GOVERNMENT OF SAINT LUCIA

Department of Sustainable Development

Solar PV Demonstration Project

IBRD SIDS DOCK GRANT# TF0A1671

SLU-SOLAR-SE-CONS-IC-01-17

REPORT

DETAILED STRUCTURAL ASSESSMENT

October, 2017
Prepared By: Norman St. Ville
Consultant Engineer

Contents

INTRODUCTION

The Government of Saint Lucia (GOSL) obtained funding from the Support for Small Island Developing States (SIDS) DOCK Support Program (SIDS DOCK SP) towards financing of the Solar PV Demonstration Project. A component of the project is the establishment of a commercial scale rooftop solar-energy photovoltaic (PV) system at the Owen King EU Hospital, Millennium Highway, Castries.

The objectives of this assignment is to undertake a structural assessment of the roofing systems of four (4) roofs at the Owen King EU Hospital (OKEU) to determine its capacity to withstand the additional proposed loads and to assess the impact of the imposed loads on the structure and performance of the structure after installation of the Solar PV system and make appropriate recommendations for enhancement. This report shall provide detailed investigation on the impact and performance of an additional dead load of five (5) pounds per square foot (24 kilograms per square meter) on each roof

SCOPE OF THE ASSIGNMENT

The assignment requires that the Consultant determine the capacity of the existing roofing structure to withstand the additional proposed loads, impact of the imposed loads on the structure and performance of the structure after installation of the Solar PV. In particular the assignment includes:

To consider the following mounting options in the structural assessment:

- The solar array racking to be attached to the corrugated metal only using sheet-metal screws and engineered attachment assemblies. In this option, the system would not attach to the roofing panels underneath.
- Bolted through the corrugated metal, then through the structural roofing panel underneath, and then use a fender washer on the underside of the roofing panel to provide wind-uplift resistance for the array.
- Screwed into the steel purlins supporting the roofing panels.
- recommend suitable structural mounting options for the concept being proposed

The assessment should consider determination / analysis of the following:

- The available reserve dead-load capacity of the roof framing and supporting structure
- The impact and performance of an additional dead load of five (5) pounds per square foot (24 kilograms per square meter) on each roof.
- The efficacy of the proposed mounting options

- The performance of the structure (after installation of the PV System) during wind, wind-uplift, shear forces, seismic forces and tropical storms and hurricane force winds typical climatic conditions for countries such as Saint Lucia. The code-mandated wind strength is 170 mi/hr (76 m/sec), including the "Climate Change Wind Factor" pursuant to OECS 1202.2.

SITE DESCRIPTION

The buildings under investigation form part of the main structures of the OKEU Hospital. The Buildings are constructed of reinforced concrete moment resisting frame and are 3-storeys with roof height of about 45 feet and positioned along the southern slope fairly exposed to the prevailing winds. The Buildings were recently constructed; construction completed in the early 2016 and the roofs construction appears to be sound with no evidence of corrosion defect. Photos were taken during the first site visit and can be viewed *in Appendix E*. Drawings of the roofs as built sections *is attached in Appendix A. The roof insulated sheet covering observed on site is similar to the sample displayed in FiG 1* Figure 1 below indicates the assumed roof covering observed at the site upon which the proposed PV system will be affixed. Fig 2 shows the proposed layout for the PV array upon the existing roofs

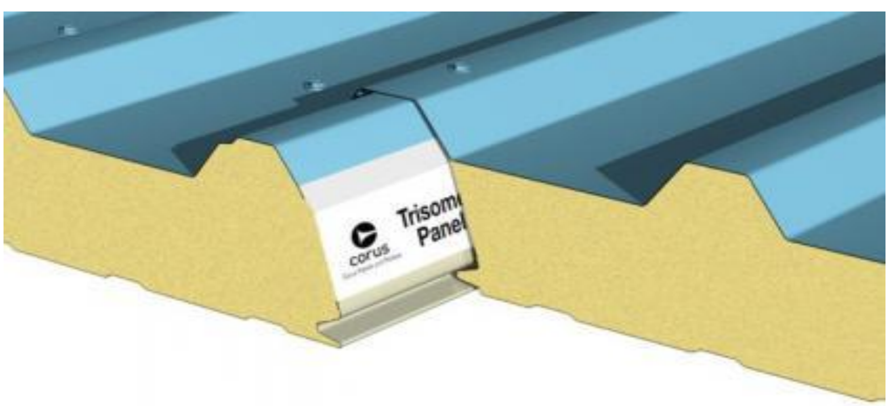
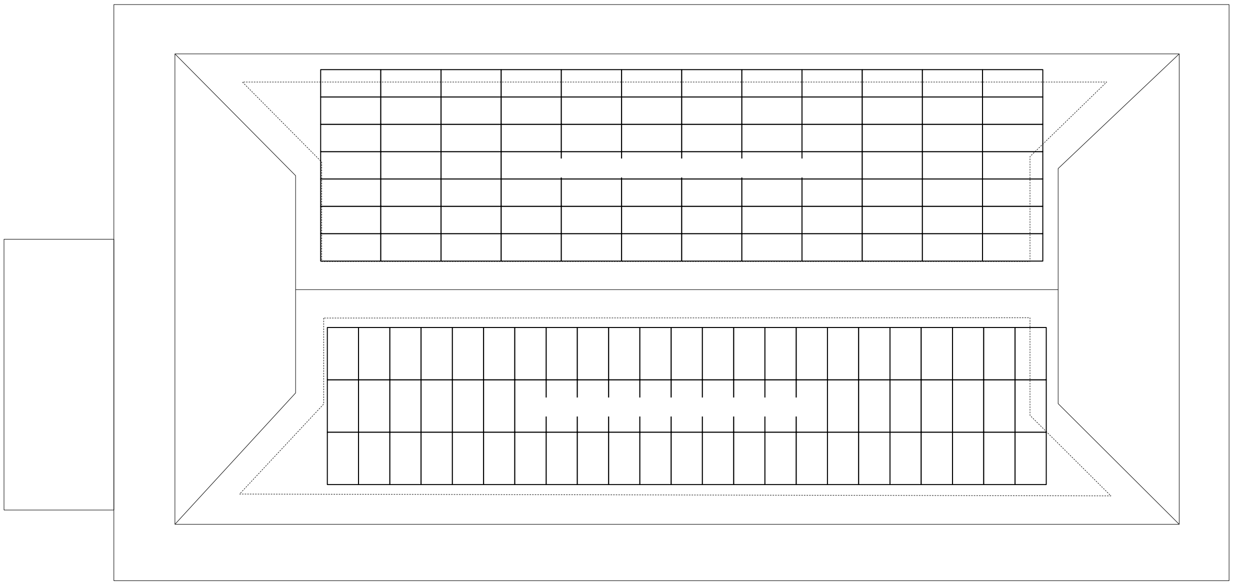


Fig 1 Trisomet 333 Insulated Panels (for roofing and cladding)

Figure 2 shows the plan for the proposed Solar PV system.



CONSTRAINTS

As built drawings are not available for the Buildings. Manufacturers specification for the roof sheeting was not available. Therefore, some level of roof reproduction was undertaken to facilitate the assignment as well as assumption for the sheet metal specification. To get an appreciation of the roof details and to arrive at a model drawing of the roof observations, inspections and measurements were obtained through site visits conducted on September 28 2017.

EXISTING CONDITIONS

The roofs are constructed of insulated metal roof covering. However, the technical are not available for confirmation. The sheeting is connected to “C” structural steel purlins that are further connected to “I” section rolled steel rafters

The design information in relation to the roofs was provided however based on observations made during the visit it is evident that the constructed roof does not conform to the plan design specifications and / or assumptions. The immediate observation was a significantly lower dead load applied than what was assumed in the engineering design (provided). The original design assumed the deal load to be 898n/m2 contributed by roof tiles, sheathing and plaster board however site observations reveal that construction materials were different to these assumptions and almost 50% reduction in dead loading.

This roof is supported by C-shape steel purlins and W-shape rafters and houses mainly mechanical plant and equipment. The load path for all roofs leads from the rafters to structural-steel columns and directly down to the foundation roof floor slab and supporting foundations.

STRUCTURAL ANALYSIS METHODOLOGY

The proposed solar panels and PV system will be located and affixed at the roof level. The majority of the roof footprint would be covered following completion of the proposed works / installation of the system.

Design roof loads were determined using ASCE 7-1 and wind speed of 170mph. The wind speed used to inform the assessment is significantly higher than the 155-mph used to inform the original roof design. The imposed load for the PV system at the roof level was derived from technical information and technical specification contained in the contract documents for the works. The loading combinations calculated are based on the total dead load combined with wind loads for each roof design. Dead and live loads were added together to determine total gravity loads. However, the live load condition is only applicable during maintenance and construction and was not included in the wind analysis undertaken. This methodology / approach resulted in a more conservative outcome.

In general, members were checked using hand calculations to obtain its capacity to carry the new loads. Sample calculations are included within the Appendices contained in the report. There is a significant reduction in the dead load assumptions from original design which results in a corresponding increase in uplift at roof level on the structures. The deviation in construction from use of the proposed / recommended design is of major concern. The roof structure has sufficient reserve dead load capacity to support the proposed additional PV dead load.

The calculations included In the Appendices provide results on the maximum shear force, maximum moment, maximum allowable deflection, moment of inertia, and plastic section modulus. The results were then compared to the C and W-shape beam properties in AISC Steel Manual. Open-web steel joists were evaluated on the basis of its capacity to carry maximum and total and live shear loads according to Steel Joist Institute Standard Load Tables.

Specifications are not available for the insulated sheet metal roof covering; therefore, suitable assumptions were made for the material observed on site. The material found to be most similar to the existing roof is *Trisomet 333 Insulated Panels (for roofing and cladding),* the specification for which can be found in Appendix D. This material can withstand extremely high uplift of 6 Kpa based on the spacing of the support purlins, 1.2m . It is unknown whether the PV module could be affixed through the sheet metal using bolts seals and suitable washers due to the absence of the material strength information. However, connection details for the standoff connection of the Solar Panel rails to the roof framing members is therefore critical. Both the lag screw diameter and the length of threaded embedment into the roof framing members will determine the standoff Uplift capacity and requires suitable fixing detail to be connected to the roof sheeting. An objective / reasonable approach could not be undertaken to verify connections through the roof sheeting material to connect solar panels. Therefore, this proposed option would require further exploration to obtain suitable detailed fixing connections for the installation contractors.

The absence of the specification left the only available option for solar panels to be affixed through sheeting and into the underlying purlins to the manufacturers fixing specification.

DESIGN STANDARD AND DATA

Design Standards and Reference

CODES & STANDARDS:

BS 8110	Reinforced Concrete Design
BS 5950	Structural Steel Design
BS 5268	Timber Design
ST.Lucia	Building Code

UBC 1997	Uniform Building Code
ASCE 7-10	Minimum Design Loads for Buildings and Other Structures

STRUCTURAL EQUATIONS

Deflection	$\Delta = (5 w l 4) / (384 E Ix)$ [in]
Maximum Deflection (total load)	$\Delta max, total = l / 240$ [in]
Maximum Deflection (live load)	$\Delta max, live = l / 360$ [in]
Maximum Service Load Moment	$Mmax = (w l 2) / 8$ [kip ft]
Maximum Service Load Shear Force	$Vmax = (w l) / 2 \leq Vn / \Omega v$ [kip]
Plastic Section Modulus about x-axis	$Zx \geq Mmax / Fy$ [in3]
Variable Symbol [Units]	
Uniformly Distributed Load	w [kips/ft]
Span Length	l [ft, in]
Modulus of Elasticity of Steel	E = 29000 [ksi]
Moment of Inertia of Cross Section	Ix [in4]
Maximum Shear Strength	Vn [kips]
ASD Safety Factor	$\Omega v = 1.67$ -
Specified MinimumYield Stress (A992 Steel)	Fy = 50 [ksi]

ASSUMPTIONS:

a. The installation would result in no removal of any existing wind resisting walls or frames and no sequent reduction in their stiffness.
b. The installation of new PV system would not result in an increase of wind exposure to areas of the existing building of 10% or more,
c. Checking for structural adequacy of the existing building due to wind loads were omitted
d. Member connections are sized based on designed capacity of members and future loads.

e. If all members are sufficiently sized for the roof structure and its supporting columns, the supporting columns and caissons are also able to support the additional green roof load.

INPUT DATA

Roof Type	Gable
Building Category	IV
Ceiling Type	None
Coverage %	20
Frame Size	187 x 104 I section (178 x 102 x 19)
Purlin size	159 x 64 C section (150 x 75 x 18)
Lag Screw Diam. (in)	3/8
Lag Screw Embed. (in)	2
PV Weight (psf)	4
PV Width (ft)	4
Rafter Span (ft)	12
Purlin span (ft)	4
Roof Mean Height (ft)	45
Roof Slope (degrees)	25
Roofing Type	Polyurethane and metal sheet composite
Standoff Spacing (ft)	4
Standoff Staggered	Yes
Wind Exposure	B

Wind Speed (mph)	170

LOAD COMBINATION

Wind uplift is the force created by strong winds will result in Wind Uplift on the Solar Panels. These panels will literally fly off the roof if not anchored securely. The Wind Uplift force is dependent upon Wind velocity, Topographic features, Roof height, Dead weight of the roof structure, such as Roofing, plywood, framing, ceiling, insulation and Solar Panels. This all helps resist the Wind uplift force.

The spacing of the standoffs will affect the Wind Uplift force attributed to each standoff. The greater the standoff spacing, the greater the Uplift Wind force. The standoff connection of the Solar Panel rails to the roof framing members is therefore critical. Both the lag screw diameter and the length of threaded embedment into the roof framing members will determine the standoff Uplift capacity and requires suitable fixing detail to be connected to the roof sheeting.

The combinations to be considered will be

2 **Added weight of the solar panels**

Existing Roof Dead Load + Solar Panel added Dead Load + Roof Live Load.

3 **Added Weight of the Solar Panels plus Wind Upward**

Existing Roof Dead Load + Solar Panel added Dead Load + Wind Force acting Upward.

DESIGN CODE

ASCE 7: American Society of Civil Engineers (ASCE)'s standard that provides minimum design loads for buildings and other structures. Gust Wind Speed: The maximum wind speed averaged over a duration of 3 seconds. The 3-second gust wind speed forms the basis of the design wind loading standard in the United States.

Basic Wind Speed: It is the 700-year wind speed divided by the square root of 1.6, at a height of 10 m (33 ft) in flat, open terrain.

The following table shows the scale broken down by central pressure, winds, and storm surge:

Category	Central Pressure (mb)	Wind Speed (mph)	Storm Surge (ft.)	Damage
5	<920	>155	>18	Catastrophic

CLIMATE CHANGE CONSIDERATIONS

The basic wind speeds (including the effect of the load factor) used for the design of buildings in the Saint Lucia area are dominated by Category 4 and 5 hurricanes passing near the Island. Climate change requirements adjust the basic wind speeds for Category III and IV buildings by about 10 percent. The proposed wind speed of 170mph is therefore considered suitable.

CALCULATIONS AND ANALYSIS

Wind pressure P = q GCp – qh (GCpi)

where

qh	=	velocity pressure evaluated at height Z=h, in kPa	=	47.3x10-6KzKztV2I
GCpi	=	internal pressure coefficient	=	0.8, -0.3
Kz	=	exposure coefficient	=	0.8
Kzt	=	wind speed over hill & escarpment coefficient	=	1.0
V	=	basic wind speed	=	280 Kph(175mph)
I	=	importance factor)	=	1

The following analysis was displayed only for the roof component and does not include walls of the structures.

Mean Roof Level (m)	**kz**	**qz = 47.3x10-6 kzkztV2Iw**	**qGCp**			**qh(GCpi) 0.8**	**-0.3**	**P(KPa) = qGCp - qh(GCpi) 0.8**			**P(KPa) = qGCp - qh(GCpi) -0.3**		
			Windward 0.3	Leeward 0.5	Sidewall 0.7			windward	leeward	sidewall	windward	leeward	sidewall
14.01	0.8	2.97	-0.71	-1.18	-1.66	2.37	-0.88	-3.08	-3.55	-4.03	0.18	-0.298	-0.778

DESIGN LOADS

DEAD LOAD

a.	Insulated sheeting	103 N/m2
b.	PV modules	236 N/m2
	SUB-TOTAL	339 N/m2
	Total applied Dead Load	376 N/m2
c.	“ C “purlins	205 N/m
d.	“W” Rafters	227 N/m

LIVE LOAD

a.	Construction Load	600 N/m2

WIND LOAD

b.	Roof Level pressure	-3.55 KPa

Slope of roof = 25 degrees

Load Condition DL + LL -

Load Condition DL + WL = -3211N/m2 or 0.067Kips /sf

CONCLUSION

The results of the structural assessment / analysis confirms / suggest that the originally designed structure should be capable of carrying the additional 5psf dead load of the proposed solar PV system.

The dead loads used in the original design were found to be significantly higher than the dead loads of the present constructed roof even with the added solar panel loads. The increased wind speed of 170mph is also significantly higher than original design and the net effect was a significantly higher uplift near 60%. Increased from the design pressure.

The existing roof materials are capable of withstanding the imposed dead loads and resultant pressure. The connection details for the standoff connection of the Solar Panel rails to the roof framing members is therefore critical and fixing details should be properly designed for fixing of the panels into the roof. This is important given the level of uplift caused by the load scenarios. Therefore, this proposed option would require further exploration to obtain suitable detailed fixing connections for the installation contractors.

The absence of the specification left the only available option for solar panels to be affixed through sheeting and into the underlying purlins to the manufacturers fixing specification. The purlin spacing is 1.2m and therefore the suppliers would be required to design the modules for fixing at 1.2m spans. If this is not an option then further design and drawings are necessary to provide connection and fixing detail.

RECOMMENDATIONS

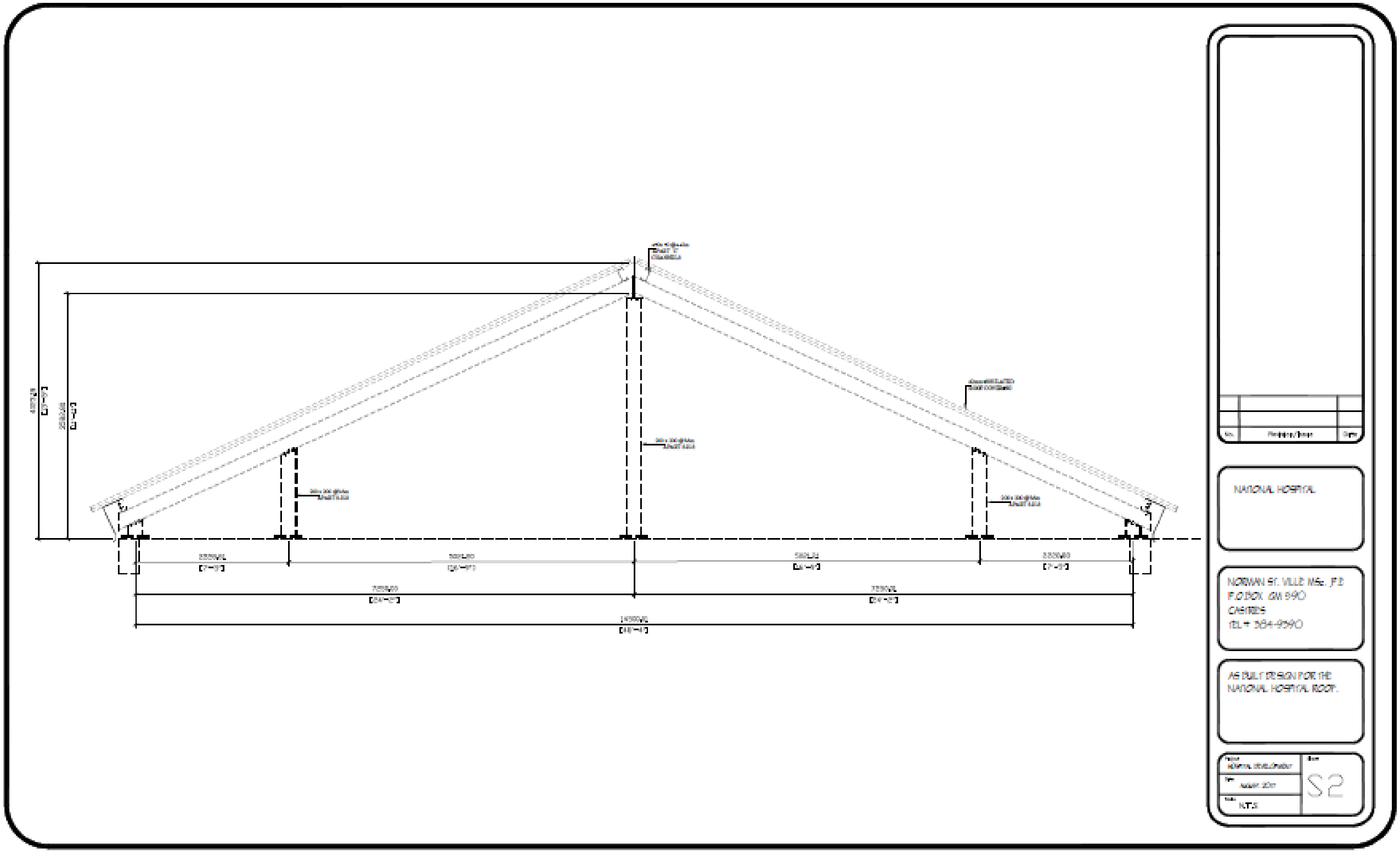
Based on the foregoing, the proposed mounting option to be considered is affixing the solar panels through sheeting and into the underlying purlins using the manufacturers' specifications to guide the installation, the panels will be required to span 1.2m for this connection to be achieved. The mounting option through the sheet metal and insulation composite requires sourcing of the manufacturer's specifications for the installed roofing panels, for further review. and development of detailed drawings (*depicting the connections for installation of the solar pv panels*). The consultant further recommends that all connections be checked due to the significant increase in uplift pressure (60%) that was obtained from combining the revised wind speeds and the reduced dead loads.

Therefore, the Consultant recommends the provision of detailed drawings *depicting the connections for installation of the solar pv panels be prepared to guide the bidding process.*

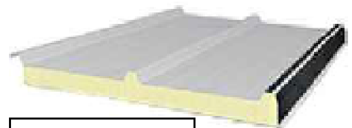
APPENDICES

APPENDIX A

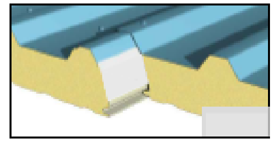
ROOF DETAILS


NATIONAL HOSPITAL
NORMAN ST. VILLE MSc. P.E
P.O BOX GM 990
CASTRIES
TEL+ 384-9590
AS BUILT DESIGN FOR THE
NATIONAL HOSPITAL ROOF.
N.T.S
S2

Parameters
Surface texture - Flat, big wave,small wave, linened
Steel Thickness - 0.4~0.8 mm
Core Thickness - 50~200mm
Effective width - 800mm,1000mm
Length - as per customer's request, less than 11.8m
Ripple height - 40mm
Materials - polyurethane & steel sheets
Polyurethane Density - 40kg/m³
Color - white grey, silver grey, sea blue, bright red
Cladding - hot galvanized,galvalume
Coating - PE/SMP/HDP/PVDF
Character - light weight, heat insulation, fire proof,
water proof, environment friendly
Application - large size factory, store house, exhibition halls,
gymnasiums,etc.



INSULATED ROOF COVERING



INSULATED ROOF COVERING

1. Introduction

PU is polyurethane, a general term for large molecular compounds containing repeated carbamate groups in the main chain.It is made from organic diisocyanate or polyisocyanate with dihydroxy or polyhydroxy compounds. Polyurethane foams are widely used. Polyurethane composite board also known as PU sandwich board. It is composed of polyurethane as core material in the middle and two metal surfaces. Foaming adopts world advanced mixing pouring technology of the six components of on-line automatic operation and can one time complete ingredients and proportion, also can online adjust according to the temperature, so as to produce a distinctively high strength, energy saving, green environmental protection material. Because of its good fire protection and moistureproof performance, the polyurethane foams commonly used in composite board sealing side.

2. Application scope

The polyurethane core board is an excellent energy-saving building material, its excellent thermal insulation, fire protection and sound insulation performance can provide an efficient solution to world's energy consumption crisis. Polyurethane sandwich panel is widely used in large industrial plants, cold storage, garage, mobile houses, pavilion, gymnasium, shopping centers, airports, power plants, villa, hospitals, high-rise office buildings,etc.

3. Air tightness

The polyurethane roof board is connected by a blind nail, and the board is tightly connected.
The unique design of the water tank prevents rainwater from penetrating and avoids the phenomenon of cold bridge.
The height of 40mm wave peak greatly increases the bearing capacity of roof plate.

4. Efficient heat preservation

The good composite plate has the lowest thermal conductivity of the organic thermal insulation materials (less than 0.022), and the 3.5cm thick of polyurethane composite plate is equivalent to the insulation effect of 1m thick concrete. Polyurethane composite board is an ideal heat preservation product to realize the target of 75% energy saving in China.

5. Strong flame retardant

Fireproof rating B, and the composite panels tested by 1000 ℃ flame burning for 30 minutes don't wear.

6. Durable

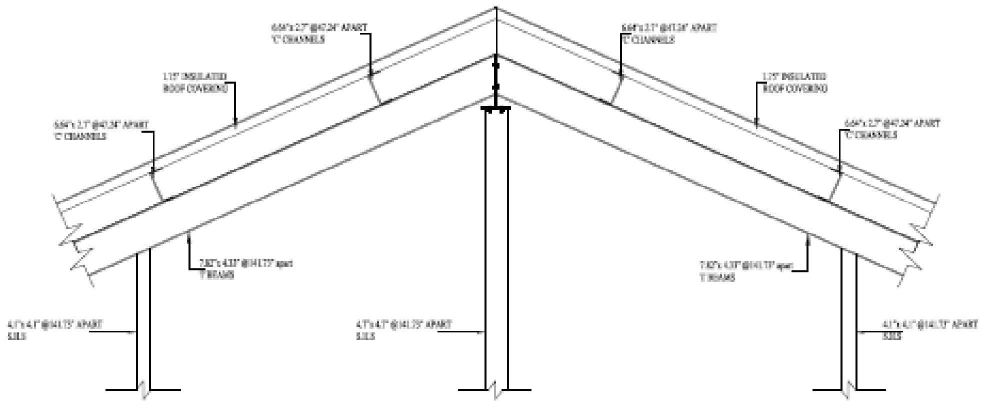
The composite plate has been weathering tested for more than 6 months and has stable performance, which can be used for the life as long as the building.

7. Good dimensional stability

The compressive strength is more than 200kpa, not deformed under high temperature.

8. Low carbon & environmental protection

The polyurethane composite board adopts biological raw materials without fluorine foaming. It does not contain the harmful substances which are prohibited or restricted by the state



No.	Revision/Issue	Date

NATIONAL HOSPITAL

NORMAN ST. VILLE MSc., P.E
P.O.BOX GM 5910
CASTRIES
TEL# 584-9590

AS BUILT DESIGN FOR THE
NATIONAL HOSPITAL ROOF.

Project: NATIONAL HOSPITAL	Sheet: S1
Date: AUGUST, 2017	
Scale: N.T.S	

APPENDIX B

SAMPLE RAFTER CALCULATION

This is the calculation for the typical purlin loading case according to the typical loading pattern.

$\Delta total$ = (5 w l 4) ⁄ (384 E Ix)
= (5 (0.27)(30) 4(12) 3) ⁄ (384 (29000) Ix)
= 10.7 in5 ⁄ Ix

Where w = 1.62kips acting at three point loads

Δmax, total = l ⁄ 240
= (12*12) ⁄ 240
= 0.6 in

$\Delta total$ ≤ Δmax, total

10.7 in5 ⁄ Ix ≤ 0.6 in

→ Ix ≥ 17.83 in4 (GOVERNS)

Vmax = 3 x 1.6 / 2
= 4.8 ⁄ 2
Vmax = 2.4 kips

Mmax = 8 ft kips

Zx ≥ Mmax ⁄ Fy
≥ (8)(12) ⁄ 50
Zx ≥ 1.92 in3

→ Select a W 8 X 10 Member (Ix = 30.8in4, Zx = 8.87in3)

Check: $\Delta total$ = 10.7 in5 ⁄ 30.8 ≤ 0.6 in

= 0.35 in ≤ 0.6 in OK

APPENDIX C

SAMPLE PURLIN CALCULATION

This is the calculation for the typical purlin loading case according to the typical loading pattern

$\Delta total = (5\ w\ l\ 4) / (384\ E\ Ix)$
$= (5\ (0.27)(30)\ 4(12)\ 3) / (384\ (29000)\ Ix)$
$= 10.7\ in5 / Ix$

Where w = 0.27kips/ft
L = 12 ft

$\Delta max, total = l / 240$
$= (12*12) / 240$
$= 0.6\ in$

$\Delta total \leq \Delta max, total$
$10.7\ in5 / Ix \leq 0.6\ in$
$\rightarrow Ix \geq 17.83\ in4$ (GOVERNS)

$Vmax = (w\ l) / 2$
$= (.27)(12) / 2$
$Vmax = 1.62\ kips$

$Mmax = (w\ l\ 2) / 8$
$= (0.27)(144) / 8$
$= 4.86\ ft\ kips$

$Zx \geq Mmax / Fy$
$\geq (4.86)(12) / 50$
$Zx \geq 1.16\ in3$

→ Select a C7 X 14.5 Member (Ix = 27.2in4, Zx = 9.75 in3)

Check:

$\Delta total = 10.7\ in5 / 27.2 \leq 0.6\ in$
$= 0.44\ in \leq 0.6\ in$ OK

APPENDIX D

Trisomet 333 Insulated Panels Specifications

Permissable wind uplifts (negative) loads in kN/m2

Sheet Thickness	Weight kg/m2	Span Condition	Span mm												
			1200	**1400**	**1600**	**1800**	**2000**	**2200**	**2400**	**2600**	**2800**	**3000**	**3200**	**3400**	**3600**
40mm	10.45	single	6.29	5.11	4.27	3.63	3.14	2.74	2.41	2.14	1.91	1.72	1.55	1.41	1.28
		double	6.29	5.11	4.27	3.63	3.14	2.74	2.41	2.14	1.91	1.72	1.55	1.41	1.28
		multi	6.29	5.11	4.27	3.63	3.14	2.74	2.41	2.14	1.91	1.72	1.55	1.41	1.28

Permissable Loads:

Permissable downward (imposed) loads in kN/m2

Sheet Thickness	Weight kg/m2	Span Condition	Span mm												
			1200	**1400**	**1600**	**1800**	**2000**	**2200**	**2400**	**2600**	**2800**	**3000**	**3200**	**3400**	**3600**

40mm	10.45	single	6.21	4.99	4.12	3.46	2.95	2.54	2.2	1.79	1.42	1.14	0.91	0.72	0.57
		double	6.21	4.99	4.12	3.46	2.95	2.54	2.2	1.92	1.69	1.49	1.33	1.19	1.06
		multi	6.21	4.99	4.12	3.46	2.96	2.54	2.2	1.92	1.69	1.49	1.33	1.19	1.06

APPENDIX E

Photographs of Roof Support Structure