented in a format that is intended to allow it to be readily adopted and made available for use, including on a municipality's website.

The contents of the recommended toolkit have been submitted to DOER for review, and include the following:

- Solar PV Basics and Definitions
- Flowchart of the Rooftop Solar PV Permit Process
- Standard Permit Application for Rooftop PV Systems Sized 300 kW and Less
- Qualification Flowchart for the Fast Track Permit Application
- Fast Track Permit Application for Residential Rooftop PV Systems Sized 10 kW and Less
- Design Template Package
- Application and Template Guide
- Permit Fee Table
- Suggested Procedural Guidelines

3.2 Source Material

The toolkit we developed is based on the "Expedited Permit Process for PV Systems" report, prepared by Bill Brooks, P.E. (July 2012) for the Solar America Board for Codes and Standards (also called the Solar ABCs).[3] The intent of this report was to provide a national standard of solar PV permitting for small systems. We adapted this content for the Commonwealth of Massachusetts. The templates and template specific guidance were taken directly from the Solar ABCs report with minimal customization. As code evolves and technology develops, the Solar ABCs templates and corresponding guidance material will be updated. By using the most recent version of the Solar ABCs templates and templates guidance, municipalities can be sure they are using material reflecting current standards.

The recommended permit applications were adapted directly from the existing Commonwealth Building and Electrical permit applications provided by the Massachusetts Building Board of Regulations and Standards (BBRS) and the Massachusetts Board of Fire Prevention Regulations (BFPR). We designed the recommended applications to contain all of the basic minimum permit information as well as the applicable information to solar PV projects.

[3] http://www.solarabcs.org/about/publications/reports/expedited-permit/

The recommended permit fee table and the suggested procedural guidelines were designed specifically for the Commonwealth of Massachusetts and based primarily on the assessment conducted of 25 municipalities throughout the Commonwealth, as well as on the Interstate Renewable Energy Council's (IREC) "Sharing Success: Emerging Approaches to Efficient Rooftop Solar Permitting" report by Stanfield, Schroeder and Culley (May 2012).[4] The IREC report covers several current solar PV permitting practices nationwide and provides insightful guidance on best practices based on the current permitting environment.

[4] http://www.irecusa.org/wp-content/uploads/FINAL-Sharing-Success-w-cover-revised-final052012.pdf

4. Structural Review Guidance – Introduction and Approach

4.1 *Stated Goals of the Project*

In addition to providing mode permitting processes to Massachusetts municipalities, a stated goal of this project was to develop standard guidelines for the review and approval of some common types of small residential rooftop PV systems (10kW and less) throughout the Commonwealth of Massachusetts. Under current state rules, local building inspectors have discretionary authority to require a "wet stamp" and/or affidavit from a registered Professional Engineer or Structural Engineer for any roof mounted installation, residential or otherwise. This requirement represents a significant cost to smaller systems and thus plays a role in hindering the widespread adoption of PV.

It is not the intent of this project to circumvent the engineering process or discount the value and importance of a professional engineer's analysis. Rather, the intent is to address the engineering concerns by recognizing the similarities among smaller rooftop systems and establishing guidelines to determine when a PV project can safely be supported by a well-engineered and properly constructed 1 or 2 family residence.

In keeping with the overall goal of the DOER's initiative, and the goals of the U.S. Department of Energy SunShot Initiative Rooftop Solar Challenge, the intended impact of this guidance is to reduce the time, cost and effort required to develop, design and review residential PV projects. The result would then help further accelerate the deployment of solar PV systems throughout Massachusetts.

4.2 *Early Approach and Issues*

The initial approach to this task was to develop a matrix designed to guide a user (both permit applicant and building official) to an acceptable PV system solution, based on the structural conditions of the home in question. The intent of the matrix concept was to offer what would be essentially a pre-engineered or engineer-approved solution based on the particular structural elements of a given home.

As the team began to assess the housing stock in Massachusetts and consider the design elements that ultimately drive the structural analysis associated with the installation of a solar PV system, it became clear the number of potential variations could not be captured by this matrix method. Likewise, the variations in the type and deployment of attachment and racking solutions were similarly too diverse to be captured in this matrix format.

4.3 *Final Approach Overview*

The final approach taken for this task was to develop a prescriptive process, whereby the user tests a building's condition against a series of questions using the Flowchart provided in Appendix B. If the building conditions successfully meet the standards set forth in the prescriptive process, the user can then utilize a custom span table designed to contemplate the particular design factors for the

Commonwealth of Massachusetts to determine if the roof of the building in question can adequately support the proposed PV system.

The development of a prescriptive method was undertaken to specifically address the installation of a rooftop solar PV system on the roof of a one- and two-family residence without the expense and time of utilizing a licensed structural engineer for evaluation of load carrying capacity. The process is designed to be applied to all cities and towns in the Commonwealth of Massachusetts. Small PV systems, sized 10 kW and less, are typically very lightweight, approximately 3.0 to 3.5 pounds per square foot. Adding this amount of weight to a roof compares favorably to adding a second layer of roofing shingles, which does not require the advice of a licensed structural engineer in Massachusetts. The prescriptive method proposed herein is limited to flush-mounted PV systems, for which the effects of wind and snow accumulation can be better quantified using existing building code metrics.[5] PV systems are sometimes installed at a tilt to get the best exposure of the PV modules to the sun, but the tilt can cause an increase in the effect of wind and snow accumulation.

The first step in developing the prescriptive process was to determine the increase in load a rooftop would endure from a PV system and snow load, adjusted for temperature. Figure 16 contains this analysis, which is also described below.

Figure 16. Roof Load Considerations

A	B	C	D	E	F	G	H	I	J	K	L	M
City/Town	**5/6 Ed P_f**	**8th Ed P_g**	**8th Ed P_f**	**Increase/ decrease**	**1/2 family P_g**	**1/2 family P_f**	**P_f, adjusted for temp**	**PV Dead Load**	**Roof Dead Load**	**Original Total Load**	**With PV Total Load**	**% increase in Total Load**
	lbs/ft²	**lbs/ft²**	**lbs/ft²**	**lbs/ft²**	**lbs/ft²**	**lbs/ft²**	**lbs/ft²**	**lbs/ft²**	**lbs/ft²**	**lbs/ft²**	**lbs/ft²**	**%**
			C x 0.7	D - B		F x 0.7	G x 1.15			G + J	H + I + J	L / K - 1
Boston	30	45	31.5	1.5	40	28	32.2	3.5	10	38	45.7	20%
Cambridge	30	45	31.5	1.5	40	28	32.2	3.5	10	38	45.7	20%
Falmouth	25	35	24.5	-0.5	30	21	24.2	3.5	10	31	37.7	21%
Harvard	35	55	38.5	3.5	50	35	40.3	3.5	10	45	53.8	19%
Hatfield	35	55	38.5	3.5	40	28	32.2	3.5	10	38	45.7	20%
Pittsfield	40	65	45.5	5.5	50	35	40.3	3.5	10	45	53.8	19%
Rutland	35	55	38.5	3.5	50	35	40.3	3.5	10	45	53.8	19%
Winchester	30	55	38.5	8.5	40	28	32.2	3.5	10	38	45.7	20%
											Average	**20%**

Definitions

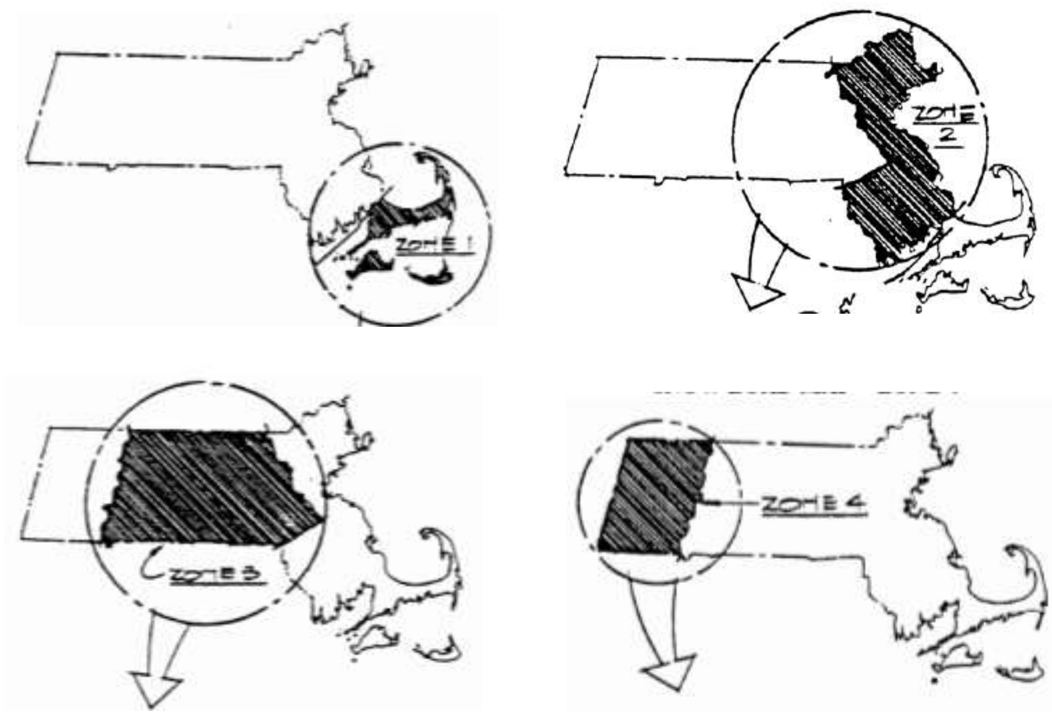
- P_f Flat roof snow load (pounds per square foot)
- P_g Ground snow load (pounds per square foot)
- C_t Coefficient which relates snow load including effective temp of supporting structure

In order to consider all four original Massachusetts State Building Code (MSBC) snow zones (see Figure 2), we selected eight cities and towns from the 25 that we surveyed as part of this assignment that

[5] In flush-mounted PV systems, the modules are installed parallel to the existing roof at a height of no more than 8 to 12 inches above the roofing.

represent geographic diversity and have a significant amount of PV installed. The first step was to determine the expected snow load for each municipality in flat roof snow load, rather than ground snow load. The 5th and 6th editions of the MSBC use P_f (flat roof snow load) (values shown in Column B), while the current 8th edition MSBC utilizes P_g (ground snow load) (values shown in Column C). Employing the ASCE 7 recommended conversion coefficient we converted the P_g numbers in the 8th edition to P_f (Column D). The resulting P_f numbers for the 8th edition were compared to the P_f numbers in the 5th and 6th editions to determine whether the 8th edition MSBC represented an increase or a decrease in the snow load effects for each town (as shown in column E). This comparison showed that expected snow load decreased for some municipalities by 0.5 pounds per square foot (psf) and increased for some municipalities by as much as 8.5 psf, as a result of the "re-drawn" snow zone differentiating lines prior to the issuance of the 7th edition MSBC.

Figure 17 Snow Load Zones – Massachusetts State Building Code, 6th Edition



We also recognized that the one- and two-family dwelling building code requirements were included as Chapters/Articles through the 6th edition of the MSBC. However, these residential buildings requirements are now contained in the International Residential Code (IRC) with Massachusetts amendments. From the IRC with Massachusetts amendments, we determined the current P_g for one-two family dwellings for each municipality (Column F) and converted these numbers to a basic P_f (snow load on flat roofs) (Column G). This P_f was then further modified as required by ASCE 7-05, by applying coefficients I, C_e and C_t to the code values. I refers to the importance factor of the building based on its occupancy category. C_e is the coefficient associated with exposure, where less exposure to wind (i.e., confined within high conifer type trees) translates to a higher coefficient. C_t is the coefficient that adjusts snow load given the existing temperature of the supporting structure. In the case of the prescriptive analysis that is described later in this report, I=1.0 (Type II: Occupancy Category). Terrain Category B or C was considered as “partially exposed” resulting in $C_e = 1.0$ (which is not overly conservative but considered realistic for normal residential buildings in neighborhoods and communities; as opposed to isolated buildings on mountainsides or deep within a heavily wooded environment.). $C_t = 1.15$ was used as an average of the unheated attic space and a space kept intentionally below freezing.

Applying the described coefficients, the snow load for the average of the combinations of the coefficients resulted in an adjusted P_f as shown in column H.

Typical 60 cell PV modules weigh 2.48 psf. The associated framing required to adequately support these modules include 2 module rails per module and 1 base rail per module. These are customarily aluminum and weigh slightly less than 1 pound per linear foot. Typical module dimensions are 40 inches wide by 65 inches long resulting in approximately 12 feet of framing per module, equaling approximately 11 pounds of framing, plus approximately 5 pounds for the stainless steel lag screw and aluminum offset post and flashing. The area of the module is approximately 18 square-feet which results in approximately 1 psf of framing. This 3.5 psf dead load of a PV system is shown in Column I.

The assumed roof dead load of 10 psf, which is currently included in the IRC, is shown in Column J. This dead load accommodates a composition shingle or other lightweight material roofing, not clay tile or any other cement based products.[6]

Based on the above components, the gravity design loading was determined consistent with the original design conditions without PV, as shown in column K. Adding PV to the roof necessitates that the inclusion of the PV dead load and the temperature effects of snow on the slightly elevated modules be added to the roof dead load, summed to a new gravity design loading as shown in Column L. A comparison of total gravity design loads is shown in column M. This shows that the addition of the PV can result in an increase of total gravity design load by an average of approximately 20%.

The above comparative analysis results in the decision to develop a span table for frequently used roof framing members, spacing, lumber species and grade of material to reflect the slightly increased gravity design loading effects by reducing the spanning capability appropriately. Deflections were also included in the analysis by limiting total load deflection to L/180, where L is the length of the rafter. The table lists

[6] If clay tiles or any other cement based products are used in the roof, an engineer should be involved to determine weight considerations as well as fastening and support details.

the maximum allowed span for the rafter member size based on allowed stress or limiting deflection to L/180, whichever is less.

The use of the Maximum Rafter Span Table (Appendix C) requires the user to determine the Code required ground snow load, and to identify the rafter species and grade, size and spacing to identify the maximum span for the framing. If the existing span is less than the maximum span of the table for the ground snow, rafter material and species and rafter size and spacing, then PV may be installed on the roof without further analyses. Otherwise, a Registered Design Professional (e.g., a Professional Engineer, a Structural Engineer, or an Architect who can perform the required services) should be consulted. The maximum spacing of PV supports is stipulated to be twice the rafter spacing and alternating such that all rafters carry the proposed system. There are several limiting conditions contained in the table such as the shorter of the stress limiting span and the maximum span where deflection will be limited to L/180 is listed.

4.4 The Prescriptive Process and Building Codes

We developed a prescriptive process that directs users to a span table specifically developed for this purpose because these types of tables are common in the one- and two-family building code. Staff from the Building Board of Regulations and Standards (BBRS) will issue an FAQ on the Department of Public Safety (DPS) website that instructs building inspectors and other knowledgeable parties on the use of the prescriptive process and associated span table.[7]

[7] The Department of Public Safety FAQs can be found at http://www.mass.gov/eopss/agencies/dps/faqs.html.

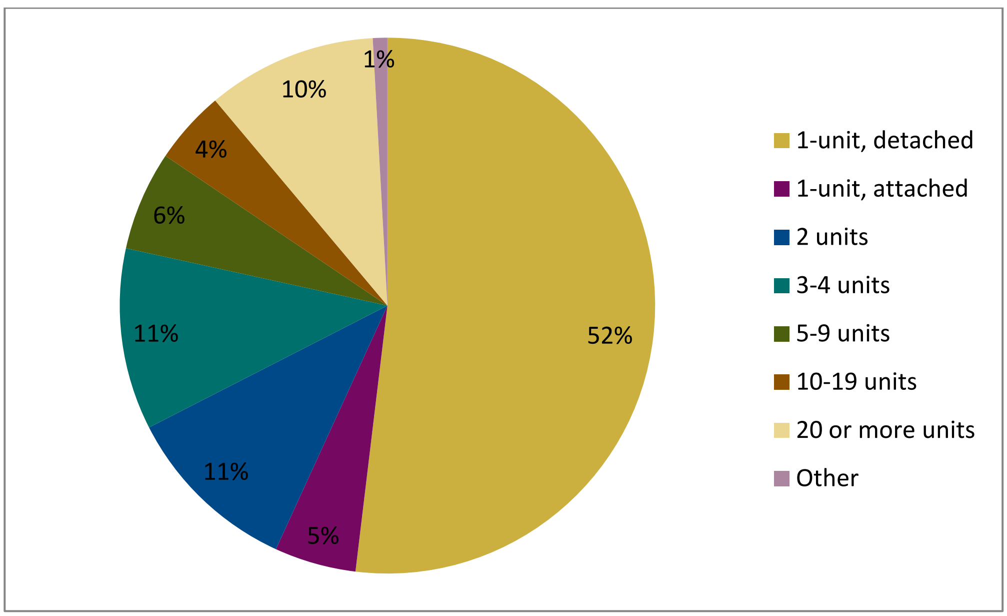
5. Structural Review Guidance – Housing Stock Assessment

5.1 *Housing Stock Statistics*

The following section provides an assessment of the Massachusetts housing stock, with an emphasis on determining the number of housing units that may qualify for the use of the prescriptive structural analysis process. This process was developed specifically for residential applications; as such, the assessment focuses primarily on one- and two-family dwellings. Two of the major driving factors built in to the prescriptive process for one- to two-family homes are the age of the home (built before or after 1976) and the type of roof framing construction utilized (light wood frame construction).

The Commonwealth of Massachusetts currently has 2,819,028 housing units[8]. Fifty-two percent of the residential buildings are 1-unit detached, which refers to a dwelling unit designed for occupancy by one family with exterior walls completely surrounded by permanent open space. Only 5% of the housing stock is made up of 1-unit attached homes that are connected to one or more houses (i.e., row houses and townhouses). Eleven percent of the housing stock is made up of 2-unit apartment buildings. The full breakdown of Massachusetts' housing stock can be seen in Figure 18.

Figure 18. Housing Unit Structure in Massachusetts, 2.8 million units



Although one- and two-family homes make up a significant portion of the housing stock, it should be noted that the Massachusetts housing stock is relatively old. Although aging housing stock is common in

[8] U.S. Census Bureau. *2011 American Community Survey 1-Year Estimates: Selected Housing Characteristics*.

New England, Massachusetts has the third highest median age of housing in the U.S. Roughly 70% of the housing stock in Massachusetts was built before 1975.

We highlight this delineation because the first Massachusetts Statewide Building Code (MSBC) was adopted in 1975. One can safely assume that a house built later than 1975 was designed and built according to a set of quantifiable codes and standards. Therefore, the first qualifier in the prescriptive process is: "Was the house built in 1976 or later?" The year 1976 was chosen instead of 1975 based on the assumption that while the code was adopted in 1975, certain structures may have already been designed, permitted or under construction that year, prior to implementation of the code.

5.2 Applicable Structures

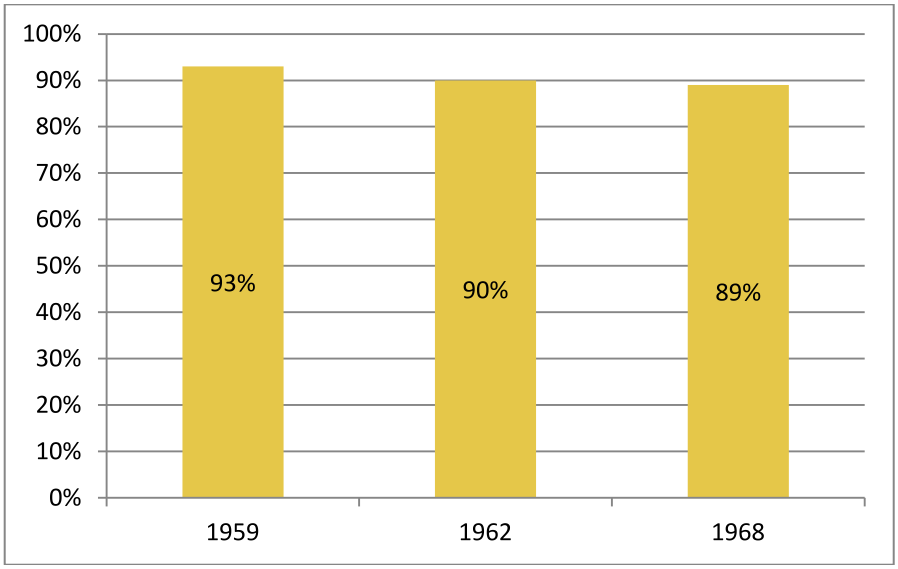
The second of the two main driving factors in the prescriptive process is if the roof framing system is a light wood frame construction type system. This type of system is often referred to as "stick-built" construction as it is comprised of various 2"x members (i.e., 2"x 4", 2"x 6", 2"x 8", etc.). As reflected in the Flowchart (Appendix B) and identified in the maximum rafter span table (Appendix C), these types of structural members have quantifiable structural properties and can thus be evaluated via a prescriptive process.

An important distinction to make when evaluating the light wood frame construction housing stock is the use and prevalence of panelized or modular construction, specifically the use of pre-engineered trusses. A professional engineer should be employed when evaluating a home constructed using pre-engineered trusses, because the structural properties of a pre-engineered truss system are often application-specific and typically include a certain amount of value engineering which does not allow for many general assumptions to be made nor evaluated relative to a prescriptive process and span table calculation.

Residential homes built in the North Atlantic region of the U.S. before 1975 were almost entirely wood-frame buildings. As shown in Figure 19, a study by the USDA Forest Service showed that roughly 9 out of 10 single-family homes in the North Atlantic were built using wood-frame construction from 1959 to 1968.[9] There was a small decrease in wood-frame construction from 1959 to 1962 and again from 1962 to 1968.

[9] U.S. Department of Agriculture – Forest Service. *Wood Products Used in Single-Family Houses: Inspected by the Federal Housing Administration 1959, 1962 & 1968*. Statistical Bulletin No. 452. October 1970.

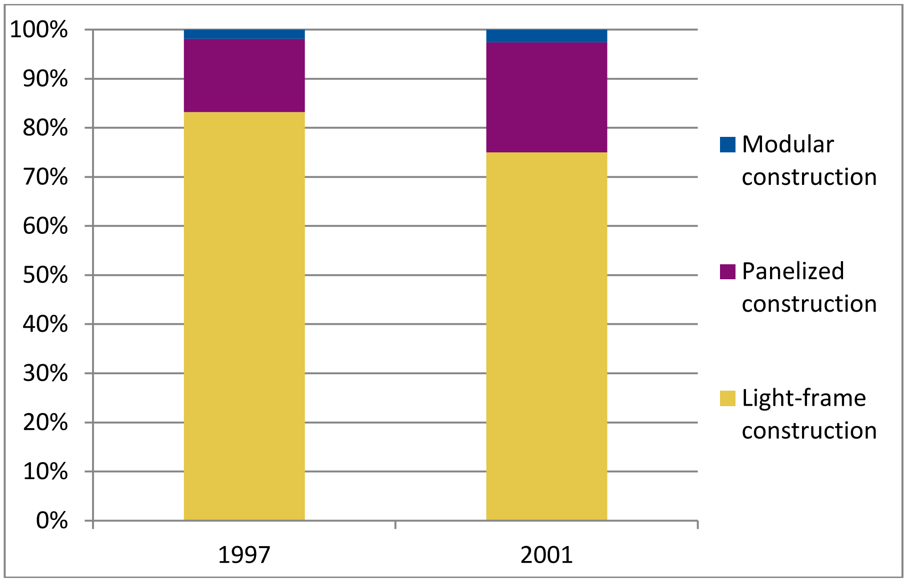
Figure 19. New Single-Family Homes with Wood-Frame Construction in the North Atlantic Region



While light-frame construction continues to dominate in the Northeast, increases in panelized and modular construction in new residential buildings have continued the downward trend of light-frame construction. As seen in Figure 20, light-frame construction accounted for 82.8% of new residential construction in the Northeast in 1997 and dropped to 74% by 2001.[10] Panelized construction (i.e., homes assembled from factory-built wall panels and roof trusses) accounted for 14.8% of new residential construction in the Northeast in 1997 and 22.1% in 2001.

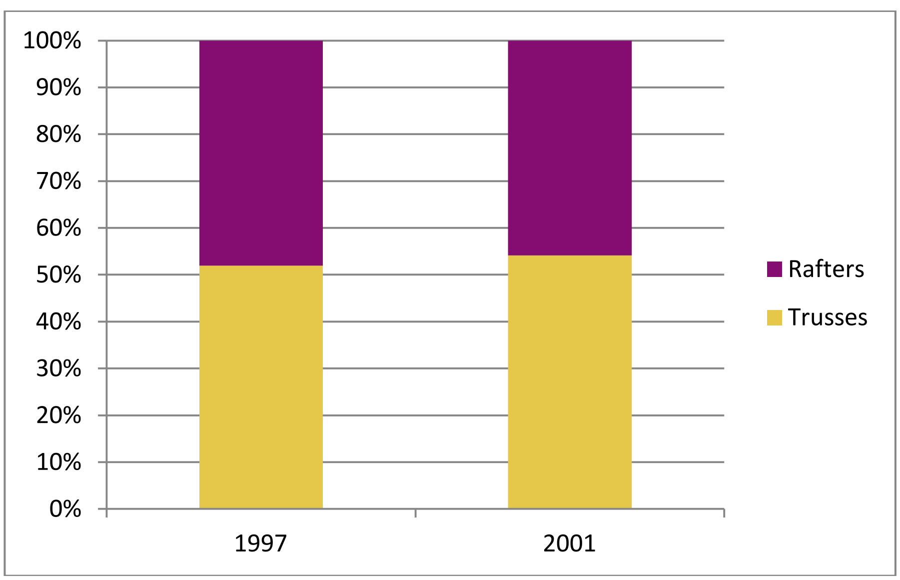
[10] United States International Trade Commission. *Conditions of Competition in the U.S. Market for Wood Structural Building Components*. Publication 3596. April 2003.

Figure 20. Construction Method for New Residential Construction in the Northeast U.S.



The Northeast has been the most resistant U.S. region in the uptake of metal plate connected wood trusses in residential roof construction; however, as seen in Figure 21 trusses still made up the majority of roof construction in the Northeast in 1997 and 2001. The remaining new residential construction used traditional site-constructed rafters.

Figure 21. Roof components used in new residential construction in the Northeast U.S.



Conclusion

In order to qualify for the prescriptive permitting process, a building must be a 1-2 family dwelling built after 1975 with a light-frame wood construction and traditional rafters for the roof. Considering lightweight construction and rafter/truss data from 1997 and 2001 presented above, one could roughly estimate that approximately 10%-12% of homes in Massachusetts fit this description as follows:

- In 1997, 30% of homes were newer than 1975 x 74% were of light frame construction x 44.7% of homes were built with rafters = 10%
- In 2001, 30% of homes were newer than 1975 x 82.8% were of light frame construction x 47.7% of homes were built with rafters = 12%

This translates to approximately 188,000 to 225,000 homes out of the 1,902,385 1-2 family dwellings in Massachusetts (comprised of 1,463,243 1-unit detached, 139,039 1-unit attached and 300,093 2 units).

Appendix A. Questionnaire and Municipalities Surveyed

Below is the questionnaire that we used for our interviews with municipalities. This questionnaire was adapted from DOE's SunShot Initiative Rooftop Solar Challenge market assessment.

			PERMITTING PROCESS				
Sub-Area	#	Question	RESIDENTIAL <10kW		COMMERCIAL <300kW		DATA SOURCES/NOTES (optional)
			Options	Check Box	Options	Check Box	
Desk Research	1	How is information describing the permitting process accessible? (Check all that apply)	Online and easily accessible		Online and easily accessible		
			Online		Online		
			Email		Email		
			In person/mail		In person/mail		
	2	What are the options for obtaining an application? (Check all that apply)	Online		Online		
			Email		Email		
			In person		In person		
			Mail		Mail		
	3	What are the options for submitting an application? (Check all that apply)	Online		Online		
			Email		Email		
			In person		In person		
			Mail		Mail		
	4	How is information on permit fees made available? (Check all that apply)	Online		Online		
			Email		Email		
			In person		In person		
			Mail		Mail		
			Not Available		Not Available		
	5	How is information on inspection requirements made available? (Check all that apply)	Online		Online		
			Email		Email		
			In person		In person		
			Mail		Mail		
			Not Available		Not Available		
	6	Is there an accessible designated point of contact, with contact information available online, for questions about the PV permitting process?	Yes		Yes		
			No		No		

Application & Review	1	To how many departments does an installer have to submit separate applications for a typical installation? (a municipal utility does not count as a city department here)	1		1		
			2		2		
			≥ 3		≥ 3		
	2	What types of departmental approvals are required for a typical installation? (check all that apply)	Building		Building		
			Electrical		Electrical		
			Fire Protection		Fire Protection		
			Mechanical		Mechanical		
			Planning		Planning		
			Plumbing		Plumbing		
			Structural		Structural		
			Zoning		Zoning		
			DPW		DPW		
			Fire Dept		Fire Dept		
			Other (*Specify)		Other (*Specify)		
	3	What approvals from Professional Engineers are required as part of the permit package for a typical installation? (Check all that apply)	Civil		Civil		
			Electrical		Electrical		
			Environmental		Environmental		
			Fire Protection		Fire Protection		
			Mechanical		Mechanical		
			Structural		Structural		
	4	Do you offer over-the-counter permit reviews? Is it by appointment or are there set days/hours?	Yes, *Specify		Yes, *Specify		
			No		No		
			Day(s)		Day(s)		
			Hour(s)		Hour(s)		
	5	Do you maintain or utilize a permitting checklist or plan templates in general? For solar?	general, yes		general, yes		
			general, no		general, no		
			electrical, yes		electrical, yes		
			electrical, no		electrical, no		
			solar. Yes		solar. Yes		
			solar, no		solar, no		
	6	Is there a policy to review permits wihtin a specified number of days? What is the typical turnaround to full permit, including re-submittal? For solar?	Yes, # days		Yes, # days		
			no		no		
			typical # days		typical # days		
			solar # days		solar # days		
	7	Do you offer expedited permit options? Additional fees?	Yes, *Specify		Yes, *Specify		
			No		No		
Fees	8	What is the cost of the applicable permit fee(s) for typical installations?	exact		Please *Specify		
			estimated				
			Other (*Specify)				
	9	Is/are the permit fee(s) structured as flat, cost recovery, valuation open ended, or valuation capped?	Flat		Flat		
			Cost Recovery		Cost Recovery		
			Valuation Open Ended		Valuation Open Ended		
			Valuation Capped		Valuation Capped		
			Valuation with Exclusions		Valuation with Exclusions		
			Other (*Specify)		Other (*Specify)		
Inspection	10	Describe the inspection process					
	11	Timeline/process from request to inspection?	call in, same day		call in, same day		
			call in, schedule based		call in, schedule based		
			fixed day(s)		fixed day(s)		
			online/email		online/email		
			Other (*Specify)		Other (*Specify)		
	12	What are the typical number and/or types of inspections required?	Single Comprehensive Inspection		Single Comprehensive Inspection		
			Electrical Rough-in		Electrical Rough-in		
			Electrical Final		Electrical Final		
			Roof Penetrations (pre-install)		Roof Penetrations (pre-install)		
			Structural / Building Final		Structural / Building Final		
			Other (*Specify)		Other (*Specify)		

Qualitative Questions

1. What are the challenges with your solar permitting process? Any suggestions or plans to remedy them?
2. Would you be willing to adopt a standard statewide permitting process that would help streamline all solar permitting in Massachusetts?
3. What area(s) of a solar permit package/design do you focus on the most? Structural, electrical, fire, building, etc.?
4. How would you rate the quality of the permits/plans submitted by solar contractors relative to other electrical/mechanical contractors?
5. What areas of permits/plans submitted by solar contractors are typically deficient?
6. How often do you receive training or attend workshops on new areas of code or emerging construction trades? Have you received or attended any for solar? Would you be willing to if offered?
7. Do you have adequate staff/budget for permitting PV projects?

Municipalities Surveyed

- Belchertown
- Boston
- Cambridge
- Falmouth
- Gloucester
- Greenfield
- Harvard
- Hatfield
- Hingham
- Hudson
- Lowell
- Middleborough
- Natick
- New Bedford
- Northampton
- Pittsfield
- Quincy
- Rutland
- Scituate
- Sutton
- Tisbury
- Waltham
- Wellesley
- Williamsburg
- Winchester

Appendix B. Prescriptive Process for Structural Approval of Small PV Systems

Prescriptive Process Flowchart for Residential PV <10 kW

1. Is the house older than 1976? — Yes → Employ Registered Design Professional to evaluate rooftop; No ↓
2. Is there only one layer of roofing shingles? — No → Employ Registered Design Professional to evaluate rooftop; Yes ↓
3. Is the slope of the roof 4:12 or greater? — No → Employ Registered Design Professional to evaluate rooftop; Yes ↓
4. Are the roof rafters typical 2x lumber of a regular spacing? — No → Employ Registered Design Professional to evaluate rooftop; Yes ↓
5. Are the roof rafters “Spruce-Pine-Fir (SPF)” or “Hem-Fir”? — No → Employ Registered Design Professional to evaluate rooftop; Yes ↓
6. Have Fasteners been observed and determined to be compliant with the requirements of the Fastener Table (below)

   Fastener Table for Structural Members
   - Ceiling Joists to plate, toe nail (3-8d)
   - Ceiling Joist, laps over partitions, face nail (3-10d)
   - Ceiling joist to parallel rafters, face nail (3-10d)
   - Rafter to plate, toe nail (2-16d)
   - Roof rafter to ridge, valley or hip, to nail (4-16d)
   - Roof rafter to ridge, valley or hip, face nail (3-16d)
   - Collar tie to rafter, face nail (3-8d)

   — No → Employ Registered Design Professional to evaluate rooftop; Yes ↓
7. Are the skylights, dormers, or other similar components in the roof within 2 feet of the proposed PV system? — Yes → Employ Registered Design Professional to evaluate rooftop; No ↓
8. Is there any equipment supported from the roof framing (above or below) within 2 feet of the proposed PV system? — Yes → Employ Registered Design Professional to evaluate rooftop; No ↓
9. Are there any additions or renovations to the existing roof or directly abutting the roof within 6 feet of the proposed PV systems — Yes → Employ Registered Design Professional to evaluate rooftop; No ↓
10. Are there any indications of distress in the roof framing (i.e., ridge sagging, walls out of plumb, significant ceiling cracks)? — Yes → Employ Registered Design Professional to evaluate rooftop; No ↓
11. Are there signs or knowledge of previous damage (i.e.: water incursion, fire damage, impact from an object, etc.) or repairs to the roof? — Yes → Employ Registered Design Professional to evaluate rooftop; No ↓

If none of the answers to the above questions caused you to employ a Registered Design Professional to evaluate the structure, you may proceed to utilize the Maximum Rafter Span table for the evaluation of the roof framing to support the proposed PV system.

Appendix C. Maximum Rafter Span Table

Maximum Rafter Spans (for non-cathedral ceilings)

DL = 10 psf, Max PV weight = 3.5 psf, max PV supports at 2 x Rafter spacing (alternate rafter loading)

		12" RAFTER SPACING				16" RAFTER SPACING				24" RAFTER SPAC		
		2x6	2x8	2x10	2x12	2x6	2x8	2x10	2x12	2x6	2x8	2x1
	SS	13' - 8"	18' - 0"	23' - 0"	28' - 0"	12' - 5"	16' - 5"	20' - 11"	25' - 5"	10' - 6"	13' - 11"	17' -
	#1	12' - 5"	16' - 5"	20' - 11"	25' - 5"	10' - 9"	14' - 2"	18' - 1"	22' - 0"	8' - 9"	11' - 7"	14' -
	#2	11' - 7"	15' - 4"	19' - 6"	23' - 9"	10' - 0"	13' - 3"	16' - 11"	20' - 7"	8' - 2"	10' - 10"	13' -
	#3	8' - 11"	11' - 9"	15' - 0"	18' - 3"	7' - 8"	10' - 2"	13' - 0"	15' - 9"	6' - 3"	8' - 3"	10' -
ne-Fir	SS	13' - 5"	17' - 8"	22' - 6"	27' - 5"	12' - 2"	16' - 0"	20' - 6"	24' - 11"	9' - 11"	13' - 1"	16' -
ne-Fir	#1	11' - 9"	15' - 6"	19' - 10"	24' - 1"	10' - 2"	13' - 5"	17' - 2"	20' - 11"	8' - 4"	11' - 0"	14' -
ne-Fir	#2	11' - 9"	15' - 6"	19' - 10"	24' - 1"	10' - 2"	13' - 5"	17' - 2"	20' - 11"	8' - 4"	11' - 0"	14' -
ne-Fir	#3	8' - 11"	11' - 9"	15' - 0"	18' - 3"	7' - 8"	10' - 2"	13' - 0"	15' - 9"	6' - 3"	8' - 3"	10' -
	SS	12' - 10"	16' - 11"	21' - 7"	26' - 3"	11' - 8"	15' - 4"	19' - 7"	23' - 10"	9' - 7"	12' - 7"	16' -
	#1	11' - 3"	14' - 10"	19' - 0"	23' - 1"	9' - 9"	12' - 10"	16' - 5"	20' - 0"	8' - 0"	10' - 6"	13' -
	#2	10' - 6"	13' - 11"	17' - 9"	21' - 7"	9' - 1"	12' - 0"	15' - 4"	18' - 8"	7' - 5"	9' - 10"	12' -
	#3	8' - 1"	10' - 8"	13' - 7"	16' - 6"	7' - 0"	9' - 2"	11' - 9"	14' - 4"	5' - 8"	7' - 6"	9' -
ne-Fir	SS	12' - 7"	16' - 6"	21' - 1"	25' - 8"	11' - 1"	14' - 7"	18' - 7"	22' - 8"	9' - 0"	11' - 11"	15' -
ne-Fir	#1	10' - 8"	14' - 1"	18' - 0"	21' - 11"	9' - 3"	12' - 2"	15' - 7"	18' - 11"	7' - 6"	9' - 11"	12' -
ne-Fir	#2	10' - 8"	14' - 1"	18' - 0"	21' - 11"	9' - 3"	12' - 2"	15' - 7"	18' - 11"	7' - 6"	9' - 11"	12' -
ne-Fir	#3	8' - 1"	10' - 8"	13' - 7"	16' - 6"	7' - 0"	9' - 2"	11' - 9"	14' - 4"	5' - 8"	7' - 6"	9' -
	SS	12' - 2"	16' - 0"	20' - 5"	24' - 10"	10' - 9"	14' - 3"	18' - 2"	22' - 1"	8' - 10"	11' - 7"	14' -
	#1	10' - 5"	13' - 9"	17' - 6"	21' - 4"	9' - 0"	11' - 10"	15' - 2"	18' - 5"	7' - 4"	9' - 8"	12' -
	#2	9' - 8"	12' - 10"	16' - 4"	19' - 11"	8' - 5"	11' - 1"	14' - 2"	17' - 3"	6' - 10"	9' - 0"	11' -
	#3	7' - 5"	9' - 10"	12' - 6"	15' - 3"	6' - 5"	8' - 6"	10' - 10"	13' - 2"	5' - 3"	6' - 11"	8' -
ne-Fir	SS	11' - 9"	15' - 6"	19' - 10"	24' - 1"	10' - 2"	13' - 5"	17' - 2"	20' - 11"	8' - 4"	11' - 0"	14' -
ne-Fir	#1	9' - 10"	13' - 0"	16' - 7"	20' - 2"	8' - 6"	11' - 3"	14' - 4"	17' - 6"	6' - 11"	9' - 2"	11' -
ne-Fir	#2	9' - 10"	13' - 0"	16' - 7"	20' - 2"	8' - 6"	11' - 3"	14' - 4"	17' - 6"	6' - 11"	9' - 2"	11' -
ne-Fir	#3	7' - 5"	9' - 10"	12' - 6"	15' - 3"	6' - 5"	8' - 6"	10' - 10"	13' - 2"	5' - 3"	6' - 11"	8' -

umptions for Use of Above Table

' this Table, comply with the Prescriptive Process Flowchart for Residential PV <10 kW.

e utilized by appropriately knowledgeable engineering or construction individuals.

le assumes construction is Code Compliant, i.e., collar ties exist at appropriate spacing, rafters are correctly located on opposing si

xceeding the Table values may be reduced by installing rafter braces to appropriate bearing wall locations, employ a Registered De
P) for proper details.

Loads (P_g) based on 780 CMR 58.00.

ss design based on NDS-2005, maximum total load deflection limited to L/180.

alled parallel to the roof plane and the distance between the roof covering and bottom of the PV panel is ≤ 12".

Appendix D. Contributors to this Report

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