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3 Warm cryostat design and layout (Dimie, Christoph)

3.1 Global design (Dimi, Christophe)

3.2 Member size and availability (Dimi)

Standard members have been selected available off the shelf and hot rolled sections

“Standard” length is anything between 9’000mm and 15’100mm.

With some small price addition (~20 euro per ton) they can manufacture anything up to 24’100mm.

3.3 Choice of splice corner pieces (Dimi)

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4 Cold membrane cryostat design and layout (Marzio)

5 Warm cryostat components list (Dimie, Christoph)

6 Warm cryostat mechanical calculation

6.1 Relevant safety codes (Olga and Andrea)

Applicable codes for the design of the steel support structure for the LBNF cryostat.

1) The internal **Fermilab ES&H document** pertaining to the design, procurement and construction of membrane cryostats (FESHM 5031.7) has been approved and posted on the Fermilab ES&H website: http://esh-docdb.fnal.gov/cgi-bin/ShowDocument?docid=3067

2) **Concerning the allowable stresses.**
The design can be made according to any Code: ASME Section VIII Div. 1, Div. 2, ANSI/AISC 360, European steel building code, etc. However, as additional precaution and safety considerations, such design needs also to satisfy the following two conditions:

a) The design with all applicable loads shall be verified with Finite Element Analysis to ensure a level of safety equivalent to that afforded by the current version of the ASME Boiler and Pressure Vessel Code, Section VIII Div. 1. Table 7.1 presents the current allowable stress limits per ASME Boiler Pressure Vessel Code, Section VIII, Div.1: **the minimum of St/3.5 or Sy/1.5.**

b) For a support structure made of structural steel, the U.S. code ANSI/AISC 360-10 "Specifications for Structural Steel Buildings" shall be used by a professional structural engineer to ensure tensile, shear, and compressive stresses do not exceed limits for design stresses given in Table 7.1, temperatures, and temperature differentials.

This does not imply that such codes (ASME Section VIII Div. 1 and/or ANSI/AISC 360) need to be used for the design. ASME Section VIII Div. 2 can be used for the design of any and/or all parts of the structure.

However the allowable stresses are to be taken from Table 7.1 of the document "FESHM 5031.7 Guidelines" for any part: steel beams, bolts, etc. **The minimum of St/3.5 or Sy/1.5**.

It is also possible to have localized higher stresses (than those presented in Table 7.1), providing that they are adequately compensated from adjacent members (according to a specific design Code).

At today the warm steel structure is calculated according to the EUROCODE 3 – some cross checks are presented hereafter in relation to the ASME BPVC-VIII-1-2013, BPVC-VIII-2-2013, ASME BPVC-IID-2013_Customary

6.2 Dimensions and Table of actions

Table with nominal loads (pressure, weight), dimensions, safety factors (Dimi with Andrea, Joao)

6.2.1 Dimensions:

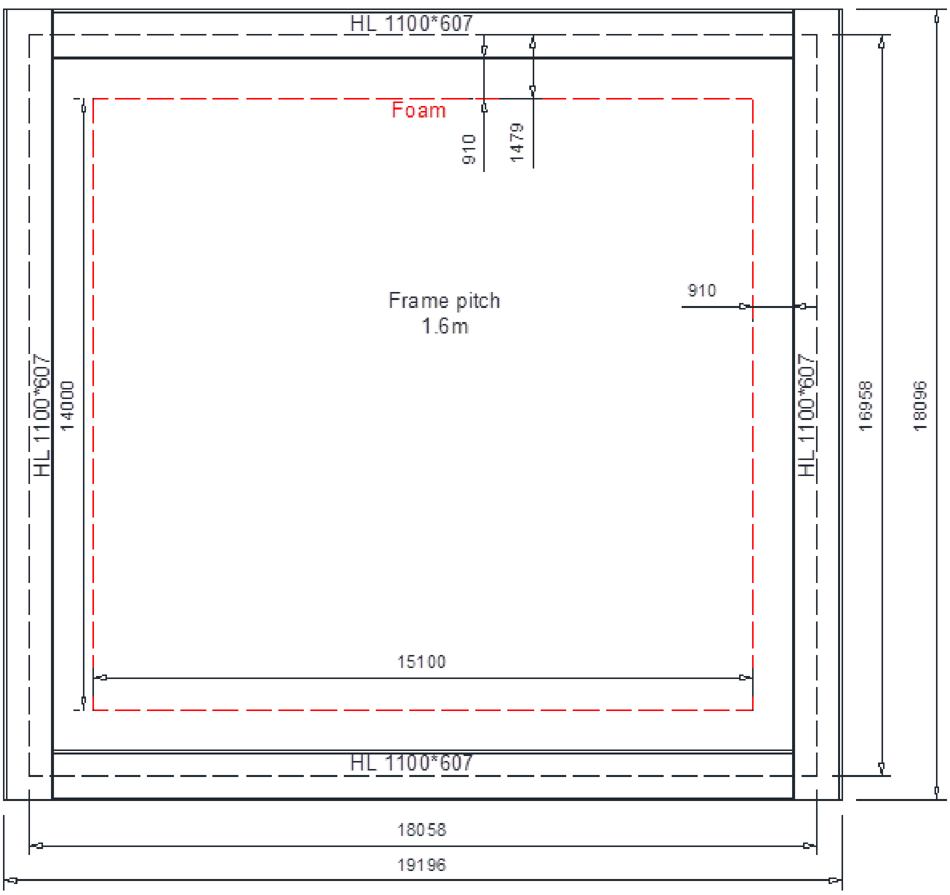
The insulation thickness was decided to be increased by 300mm, from the current 600mm to 900mm, per side.

Therefore the internal dimensions between the two 10mm stainless steel plates will be: L = 63'800mm; W = 16'900mm; H = 15'800mm

the support structure (after the 10mm SS plates) shall starts at:

Internal dimensions of warm structure	Length	Width	Height
[mm]	63'820	16'920	15'820

The dimensions of the main transverse portal frame are shown below:



6.2.2 Pressure loads and LAr weight

Filling ratio up to 98% of liquid (rounded in the following models at 100%)

Top pressure: working pressure between 50 to 120 mbar. Safety valve opening pressure set at 350 mbar, which becomes the design nominal pressure.

Static head of Lar (14 m). Density taken as 1400 kg/m3

$$\Delta H := 14 \cdot m$$

$$static\_head := \rho \cdot g \cdot \Delta H = 1.922 \cdot bar$$

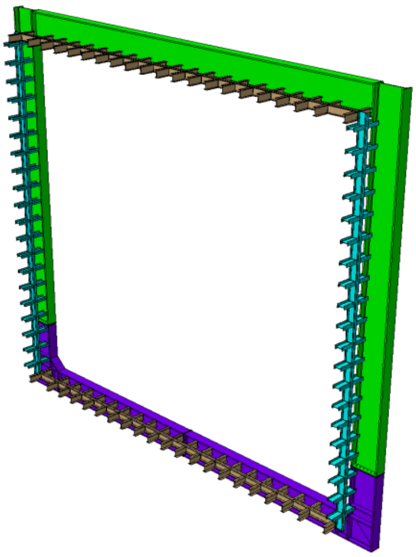
$$p_{grad} := \frac{\rho \cdot g \cdot \Delta H}{L} = 0.126 \cdot \frac{bar}{m}$$

6.2.3 Masses

Self-weight of composing members.

Main beam members: **HL1100-607** (607 kg/m)

The weight of the insulation with the stainless steel and intermediate membranes shall be in the order of 90kg/m2, which will make it approximately 350T. In addition the weight of the 10mm SS plates is not included in the calculation above. It would add another 80kg/m2. I.e. total: 170kg/m2.



Small grid beam / m = 131.5 kg/m

Table with loads coming from all members, local reinforcements, bracings, inspection platforms, detector load, equipment load on the roof, etc - See for details **Annex 6A: Total Mass of the cryostat mass**, for estimates of the entire structure and unit cell (pitch of 1.6 m)

6.3 Calculation models:

Providing a bullet description and results from.

6.3.1 Structural members

6.3.2 Analytical models (stress, deflection and M,T diagrams) (Andrea and Joao)

In order to determine to extreme cases of top and bottom connection for the vertical main members, two analytical models were developed.

First models of a cell unit, a portal frame with a pitch of 1.6 m, loaded with pressure gradient, no structural self-weight, boundary conditions top pinned, bottom fully constrained, or pinned top and bottom

………………..

6.3.3 *Global "box" models: to shows that a portal model is well representative (Piet? and Diego)*

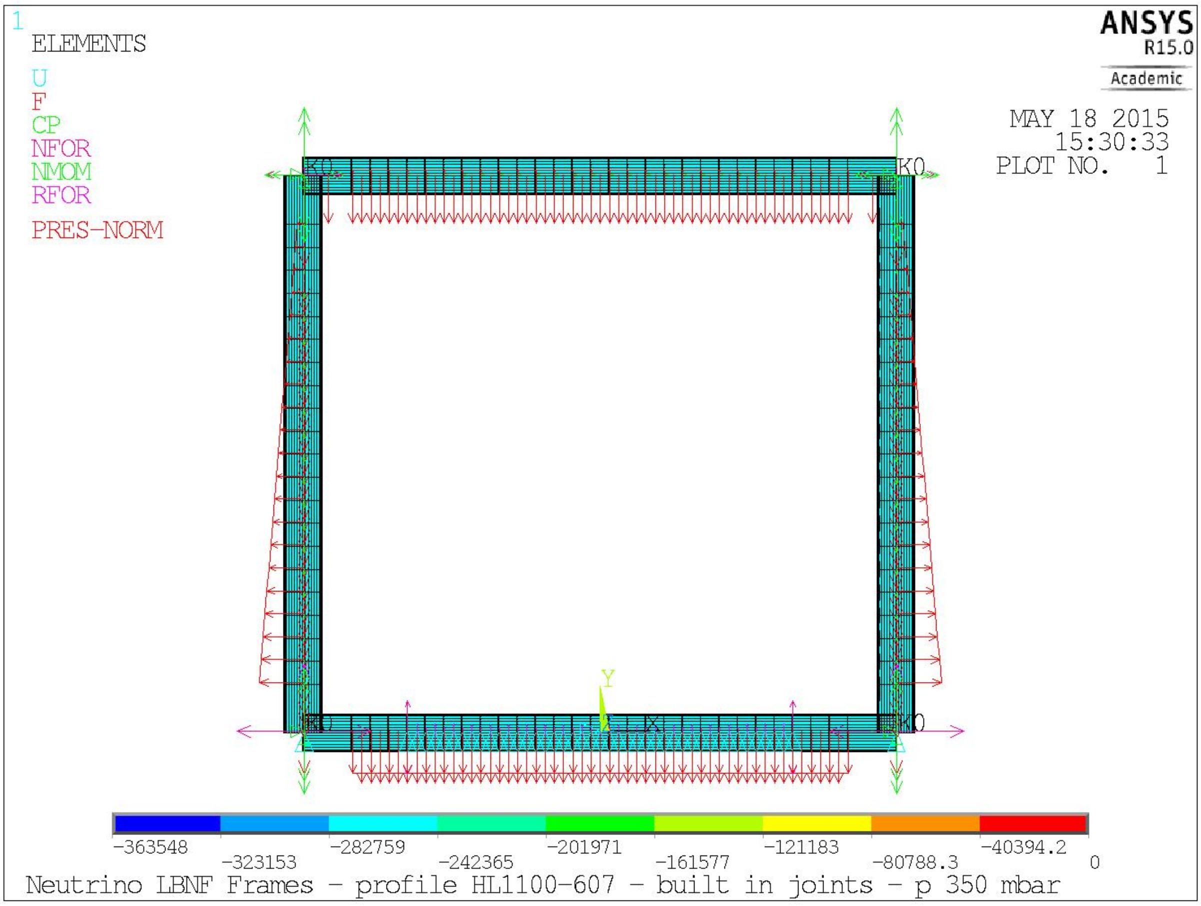
6.3.4 Static and buckling portal beam model (Andrea)

Parametric ANSYS apdl script for the calculation of one main transversal portal frame.

Elements: 3 nodes beam 189 and linear rotational spring combin14

Parameters:

```
w=18.058                ! new beam neutral axis width
h=16.958                ! new beam neutral axis hight
gap=0.91+1.138/2        ! do not put gap to zero, rather 600: use it in this version V4 to offset the
load top and bottom
foam=0.91+1.138/2
divide=20
lockbottom=6    ! to get 4.75 +/- part touching the floor (from the old center axis)
po=3.5E4        ! 3.5E4 Pa - 0.035 MPa - 350 mbar
pitch=1.6
ro=1400
rotstiff=1.25E9 ! average top bottom - 1.2 top 1.3 bottom solid shell - minimal for factor 4 by PW =
0.5 x 1.7E7
ymbeam=2E11
denbeam=7800
wf11=0.410              ! HL1100-607 baseline beam
wf21=0.410
hb1=1.138
thf11=0.055
thf21=0.055
thw1=0.031
!
wf12=0.550              ! option for top and bottom sections...
wf22=0.550
hb2=1.2
thf12=0.075
thf22=0.075
thw2=0.040
```



Loading and boundary conditions:

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Static and buckling results

6.3.5 Static and buckling shell portal model (Diego)

6.3.6 Table and Comparison of results above (Andrea and Diego)

6.4 Portal minimal stability calculations (Piet): *in compatible word format*

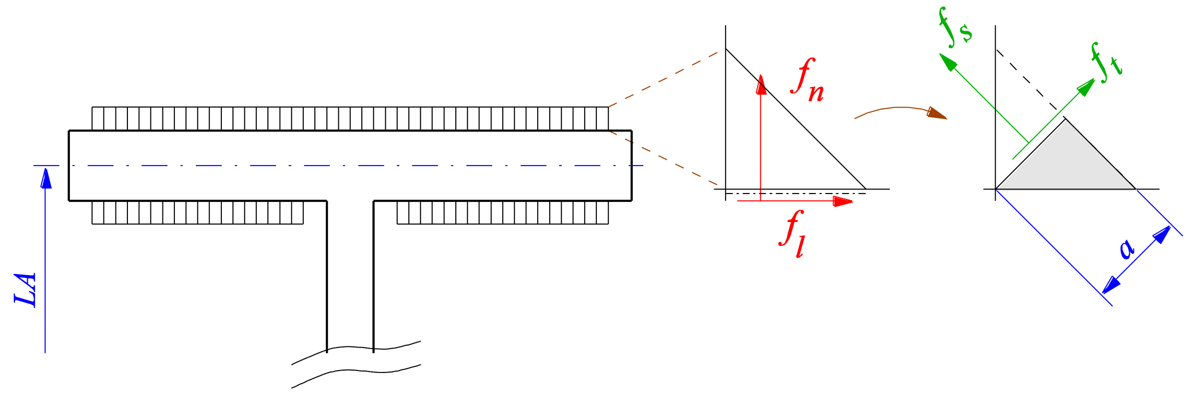
6.5 Bolted and welded connections

6.5.1 Design of main connections and analytical calculations (Joao)

6.5.2 Models and FEA results of connections (Diego)

6.5.3 Weld analytical calculations (Piet)

To provide a heavy moment connection for a beam 1138/410/31/55 mm against a thick plate, a dimensioning to the Eurocode spirit resulted in flange welds with *a* = 33 mm , web welds with *a* = 13 mm , and a moment capacity of M_0 = 7.29 MNm .



In order to simplify, we assume the moment M_0 as the *only* loading, and we neglect the *web* welds. The loading to the flange welds, again somewhat simplified :

generalized traction : $F = \frac{M_0}{LA}$ = 6.73 MN ,

where the lever arm : LA = (1138-55) mm = 1083 mm .

Now, with a useful seam length : $L = 2 \cdot 410\text{ mm} - 31\text{ mm} - 6a = 591\text{ mm}$,

(optimistic insofar as the corner rounding of the profile has been neglected), we have :

$f_l = \frac{F}{L}$, $f_n = 0$,

$f_s = |f_t| = \frac{f_l}{\sqrt{2}}$,

$\sigma_\perp = |\tau_\perp| = \frac{f_l}{\sqrt{2}a}$ ($= \sigma_0$) = 244 MPa ,

$\sigma_{\text{von Mises}} = \sqrt{\sigma_\perp^2 + 3\tau_\perp^2} = 2\sigma_0$ = 488 MPa ,

hinting at some generalized yielding of the seam(s) when loaded at its nominal capacity M_0 .

6.6 EC3 verification

SCIA verification (Joao)

6.7 Comparison EC3 and ASME global safety factors

Capacity and safety margins (Piet, Joao)

ASME allowable stresses (Andrea)

6.8 Possible future optimizations

Lighter roof, smaller floor, (Piet)

Bracings (Dimi, Joao)

7 Installation sequence

7.1 Logistics (Marzio)

7.2 Installation operations (Dimie, Crhistoph)

7.3 Schedule (Marzio)

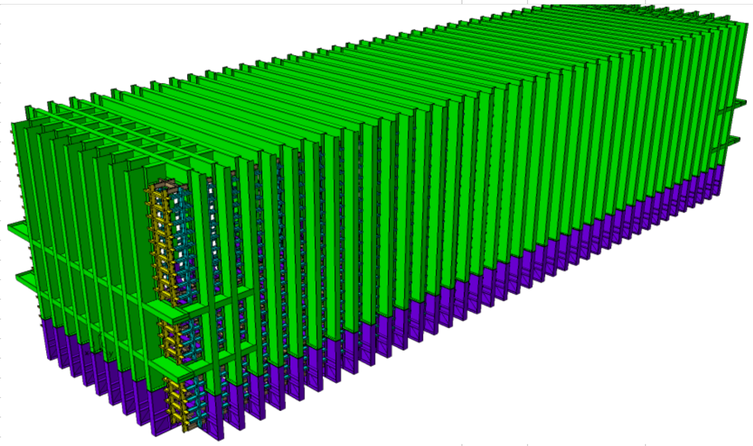
8 Overall Schedule of procurements and operations (Marzio)

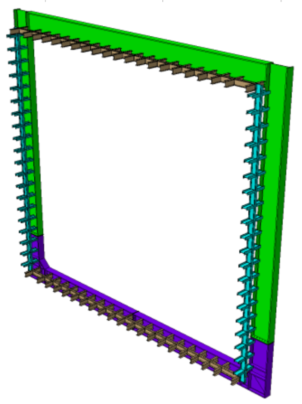
9 Conclusions (Marzio)

10 Annex 6A: Total Mass of the cryostat

when considering the vertical part and the horizontal floor part including the corner pieces:

Neutrino Lar tank					*Date: May 18th 2015*	
composed of:				For one cell		
	Quantity	Weight (kg)/unit	Total weight (kg)	Quantity	Weight (kg)/unit	Total weight (kg)
Metallic structure		***3261688***			***62551***	
Floor	**1**	**999550**	**999550**	**1**	**23126**	**23126**
Transversal beam Corner (Long side) (1.138x0.41x0.055x0.031)	78	8204	639912	2	8204	16408
Longitudinal beam Corner (Short side) (1.138x0.41x0.055x0.031)	18	3954	71172	0		
Longitudinal beam (1.2x0.55x0.075x0.04) L=1.19m	36	722	25992	0		
Grid - standard module	34	2250	76500	1	2250	2250
Grid-Intermediate Extremity Y0	32	129	4128	0		
Grid-Intermediate Extremity Y+/-	8	228	1824			
Grid-Extremity Y0	16	135	2160			
Grid-Extremity Y+/-	4	241	964			
10mm stainless steel skin (m2)	1079	80	86322	27	80	2164.48
Insulation + membrane + bariers(m2)	1006	90	90576	26	90	2304
Intermediate feet: not designed						
Roof	**1**	**705287**	**705287**	**1**	**17048**	**17048**
Transversal beam (1.138x0.41x0.055x0.031) L=16.92m	39	10269	400491	1	10269	10269
Intermediate longitudinal beam (1.2x0.55x0.075x0.04) L=1.19m	36	722	25992			
Extremity longitudinal beam (1.2x0.55x0.075x0.04) L=1.305m	18	792	14256	0		
Grid - standard module	34	2311	78574	1	2311	2311
Grid-Intermediate Extremity Y0	32	129	4128	0		
Grid-Intermediate Extremity Y+/-	8	228	1824			
Grid-Extremity Y0	16	135	2160			
Grid-Extremity Y+/-	4	241	964	0		
10mm stainless steel skin (m2)	1079	80	86322	27.056	80	2164
Insulation + membrane + bariers(m2)	1006	90	90576	25.6	90	2304
Short side	**2**	**166718**	**333436**	**0**	**0**	**0**
Vertical beam (1.138x0.41x0.055x0.031) L=14.678m	9	9028	81252	0		
Horizontal central beam (1.138x0.41x0.055x0.031) L=1.19m	16	722	11552	0		
Horizontal extremity beam (1.138x0.41x0.055x0.031) L=2.993m	4	1911	7644	0		
Grid-Y0 top	8	975	7800	0		
Grid- Extremity top	2	1836	3672	0		
Grid - Y0 middle	8	449	3592	0		
Grid - Extremity middle	2	848	1696	0		
Grid - Y0 Bottom	8	566	4528	0		
Grid - Extremity Bottom	2	1069	2138	0		
10mm stainless steel skin (m2)	267	80	21388			
Insulation + membrane + bariers(m2)	238	90	21456			
Long side	**2**	**611708**	**1223415.576**	**2**	**11188**	**22376**
Vertical beam (1.138x0.41x0.055x0.031) L=14.678m	39	9028	352092	1	9028	9028
Horizontal Intermediate beam (1.138x0.41x0.055x0.031) L=1.19m	8	722	5776			
Horizontal extremity beam (1.138x0.41x0.055x0.031) L=1.305m	4	792	3168			
Grid-Standard module	34	2160	73440	1	2160	2160
Grid- Intermediate top	4	975	3900			
Grid - Intermediate middle	4	449	1796			
Grid - Intermediate Bottom	4	566	2264			
Grid- Extremity top	2	1034	2068			
Grid - Extremity middle	2	475	950			
Grid - Extremity Bottom	2	599	1198			
10mm stainless steel skin (m2)	1009	80	80707	25	80	2024
Insulation + membrane + bariers(m2)	937	90	84349	24	90	2146





And when considering all the vertical and horizontal parts:

Neutrino Lar tank

Date: May 18th 2015

composed of:					For one cell		
	Quantity	Weight (kg)/unit	Total weight (kg)		Quantity	Weight (kg)/unit	Total weight (kg)
Metallic structure		***3261688***				***62551***	
Floor	**1**	**714622**	**714622**		**1**	**17190**	**17190**
Transversal beam Corner (Long side) (1.138x0.41x0.055x0.031)	78	5236	408408		2	5236	10472
Longitudinal beam Corner (Short side) (1.138x0.41x0.055x0.031)	18	986	17748		0		
Longitudinal beam (1.2x0.55x0.075x0.04) L=1.19m	36	722	25992		0		
Grid - standard module	34	2250	76500		1	2250	2250
Grid-Intermediate Extremity Y0	32	129	4128		0		
Grid-Intermediate Extremity Y+/-	8	228	1824				
Grid-Extremity Y0	16	135	2160				
Grid-Extremity Y+/-	4	241	964				
10mm stainless steel skin (m2)	1079	80	86322		27	80	2164.48
Insulation + membrane + bariers(m2)	1006	90	90576		26	90	2304
Intermediate feet: not designed							
Roof	**1**	**705287**	**705287**		**1**	**17048**	**17048**
Transversal beam (1.138x0.41x0.055x0.031) L=16.92m	39	10269	400491		1	10269	10269
Intermediate longitudinal beam (1.2x0.55x0.075x0.04) L=1.19m	36	722	25992				
Extremity longitudinal beam (1.2x0.55x0.075x0.04) L=1.305m	18	792	14256		0		
Grid - standard module	34	2311	78574		1	2311	2311
Grid-Intermediate Extremity Y0	32	129	4128		0		
Grid-Intermediate Extremity Y+/-	8	228	1824				
Grid-Extremity Y0	16	135	2160				
Grid-Extremity Y+/-	4	241	964		0		
10mm stainless steel skin (m2)	1079	80	86322		27.056	80	2164
Insulation + membrane + bariers(m2)	1006	90	90576		25.6	90	2304
Short side	**2**	**193430**	**386860**		**0**	**0**	**0**
Vertical beam (1.138x0.41x0.055x0.031) L=14.678m	9	11996	107964		0		
Horizontal central beam (1.138x0.41x0.055x0.031) L=1.19m	16	722	11552		0		
Horizontal extremity beam (1.138x0.41x0.055x0.031) L=2.993m	4	1911	7644		0		
Grid-Y0 top	8	975	7800		0		
Grid- Extremity top	2	1836	3672		0		
Grid - Y0 middle	8	449	3592		0		
Grid - Extremity middle	2	848	1696		0		
Grid - Y0 Bottom	8	566	4528		0		
Grid - Extremity Bottom	2	1069	2138		0		
10mm stainless steel skin (m2)	267	80	21388				
Insulation + membrane + bariers(m2)	238	90	21456				
Long side	**2**	**727460**	**1454919.576**		**2**	**14156**	**28312**
Vertical beam (1.138x0.41x0.055x0.031) L=14.678m	39	11996	467844		1	11996	11996
Horizontal Intermediate beam (1.138x0.41x0.055x0.031) L=1.19m	8	722	5776				
Horizontal extremity beam (1.138x0.41x0.055x0.031) L=1.305m	4	792	3168				
Grid-Standard module	34	2160	73440		1	2160	2160
Grid- Intermediate top	4	975	3900				
Grid - Intermediate middle	4	449	1796				
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