REPORT

Structural Performance of the Solar Dry Insulation System

Presented to:

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TABLE OF CONTENTS

1. INTRODUCTION

The Quik-Therm Solar Dry Insulation (SDI) system is an exterior wall cladding assembly consisting of a layer of continuous rigid polystyrene foam insulation with pre-formed drainage cavities and grooves for vertical furring straps. Morrison Hershfield was retained by Quik-Therm to evaluate the structural performance of this system for selected wall loading scenarios. This report describes the Morrison Hershfield analysis and results.

In general, continuous insulation (CI) cladding systems are becoming widely accepted for a variety of cladding applications. Documentation on their structural performance has been published by sources including research institutes, industry associations, individual product vendors, and public regulatory bodies. One of the limitations on the known publications to date is they are often limited to a maximum insulation thickness of 4” (100 mm).

Quik-Therm is interested in producing Solar Dry systems with a 6” (152 mm) layer of continuous insulation. There has been some prior research by others for this application, along with preliminary guidelines, but the available studies focus specifically on gravity loads (the weight of cladding). Very little documentation has been found on the effect of other building loads, including wind and seismic forces, acting on a 6” layer of continuous insulation.

The focus of the Morrison Hershfield assessment is to create an analytical model of the 6” continuous insulation system, and review the performance in terms of strength and deflection for appropriate structural loads, in consideration of the National Building Code of Canada (NBCC) and the anticipated building construction types for the product.

This analysis is theoretical, and as such cannot predict all aspects of behavior that might be present in a real-world scenario. Physical testing of specimens is a recommended future step for confirming the results from the analysis. However, the analytical model should give a good indication of performance and provide confidence in the ability of the system to meet the structural requirements of the building code.

(a) Close-up Detail of SDI Cross-Section (b) Top-down View of Wall Assembly

Figure 1: Solar Dry Insulation Product Information

2. PROJECT BACKGROUND

A brief description of past engineering studies for cladding over continuous insulation is provided below, to give an overview on the need for the current study.

2.1 PREVIOUS WORK BY OTHERS

A number of different agencies and companies have published research on the performance of cladding over continuous insulation. Some of the agencies who have commissioned and published findings that we are familiar with include:

- New York State Energy Research & Development Authority
- US Department of Energy, Office of Energy Efficiency and Renewable Energy
- International Code Council (International Residential Code)
- Foam Sheathing Coalition
- Northwest Energy Efficiency Alliance
- Cold Climate Housing Research Center

Previous research has shown that although continuous insulation is a simple system in terms of the installation, the physical behavior is somewhat complex and not necessarily intuitive. The mechanisms that the system resist gravity loads include: (i) friction between the material surfaces; (ii) bending stiffness in the screws; (iii) and a strut-and-tie system where the tension force in the screw as it rotates and elongates is balanced by a compression force in the polystyrene foam.

The contribution of each of these mechanisms to the overall stiffness of the system varies depending on the exact installation details and material properties of the selected components.

2.2 GOALS OF CURRENT ANALYSIS

The primary identified goal for the analysis is to determine recommended fastener spacing for the design load scenarios. The following additional goals have been included as beneficial to the overall understanding of the system:

- Determine vertical deflection from gravity loads (weight of cladding).

- Confirm effect of wind and seismic loads on both vertical and horizontal deflection.

- Verify finite element analysis results with previously published product test data.

- Assess theoretical behavior of system, with proportionate contribution to stiffness from EPS insulation compression, friction, screw pretension, and screw bending.

- Confirm that the drainage cavity in SDI panels does not significantly affect deflections.

- Assess strength of cladding system components for factored NBCC loads.

3. ANALYSIS CRITERIA

Morrison Hershfield worked with Quik-Therm to develop scenarios that cover a broad range of construction applications, while making efficient use of effort on the finite-element modeling and analysis, which is a relatively labour-intensive process.

3.1 LOAD SCENARIOS

Quik-Therm specified the typical target markets for Solar Dry Insulation, which was used to narrow down the criteria for the analysis. This is not intended to limit the use of the product, it was simply the first set of applications identified for assessment at this time. The following general parameters were identified:

- Low-rise buildings, less than six storeys (20 m) in height
- Wood frame backup wall, with 2x6 studs at 16” o.c., and OSB sheathing
- Typical cladding materials will be fibre-cement boards and stucco
- Wind and seismic loading to cover a wide range of Canadian urban centres

This description was used to develop to load cases for the analysis. Cladding weight was selected for two scenarios: a light weight cladding of 5 psf (0.24 kPa) suitable for fibre-cement boards, and a medium weight cladding of 12 psf (0.57 kPa) suitable for stucco.

Wind loading values were referenced from the NBCC Appendix C Climatic Data for a 50-year return period (q50). Values of 0.35 kPa, 0.50 kPa, and 0.65 kPa were chosen as representative low, medium, and high values for the mean hourly wind pressures. These values cover a wide variety of Canadian cities, and would include major urban centres such as Toronto, Ottawa, Montreal, Calgary, Edmonton, and Vancouver.

Similarly, seismic loads were chosen to cover a large proportion of Canadian municipalities, with spectral acceleration Sa(0.2) values of 0.250 and 1.000 selected to represent low and high seismic zones. The low value would be applicable for regions like Toronto, Calgary and Edmonton, while the high value is representative of the Vancouver area and a conservative value for Ottawa and Montreal.

These combinations of cladding weights, wind loads, and seismic loads were used to define the analysis models. Ultimately, the goal of the analysis is to determine an appropriate vertical fastener spacing for the furring that will meet the building code structural requirements for the applied loads.

3.2 STRUCTURAL REQUIREMENTS

The structural requirements for the analysis were mainly derived from the National Building Code of Canada (NBCC) Part 4 *Structural Design* clauses and referenced standards such as CSA O86 *Engineering Design in Wood*. This includes the applied loads, load factors, strength of materials, and deflection criteria.

The NBCC distinguishes between strength design (Ultimate Limit States / ULS) and deflection criteria (Serviceability Limit States / SLS). Both strength and deflection were considered in our analysis. Specifically, the Finite Element Analysis (FEA) software model was primarily used to determine accurate deflections in the various components for SLS criteria. Strength design was primarily done by hand, to confirm the structural adequacy of various components such as fasteners and the furring strips for factored ULS loads.

Some details of the parameters used for applied load calculations include:

- Wind exposure factor (Ce) calculated for 20 m elevation, in open terrain.
- Combined wind pressure coefficient and gust factor (CpCg) determined in accordance with NBCC Structural Commentary I *Wind Load and Effects* Figure I-8.
- Importance factor for “Normal” category buildings, with ULS = 1.00 and SLS = 0.75.
- Earthquake loads calculated in accordance with NBCC Table 4.1.8.18 *Elements of Structures and Non-Structural Components and Equipment,* using Category 1 values for Cp, Ar, and Rp coefficients.

Horizontal deflection limits for the cladding were based on International Building Code (IBC) recommendation of L/360 for stucco finishes, and L/240 for fibre-cement board products (other brittle finishes). These exceed the NBCC Structural Commentary Table D-1 values for regular walls at L/180, but are aligned with the NBCC recommended value for masonry veneer of L/360. A more stringent criteria than L/180 is considered conservative and appropriate for the cladding design, which is why the IBC limits were selected.

Vertical deflection limits for the cladding were based on US Department of Energy publications[1] which recommend values of 1/64” (0.4 mm) for brittle cladding which is considered to include stucco; and 1/16” (1.6 mm) for flexible cladding which is considered to include fibre-cement panels. Generally these values have been recommended for gravity loads (self-weight of cladding), and they have been used as guidelines for consideration with applied wind and seismic loads.

We note the purpose of this analysis did not include the design of the backup wall system, this would need to be confirmed by the design engineer on each particular building project.

[1] This limit is based on criteria listed in the *US Department of Energy* Expert Meeting Report: Cladding Attachment Over Exterior Insulation available at http://www.nrel.gov/docs/fy14osti/57260.pdf

4. MODELING PROCEDURES

The following section describes the software model used to analyze the deflections in the cladding assembly. The strength calculations for the components were performed by hand using standard engineering methods, which have not been described in detail in this report.

4.1 ANALYSIS SOFTWARE

Modeling was done using the Nx software package from Siemens, which is a general purpose computer aided design (CAD) and finite element analysis (FEA) package. The advanced non-linear static module (SOL 601) was used for the analysis, as required for convergence of contact surface definitions.

All material properties were assumed to be isometric. The sectioned planes of the insulation and furring horizontally and vertically were constrained to symmetric post-analysis.

Screw fasteners were modeled as 1D elements through the insulation layer as per Nx recommended best practices. The portion of the screw through the furring was modeled as a 3D structure to simulate realistic behavior at the contact interface between the steel screw head and the wood.

The model was developed initially from a single screw and appropriate tributary material widths based on the screw spacing. Later models were run with multiple screws to assess the system effect. The final model was run as a 1220 mm (48”) tall wall section with screws spaced vertically along this height, as this was found to be a good balance for obtaining accurate representation of the system effect with an efficient model run time.

All cladding loads were applied as uniformly distribution pressures to the exterior surface of the furring elements.

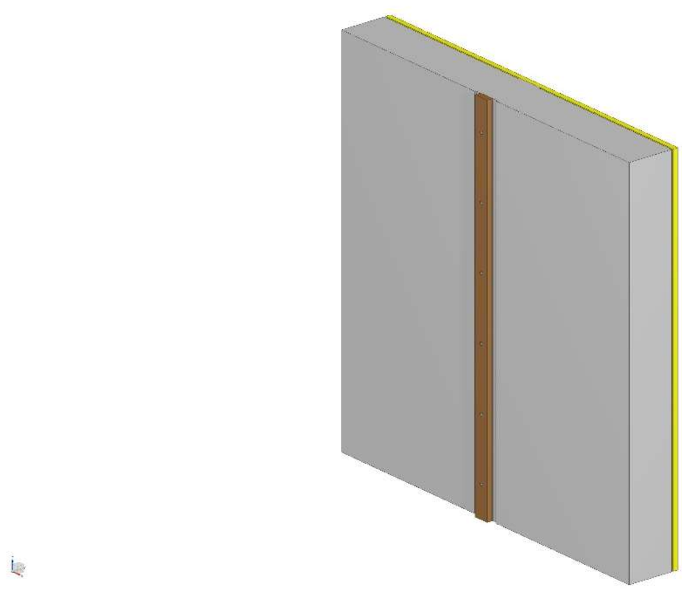

Figure 2: Nx FEA Model Geometry

4.2 MATERIAL PROPERTIES

The polystyrene foam layer was modeled as 6" (152 mm)thick EPS Type 2 rigid insulation. The preformed drainage cavity and furring strip grooves were estimated based on Solar Dry product data sheets. The modulus of elasticity of the EPS was estimated as 5.0 MPa, based on available published industry data for similar materials.

The vertical furring was modeled as 3/4" thick x 2" wide (19 mm x 50 mm) plywood strapping, spaced at 16" (406 mm) o.c. horizontally. The modulus of elasticity for the furring was taken as 7.75 MPa, corresponding approximately with CSA O86 published values for 5-ply Canadian Softwood Plywood (CSP) oriented with the face grain for bending.

The fasteners through the furring to the backup wall were modeled as ¼" wood screws, and a modulus of elasticity for the steel of 200,000 MPa. The screw rotational end constraint at the backup wall was modeled both as pinned (free to rotate) and fixed (restrained by the wood wall) in trial versions of the analysis. The results showed this parameter had little effect on the results, so a pinned connection was chosen for the final model, to be conservative. The pretension (clamping) force on the screw was found to be a critical parameter for the analysis results, and a value of 40 lb (0.18 kN) was selected for the final model based on approximately 20% of the ultimate pullout load for the screw.

The backup wall was restrained from deflection in order to focus the results on the cladding assembly outboard of the wall. A 19 mm layer of OSB sheathing was modeled for continuity with the EPS layer. A coefficient of friction of 0.25 between the EPS insulation and the wood elements of the model was used, based on US Department of Energy published data for this parameter in similar applications.

4.3 APPLIED LOADS

Loads were applied according to NBCC serviceability limit states load combinations:

- Dead Load alone (gravity, self-weight of cladding)
- Dead Load + Wind Load
- Dead Load + Earthquake Load

As identified previously, the dead load for the cladding was applied as 0.24 kPa for the light weight cladding, and 0.57 kPa for the medium weight cladding.

Wind loads for low, medium, and high wind zones were applied as 0.60 kPa, 0.86 kPa and 1.12 kPa respectively. Wind loads were applied both acting inwards towards the wall (positive pressure, compression) and outwards away from the wall (negative pressure, suction). The wind pressures were applied equally in each direction, in separate load cases.

Earthquake loads for the high seismic zone were applied as 0.10 kPa for the light weight cladding, and 0.21 kPa for the medium weight cladding. For the low seismic zone, the applied loads were 0.02 kPa for the light weight cladding, and 0.05 kPa for the medium weight cladding.

5. STRUCTURAL ANALYSIS RESULTS

The results of the engineering assessment and finite element analysis offered the following general insights regarding the behavior of the continuous insulation system:

- The 6” layer of Type II EPS rigid insulation performed adequately under the applied loads and is suitable for construction with the listed assemblies.
- The applied wind loads did not have a significant effect on the performance of the systems in terms of deflection. The one exception being negative wind pressure (suction) for light cladding with screws spaced further apart vertically (16”) which caused significant vertical deflections.
- The trial wind pressure climate zones (low, medium, high) ended up being fairly redundant, with very similar deflection results found for each pressure value. Because of this, only the high pressure (0.65 kPa) zone is referenced in the final results.
- The theoretical performance of the system under earthquake loads was quite good. Loads applied in-plane with the cladding resulted in negligible deflections. Seismic loads out-of-plane (towards or away from the wall) would be less than the wind loads for the chosen load cases.
- The gravity loads (weight) of the cladding were more significant in the performance of the system. The “medium weight” cladding (12 psf) intended for stucco had deflections that approached the recommended limit of 1/64” (0.4 mm). Since the deflection limit is so small, the recommended fastener spacings were selected with a design tolerance included in the results.
- The vertical deflection due to gravity loads varied significantly when the material properties in the analysis were modified. In particular, the coefficient of friction between materials was critical, and similarly, the pretension (clamping) force in the fasteners was critical. To a lesser extent, the modulus of elasticity of the polystyrene and the modeling details of the screw head within the wood furring played a role.
- The sensitivity to the screw pretension and friction indicates much of the deflection is related to initial slippage in the system when loads are applied, and movement occurs before the polystyrene layer can truly be engaged as a compression element.
- Initially, the model was run with a single screw and applicable tributary areas of the SDI panels. Later versions included multiple screws to assess the difference in deflections with the system effect. There was a significant reduction in deflections from one to three screws, but diminishing returns with additional fasteners.
- The rotational constraint at the end of the fastener and the bending stiffness of the screw itself did not affect the results significantly. The screw was conservatively modeled as completely free to rotate at the wood stud in the final model. This is considered beneficial as it is conducive to modeling the system in a similar way with light gauge steel studs in the future, where the screw would not be restrained from rotating at the connection.
- The ultimate strength of the various components was typically not the limiting factor in the design recommendations, generally deflections were the critical aspect.

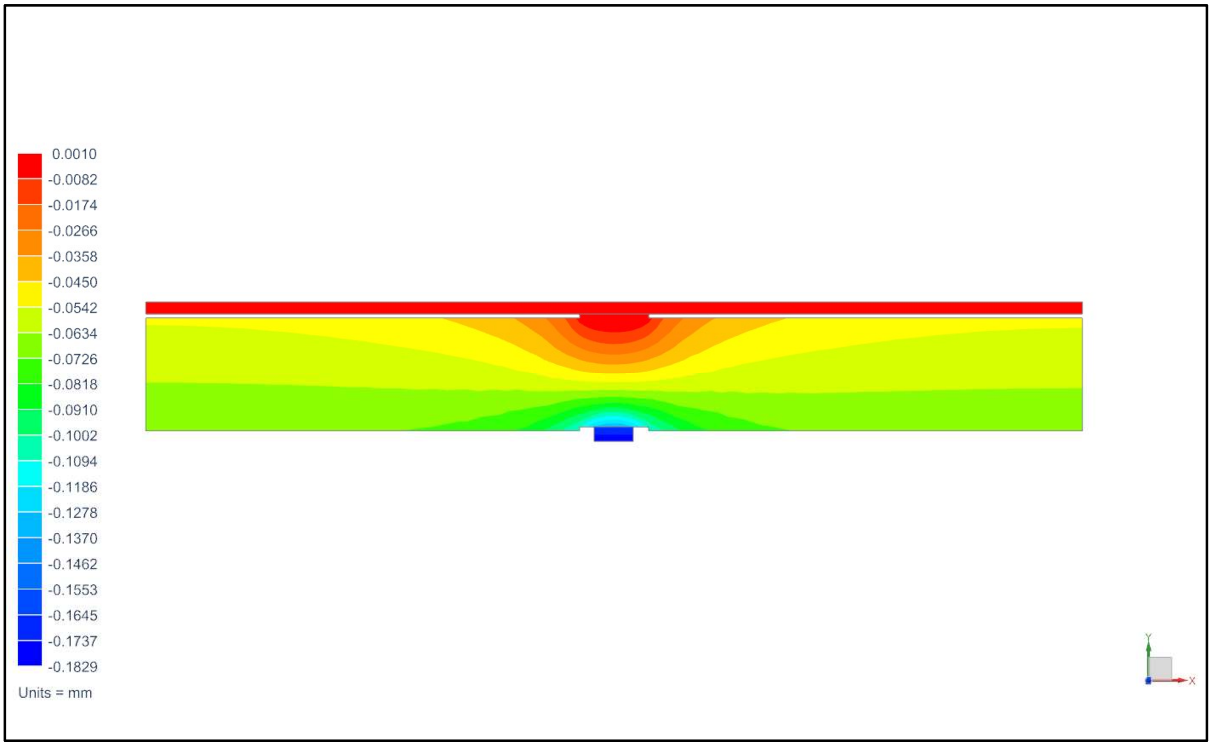

Figure 3: Cross-Section of Solar Dry Panel

The deflection results (SLS) from the Nx analysis are summarized in the table below. The results shown have been modeled with a fastener vertical spacing of 16” (406 mm) for light weight cladding, and 8” (203 mm) for the medium weight cladding. The applied loads shown are for the high wind zone and the high seismic zone. Note “- Wind” in the table refers to negative wind pressure (suction) on the face of the wall.

Table 1 – Deflection at Furring from Nx FEA Analysis (SLS)

Cladding Weight	Load Case	Vertical Deflection (mm)	Out-of-Plane Deflection (mm)	In-Plane Deflection (mm)
Light	Dead	0.07	0.19	0.00
Light	Dead + Wind	0.06	0.20	0.00
Light	Dead - Wind	0.45	0.20	0.00
Light	Dead + Seismic	0.09	0.20	0.03
Medium	Dead	0.18	0.27	0.00
Medium	Dead + Wind	0.16	0.27	0.00
Medium	Dead - Wind	0.22	0.27	0.00
Medium	Dead + Seismic	0.18	0.27	0.05

Based on the results of the Nx analysis and other hand calculations for strength parameters, we have developed the following recommendations for the vertical fastener spacing. The recommended spacing is listed for the two cladding weights (light and medium) selected for the analysis, for the targeted climatic load zones. The results are summarized in the table below.

Table 2 – Recommended Fastener Vertical Spacing

Cladding Weight	Wind Zone	Seismic Zone	Fastener Spacing
Light 5 psf (0.24 kPa)	Low (q50 = 0.35 kPa)	Sa(0.2) <= 1.0	16” (406 mm)
	Med (q50 = 0.50 kPa)	Sa(0.2) <= 1.0	16” (406 mm)
	High (q50 = 0.65 kPa)	Sa(0.2) <= 1.0	16” (406 mm)
Medium 12 psf (0.54 kPa)	Low (q50 = 0.35 kPa)	Sa(0.2) <= 1.0	8” (203 mm)
	Med (q50 = 0.50 kPa)	Sa(0.2) <= 1.0	8” (203 mm)
	High (q50 = 0.65 kPa)	Sa(0.2) <= 1.0	8” (203 mm)

As shown above, the fastener spacing does not change with the wind pressure zones ranging from a 50-year return period reference pressure of 0.35 kPa to 0.65 kPa. The results were not highly sensitive to the wind pressure value, but the spacings are shown for each for completeness.

This is not to say that the fastener spacing is independent of the wind value. We did see relatively significant deflections in the furring, particularly for negative wind pressure (suction) on the wall. It is expected that for some buildings with wind load parameters that exceed those applied in this analysis (eg post-disaster buildings, extreme wind zones, speed-up over hills and escarpments, etc.) the fastener spacing would need be confirmed on a case-by-case basis.

Similarly for earthquake loads, the fastener spacing recommendations were not highly sensitive to the particular seismic zone for the cladding weights selected. Again, there may be specific buildings where the design parameters are particularly high and would require additional engineering review.

Generally, the primary factor in the fastener spacing recommendations is the cladding weight. The recommended fastener spacing from Table 2 is considered suitable for the cladding weight listed, for wood frame buildings up to 6 storeys (20 m) in height, for the climatic load limits described in this report.

The recommended fasteners are ¼” (6 mm) diameter wood screws, embedded 1.5” (38 mm) into the wood studs of the backup wall assembly. Based on the theoretical results, the screws would require a pretension (clamping force) of 40 lb (0.18 kN) per screw for the results to be valid.

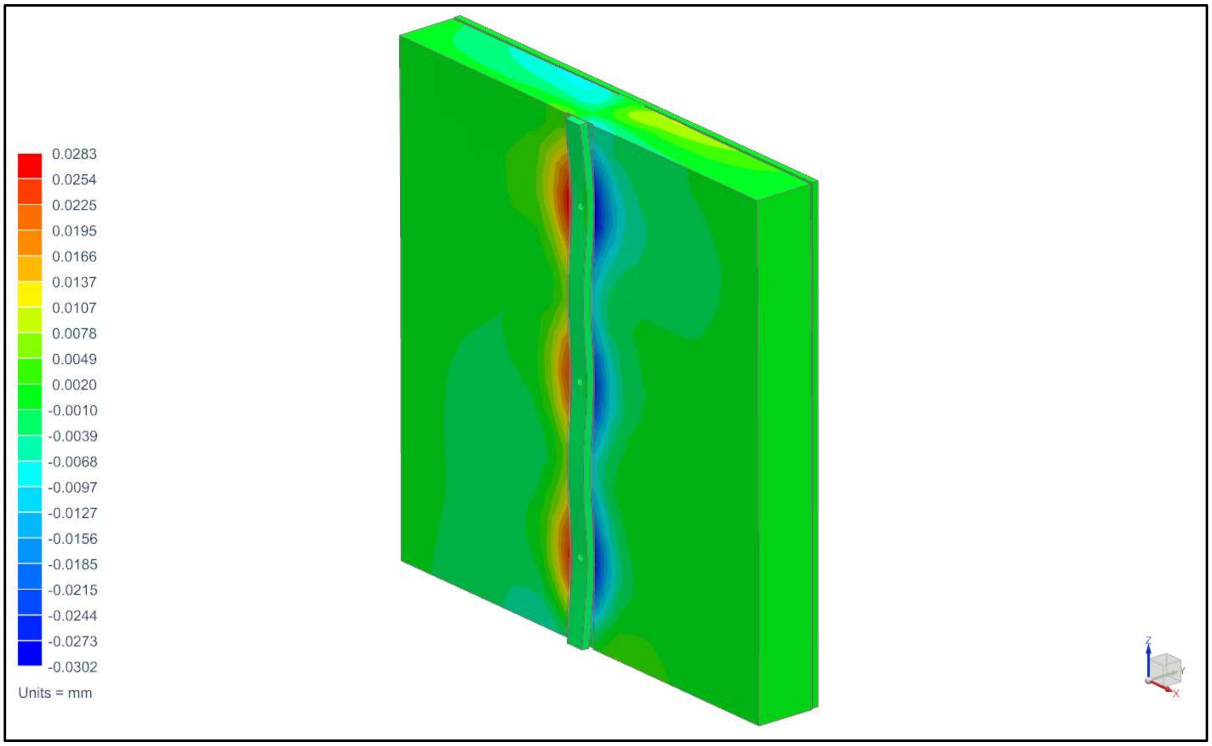

Figure 4: Solar Dry Deflected Shape under Applied Load (100x)

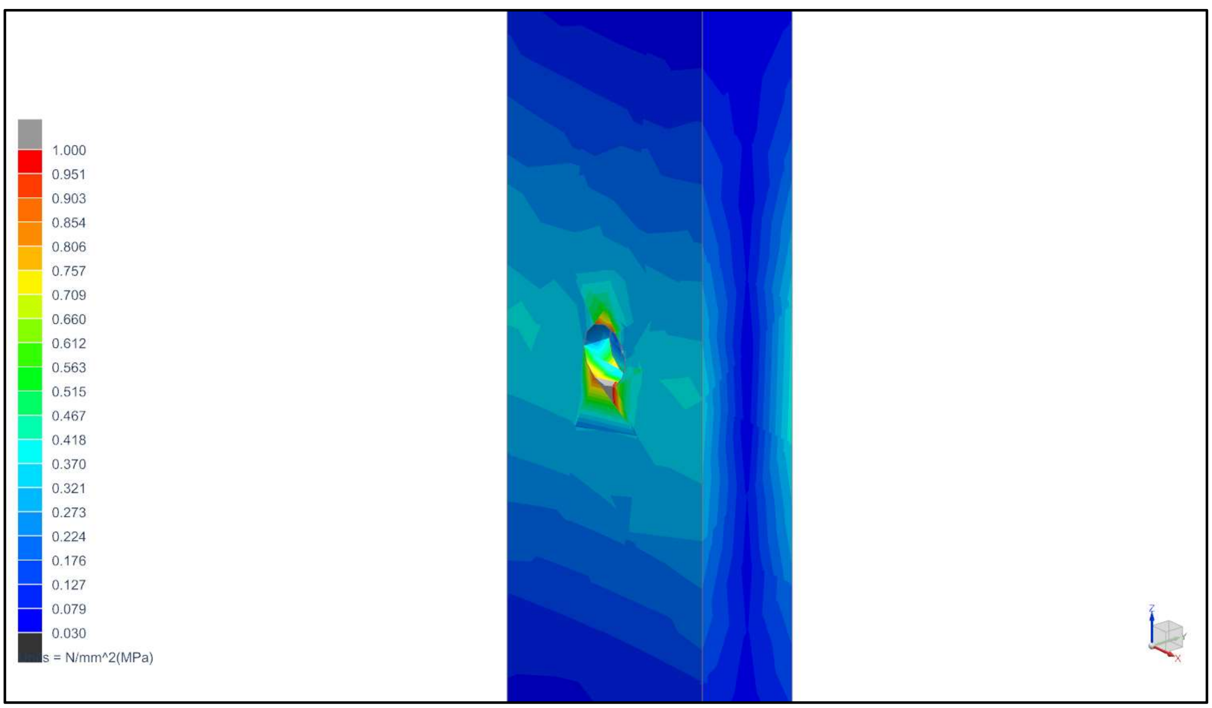

Figure 5: Detail of Stress around Fastener in Furring Strip

6. CONCLUSION

From this report, the following conclusions can be made:

- Generally the behavior of the 6" layer of continuous insulation demonstrated good performance under applied load in the analysis. The limitations on fastener spacing is based primarily on deflection criteria for serviceability limit states.

- The performance of the cladding system under applied wind and seismic loads is considered good, with the main deflections occurring to gravity loads (self-weight) of the cladding. The one exception is negative wind pressure (suction) on the wall, with light weight cladding and relatively large vertical fastener spacings.

- The behavior of the system in resisting initial vertical deflections from applied cladding weight is highly sensitive to the pretension (clamping force) in the screw. Appropriate installation procedures for the Solar Dry Insulation should be developed to provide guidance for contractors to achieve the recommended pretension of 40 lb (0.18 kN) per screw, while avoiding damage to the system components.

- The recommended fastener installation for light weight cladding (5 psf) with the Solar Dry Insulation system is ¼" wood screws spaced at 16" o.c. vertically, embedded 1.5" to the wood studs of the backup wall. This is considered suitable for fibre-cement board cladding on buildings up to 6 storeys in height.

- The recommended fastener installation for medium weight cladding (12 psf) with the Solar Dry Insulation system is ¼" wood screws spaced at 8" o.c. vertically, embedded 1.5" to the wood studs of the backup wall. This is considered suitable for stucco cladding on buildings up to 6 storeys in height.

We trust that this report provides the information that was of interest from our structural assessment. Please contact us if you have any questions or comments regarding the contents of this study.

Morrison Hershfield Limited

PROFESSIONAL PROVINCE OF G. J. McNEILL # 29443 ENGINEER

MAR 0 8 2018

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APPENDIX A – SOLAR DRY INSULATION PRODUCT DATA SHEETS

1 888 735-3012
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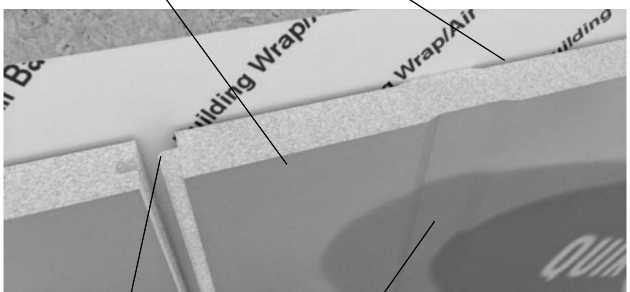
TECHNICAL DATA SHEET

ID. QT SDI
March 2016

Quik-Therm Solar Dry (SDI)

Solar Dry Panel
1.2 m wide x 2.4 m long (4′ x 8′)
3.8 cm to 15 cm (1½″ to 6″) Thick

Drainage Plane
0.5 cm (3/16″) deep x 33 cm (13″) wide channels allow walls to breathe, dry and drain



Furring Strip Channels
9 cm (3.5″) channels every 40 cm (16″) help to pre-align furring strips over wall studs to establish a code compliant rain screen

Tongue & Groove Connections
1.3 cm x 1.3 cm (1/2″ x 1/2″)

Meets CAN/ULC S701-05 / CCMC #13457-L

Quik-Therm Solar Dry (SDI) is manufactured using Type 2 closed-cell expanded polystyrene (EPS) with advanced metallic polymer facers. Located on the inboard side of SDI are drainage cavities that occupy 75% of its surface. These cavities allow walls to drain, dry and disperse moisture. On the outboard side, 1.9 cm (3/4″) thick furring strips are mechanically fastened through SDI panels directly to framing members. The location for furring is identified by shallow depressions in SDI panels. 1.9 cm (3/4″) thick furring between SDI panels and cladding achieves a code compliant rain screen. Cladding materials such as cement board cladding are fastened to the furring strips. Quik-Therm Solar Dry has been tested in accordance with CAN/ULC S-701. SDI is durable and does not easily chip crack or break. There is no thermal drift and its R-value will remain stable over its entire service life. SDI does not contain dyes, formaldehyde or blowing agents. It may contain up to 15% recycled EPS.

- Effective R-value tested to ASTM C1363 "Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies".
- Tested to ASTM E96 "Standard Test Method for Vapor Transmission of Materials". SDI is "effectively" impermeable. Qualifies as a secondary WRB (Weather Resistive Barrier).
- Tested to CAN/ULC S101-14 "Standard Methods of Fire Endurance Tests of Building Construction and Materials". Up to six story wood frame. Maximum 5 cm (2″) thick SDI. Special fasteners and installation details apply.

NOTE: For typical wall designs and Effective R-value ratings, please see back of page.

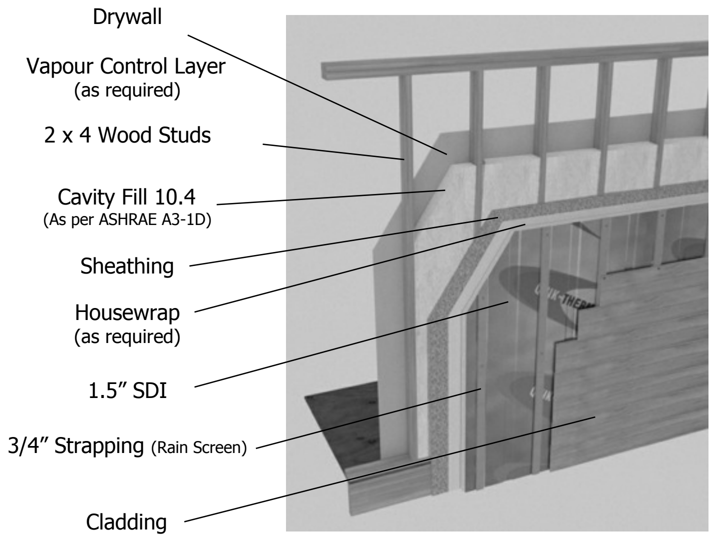
Characteristic	Units	Nominal Value	Test Method
Dimensional Stability - Maximum Linear Change	%	1.5	ASTM D2126
Length Tolerance	mm (in)	±3.2 (±0.125)	—
Width Tolerance	mm (in)	±1.6 (±.063)	—
Water Vapour Transmission	perms	<1.0	ASTM E96
Density (Type 2)	kg/m^3 (lbs/ft^3)	23 (1.4)	ASTM D1622-03
Compressive Strength (Type 2)	kPa (psi)	136 (19.7)	ASTM D1621-04a
Long Term Thermal Resistance (LTTR)	Thermal Resistance Remains Stable Over Life of Service		
Flexural Strength (Type 2)	kPa (psi)	257 (37.3)	ASTM C203-05
Limiting Oxygen Index	%	26	ASTM D2863-97
Flame Spread Index	—	250	CAN/ULC - S102.2
Smoke Density Index	—	410	CAN/ULC - S102.2

The information on this Technical Data sheet is based upon data considered accurate. Quik-Therm Insulation Solutions Inc. does not assume any responsibility for any misrepresentation or assumptions the reader may formulate.

Tested By Canadian Accredited Laboratories. Supported By Building Science Engineering

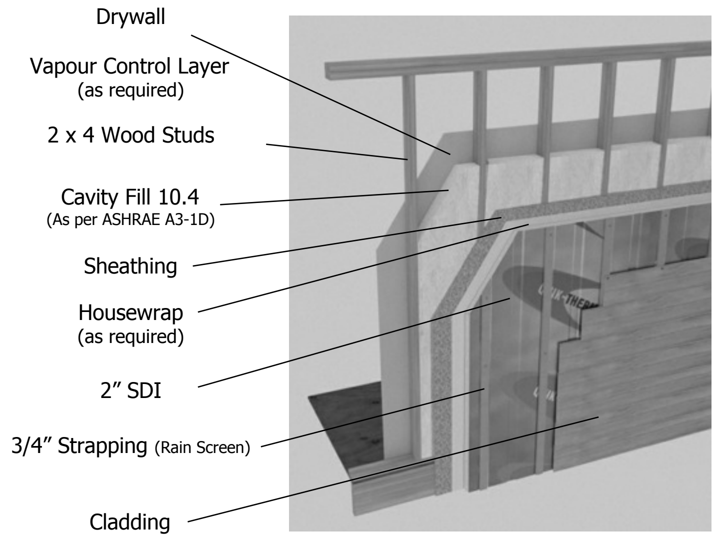
SDI Advanced Wall Assemblies

Code Compliant Part 9



Effective R-20.5

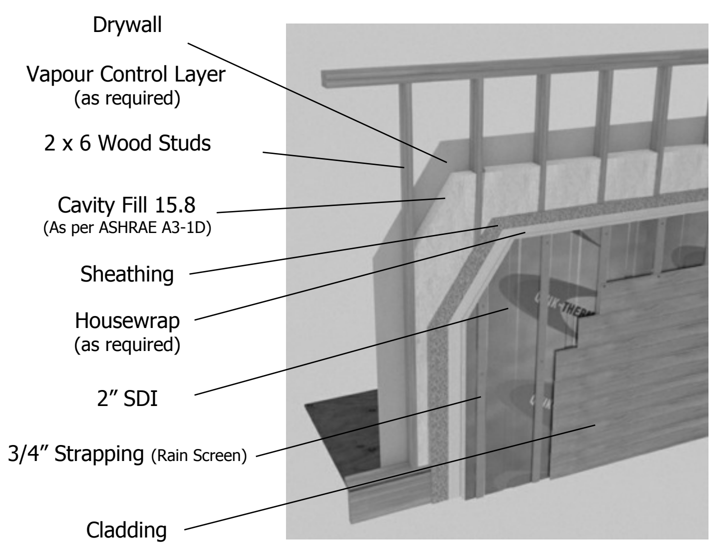
Code Compliant for Zones 5, 6, 7, 8



Effective R-22.1

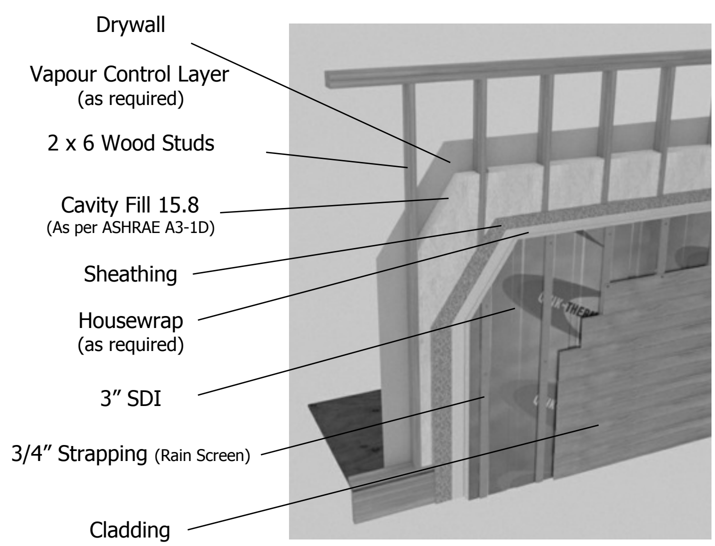
Code Compliant for Zones 5, 6, 7, 8

Code Compliant Part 3 / NECB 2011



Effective R-28.3

Code Compliant for Zones 5, 6, 7



Effective R-32.8

Code Compliant for Zones 5, 6, 7, 8

Note: Bug screen and flashing strip required at the bottom of the wall.