

PW-SAT2

PRELIMINARY REQUIREMENTS REVIEW

Thermal Control System

Phase A of the PW-Sat2 project

1.1 EN

pw-sat.pl

2014-05-08

Abstract

The following paper is a part of Phase A Summary of student satellite project PW-Sat2. The document presents the study on thermal control system of the PW-Sat2 satellite.

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PW-Sat2 – Preliminary Requirements Review

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Attention Phase A documentation may be outdated in many points. Please do not depend on Phase B or Phase A documents only. Current documentation is available on the project website pw-sat.pl

This document is also available in Polish.



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LIST OF ACRONYMS

CC	Cold Case
HC	Hot Case
N/A	Not Applicable
S/C	Spacecraft
SSO	Sun Synchronous Orbit
TBD	To Be Defined

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1 INTRODUCTION

1.1 PURPOSE AND SCOPE

The goal of the work was to determine the possibility of applying double sided solar cells on open solar panels in PW-Sat2 satellite and initial thermal analysis of existing model with given materials dataset. Two radiative cases were assumed, since orbit is not known at this phase, which might be the potential hot and cold case. Based on this analysis, further changes in the design shall be considered.

The purpose of this document is to present the results of the thermal simulations performed for PW-Sat2 project in ESATAN TMS r2 software.

1.2 APPLICABLE AND REFERENCE DOCUMENTS

[RD1] ma_launch_providers_offers_summary_orbit.xlsx – Modification date: 2013-12-07

[RD2] 30.0_azurespace_triple_junction.pdf – Issue date: 2012-04-17

1.3 DOCUMENT OVERVIEW



This document consists of the following chapters:

Chapter 1 describes the purpose of this document and provides an overview for the rest of the document;

Chapter 2 describes the geometry, material and thermo-optical properties used in the model and presents general overview of model properties;

Chapter 3 presents the results of the thermal simulations;

Chapter 4 summarizes and concludes performed work.

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2 THERMAL MODEL AND ENVIRONMENT

This section presents the GMM of the PW-Sat2 model which was based on the step file with the mechanical model.

2.1 GEOMETRY

The geometry of the PW-Sat2 thermal model was created based on the mechanical model of the S/C presented on [Figure 2-1] and [Figure 2-2]. The thermal model is made of shells with defined thickness [Figure 2-3].

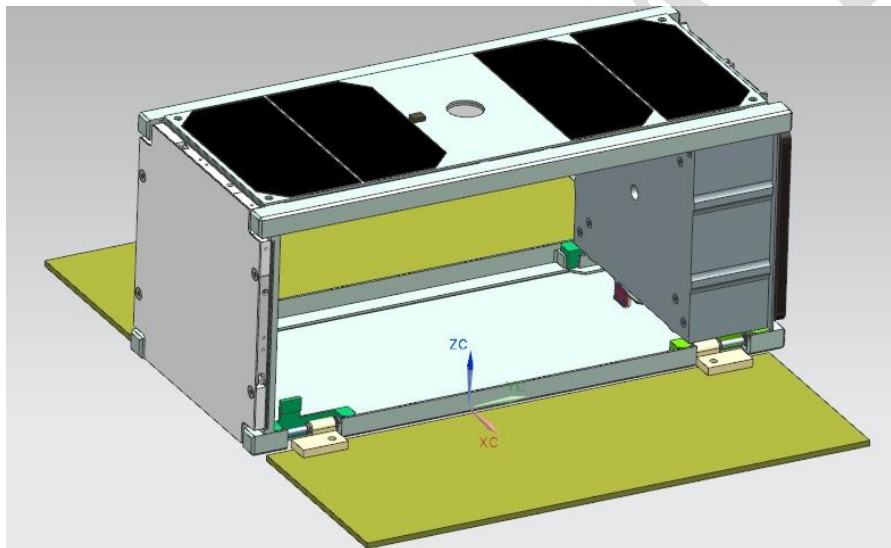




Figure 2-1 The mechanical model of the PW-Sat2 – rear view

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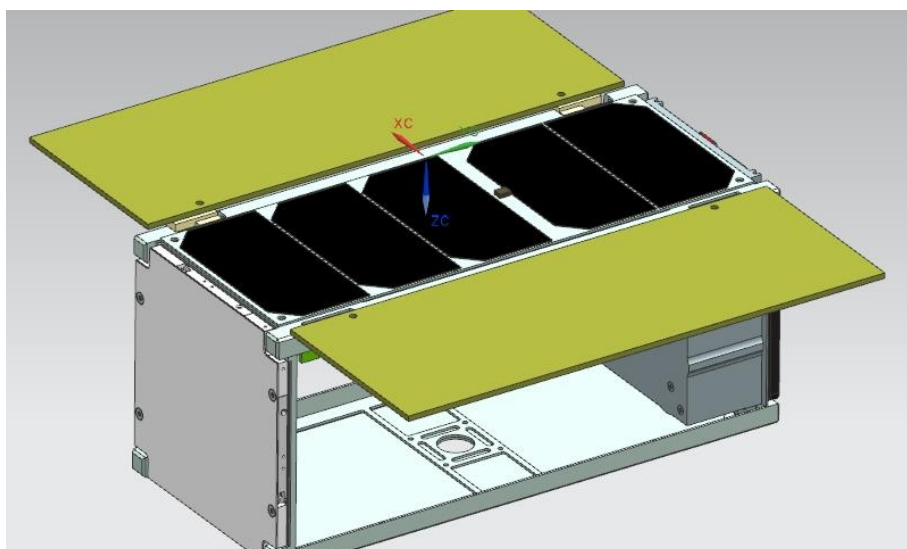


Figure 2-2 The mechanical model of the PW-Sat2 – front view

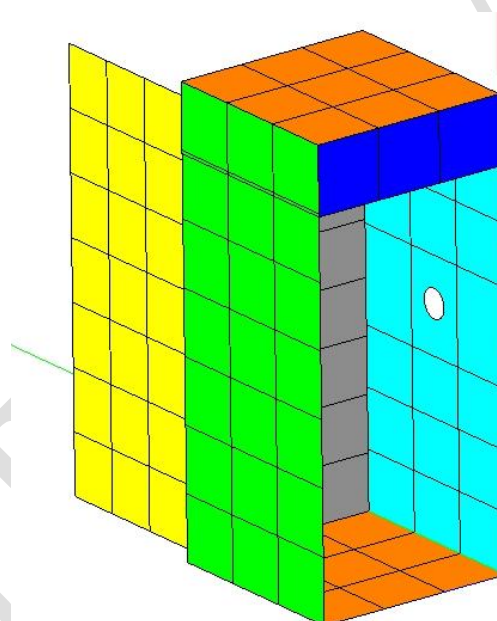




Figure 2-3 The GMM of the PW-Sat2 model

2.2 BULK PROPERTIES

The bulk properties defined for each part of the instrument are shown on [Figure 2-4] and [Figure 2-5] below. The values of the thermal conductivity, specific heat and density specified for each material are presented in [Table 2-1]. The used aluminium alloy Al-7075 and FR4

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properties were taken from the material data base. MLI properties are based on Kapton offer by Dupont company¹.

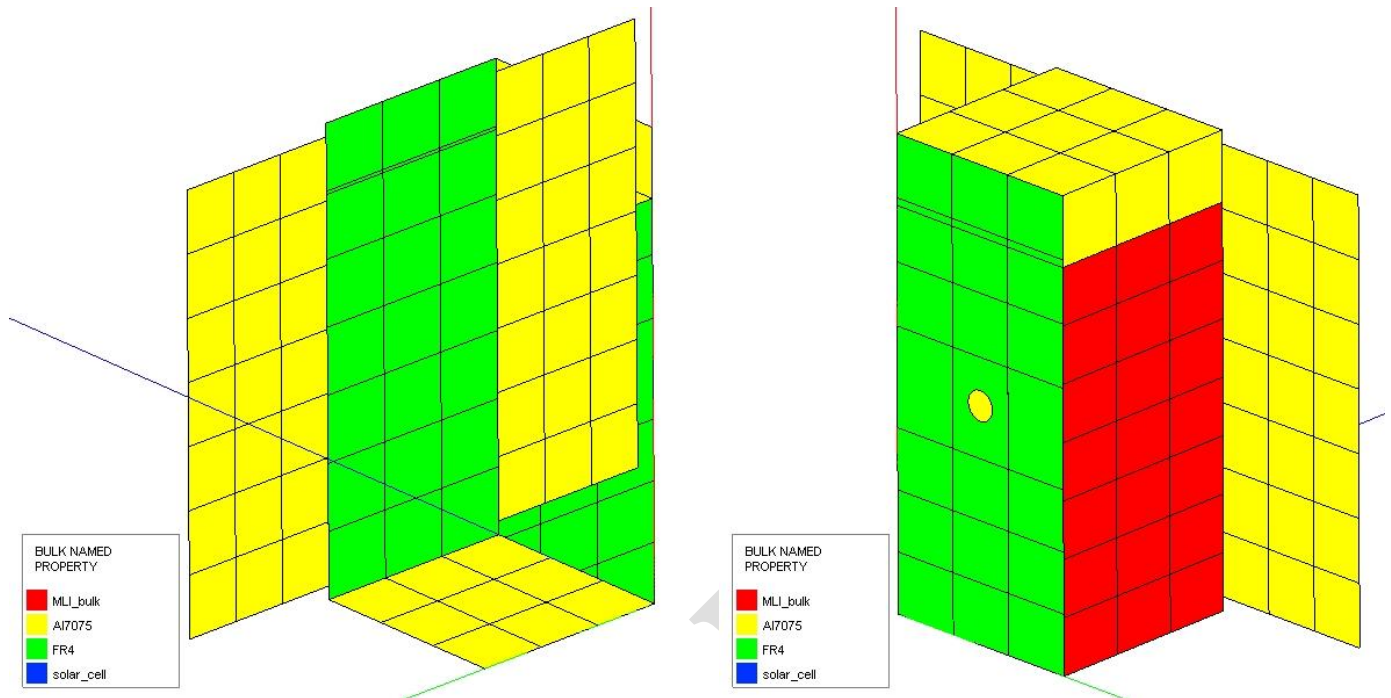




Figure 2-4 The materials used for PW-Sat2 thermal model (left-front; right-rear).

Material	Density	Specific heat capacity	Thermal conductivity	Elements
	kg/m ³	J/kg/K	W/m/K	
FR4	1850	1100	0.2	Wall_front; Wall_rear
Al. 7075	2770	900	150	Box; Wall_top; Wall_bot; Solar Panel +Y; Solar Panel -Y
MLI	1420	1090	0.12	MLI +Y; MLI -Y

Table 2-1 The material properties definition

¹ http://www2.dupont.com/Kapton/en_US/assets/downloads/pdf/summaryofprop.pdf

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2.3 THERMO-OPTICAL PROPERTIES

The [Figure 2-5] shows the thermo-optical properties defined for each of the part of the PW-Sat2 model. In [Table 2-2] the parameters such as emissivity and absorptivity for each property are presented.

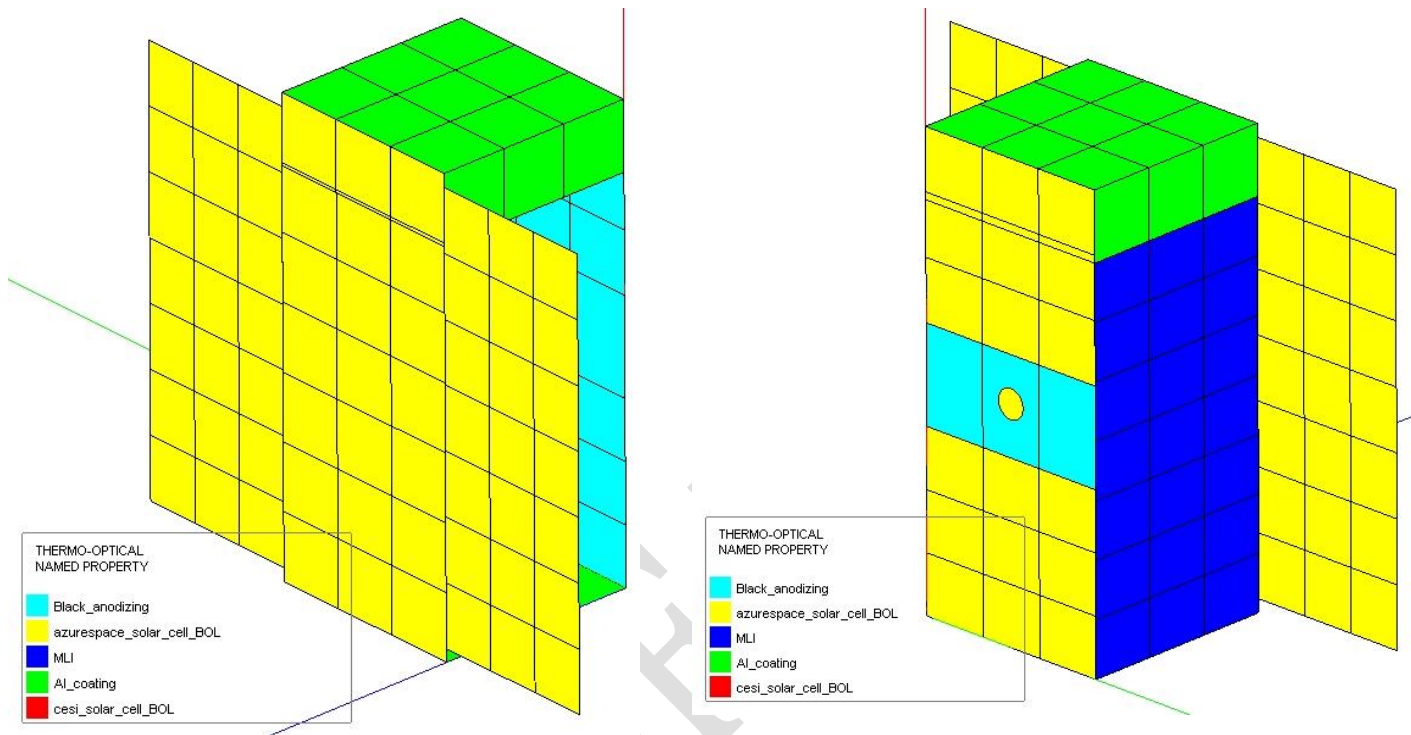




Figure 2-5 The thermo-optical parameters used in PW-Sat2 thermal model (left-front; right-rear).

Optical coating	Absorptivity	Emissivity	Elements
Black_anodizing	0.88	0.88	Radiators
Al_coating	0.13	0.07	Box; Wall_top; Wall_bot
MLI	0.05	0.05	MLI +Y; MLI -Y
Azurspace solar cell	0.91	0.85	Solar Panel +Y; Solar Panel -Y; Wall_front; Wall_rear

Table 2-2 The thermo-optical properties definition

2.4 CONDUCTIVE COUPLINGS

The conductive couplings in the PW-Sat2 thermal model were calculated automatically using ESATAN-TMS software. Although for Solar Panels and Front wall connection the values were calculated manually taking into account simplified model of sleeves and shafts. Resultant couplings are as follows:

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- For FR4 material used as a structure (per connection):
 - $GL = 0.000216426 \text{ W/K}$
- For AL7075 material used as a structure (per connection):
 - $GL = 0.030913523 \text{ W/K}$

2.5 BOUNDARY CONDITIONS

TEMPERATURE BOUNDARIES

N/A

HEAT GENERATION BOUNDARIES A

TBD

2.6 TEMPERATURE LIMITS



TBD

2.7 ORBITAL SCENARIOS DEFINITION

Since flight provider is not known at this phase a few options were chosen as the most possible orbits for hot and cold case based on [RD1] list. In both cases, S/C solar panels are always pointed at the Sun.

HOT CASE

For hot case a *United Start Launch* provider was chosen as a SSO with low orbit altitude. It was assumed that the S/C is constantly exposed to solar radiation. For full orbit definition refer to [Figure 2-6].

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Radiative Case: Hot_case

Definition Method: Orbit Parameters

☐ Ellipse

Altitude of Apogee	500,000
Altitude of Perigee	500,000
Inclination	90
Right Ascension	90
Argument of Periapsis	0

☐ Arc

Initial True Anomaly	0
Final True Anomaly	360

☐ Positions

Angle Gap	45
Number of Positions	8
True Anomalies Vector	Not Defined
Eclipse Entry Exit Points	<input checked="" type="checkbox"/>
Eclipse Offset	0.5

Figure 2-6 Hot case orbit definitione

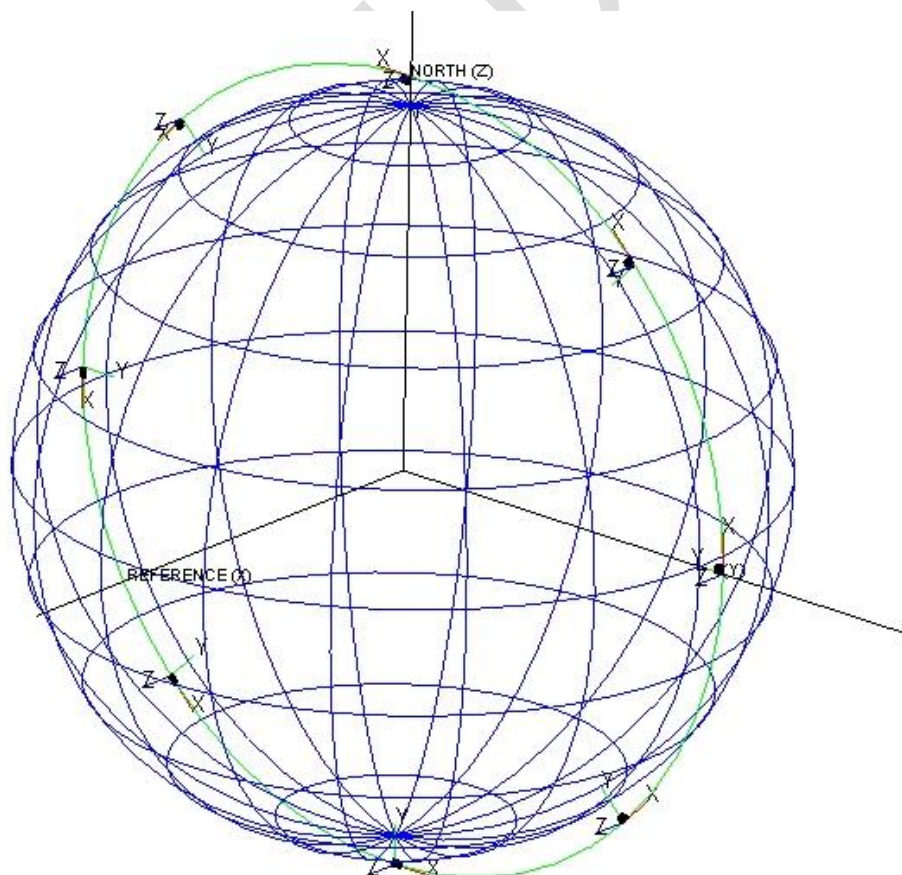




Figure 2-7 Visualisation of PW-Sat2 orbit – hot case (reference – pointing direction to the Sun)

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COLD CASE

For cold case an *ISI Launch* provider was chosen as a high orbit altitude (less affected by albedo and planet IR). It was assumed that the S/C is periodically entering eclipse during which the lowest temperatures are to be expected. For full orbit definition refer to [Figure 2-8]. In [Figure 2-9], red line is a time during eclipse.

Radiative Case:	Cold_Case
Definition Method:	Orbit Parameters
<input type="checkbox"/> Ellipse	
Altitude of Apogee	700,000
Altitude of Perigee	600,000
Inclination	90
Right Ascension	0
Argument of Periapsis	0
<input type="checkbox"/> Arc	
Initial True Anomaly	0
Final True Anomaly	360
<input type="checkbox"/> Positions	
Angle Gap	45
Number of Positions	8
True Anomalies Vector	Not Defined
Eclipse Entry Exit Points	<input checked="" type="checkbox"/>
Eclipse Offset	0.5

Figure 2-8 Cold case orbit definition

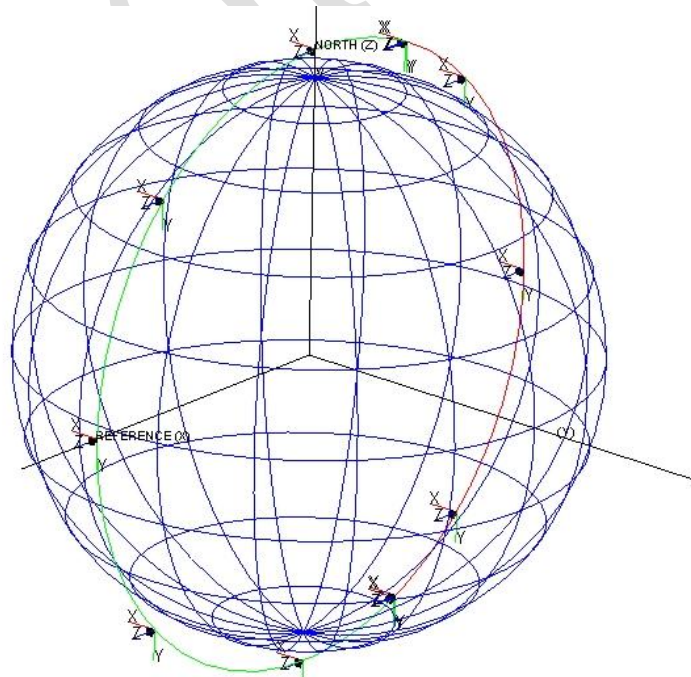




Figure 2-9 Visualisation of PW-Sat2 orbit – cold case (reference – pointing direction to the Sun)

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2.8 ADDITIONAL CASES DEFINITION

There were conducted 3 additional cases in order to test influence of radiators on the overall temperature balance and change in material properties for further enhancements in heat transfer across the S/C.

ADDITIONAL SOLAR CELLS ON THE SECOND SIDE OF SOLAR PANELS

Two additional cases were defined in order to test if there is a possibility to apply the second layer of solar cells on Solar Panel instead of radiators, since very high temperatures are expected here due to the constant exposure to solar radiation, and weak heat conduction to the remaining part of the S/C. Additionally, MLI was introduced instead of radiator on the rear wall. For the changes refer to [Figure 2-10].

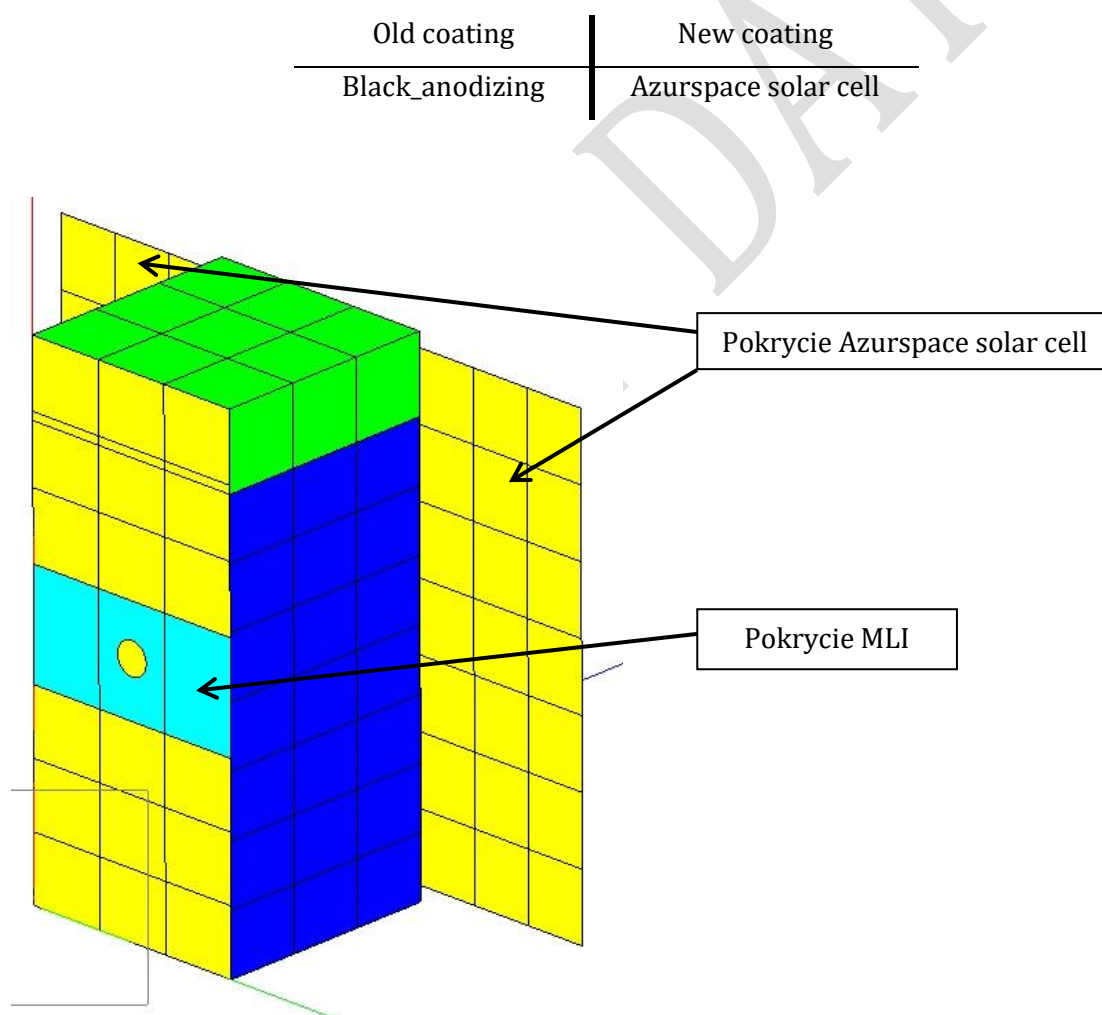




Figure 2-10 Elements affected by new thermo-optical properties

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MATERIAL CHANGE FOR FRONT AND REAR WALLS

Additional case was defined where analysis were performed for front and rear walls with a new material set to Al7075, due to the very low thermal conductivity of FR4 material. For new values refer to [Table 2-1] and for elements affected see picture below.

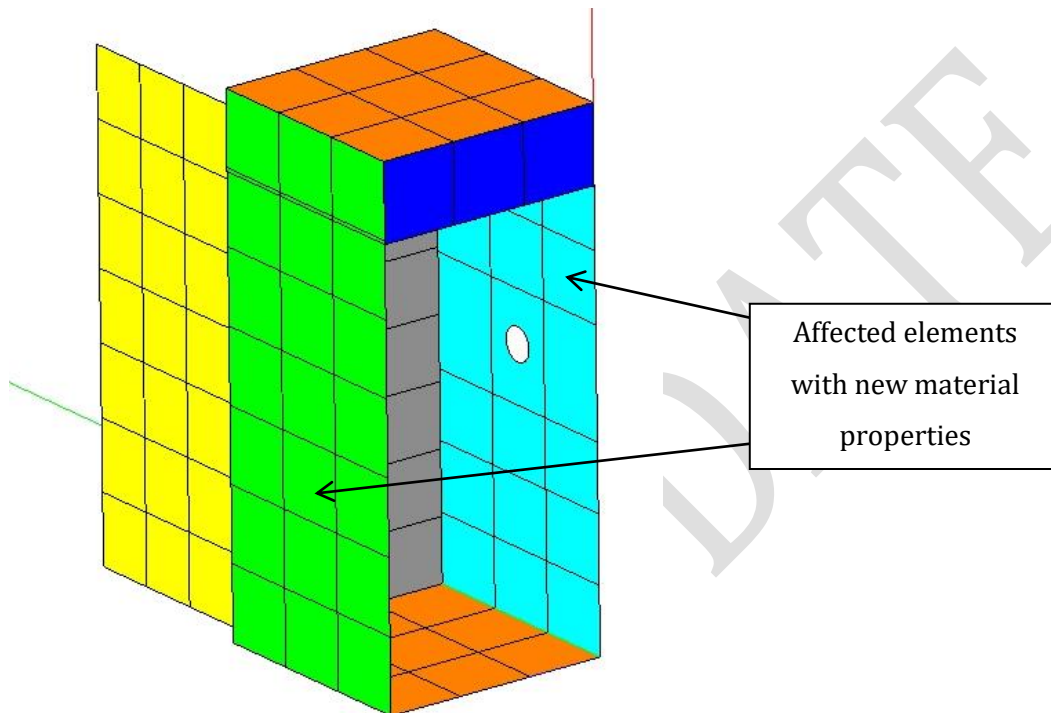




Figure 2-11 Elements affected by material change

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3 RESULTS

This section shows the temperature results in Celsius degrees of the performed analyses and is organized as follows:

- Hot case for initial design with radiators
- Cold case for initial design with radiators
- Hot case for initial design without radiators
- Cold case for initial design without radiators
- Hot case for changed design without radiators

OUT OF DATE

3.1 HOT OPERATIONAL CASE FOR INITIAL DESIGN WITH RADIATORS

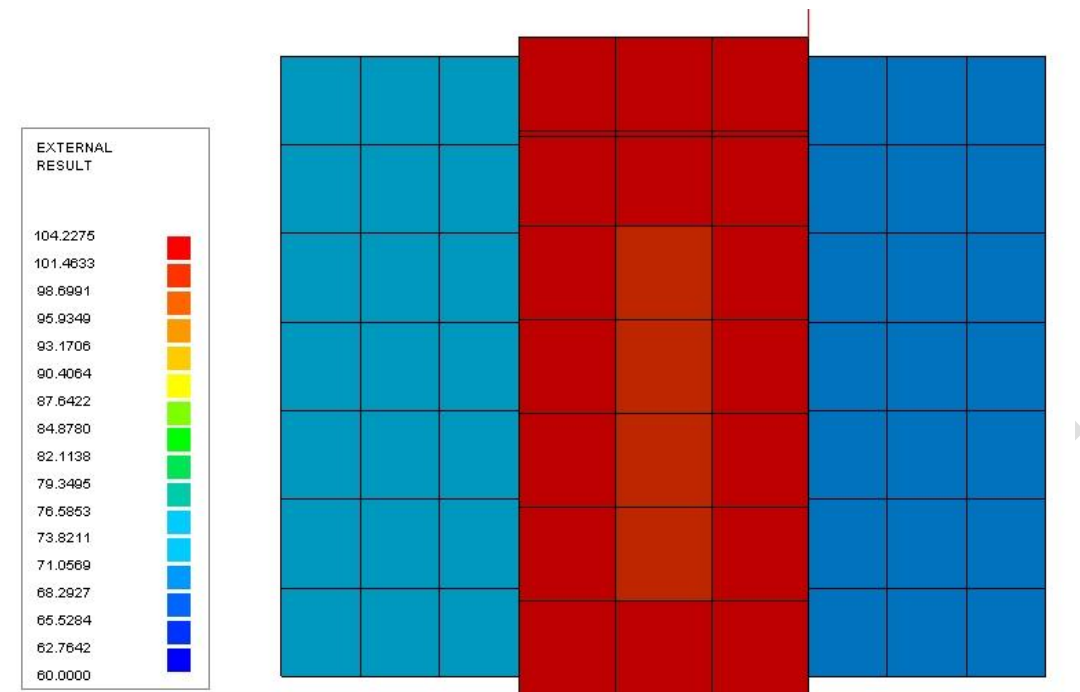


Figure 3-1 Temperature distribution on PW-Sat2 structure - front view.

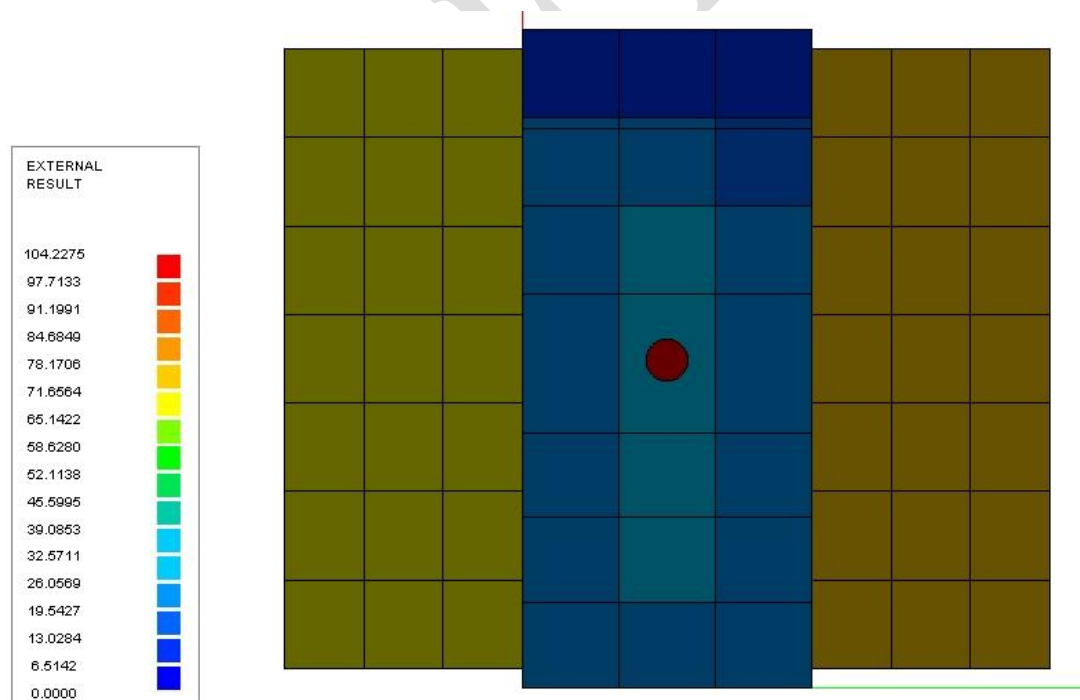


Figure 3-2 Temperature distribution on PW-Sat2 structure - rear view

3.2 COLD OPERATIONAL CASE FOR INITIAL DESIGN WITH RADIATORS

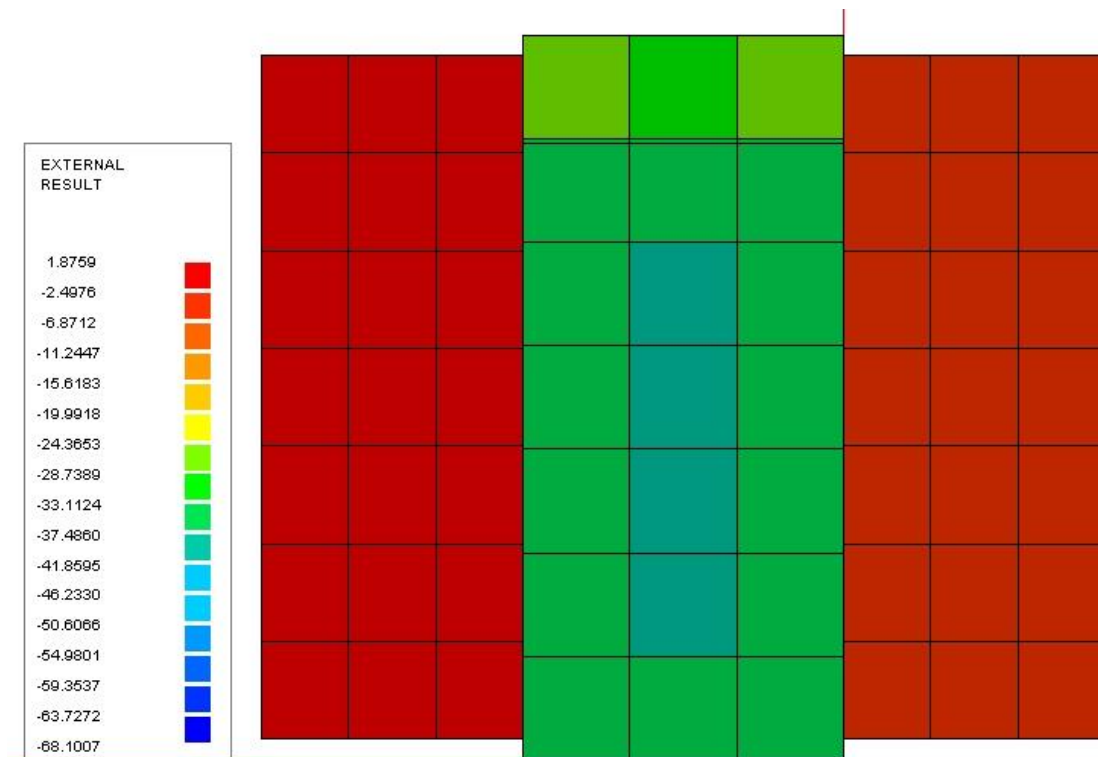


Figure 3-3 Temperature distribution on PW-Sat2 structure – front view

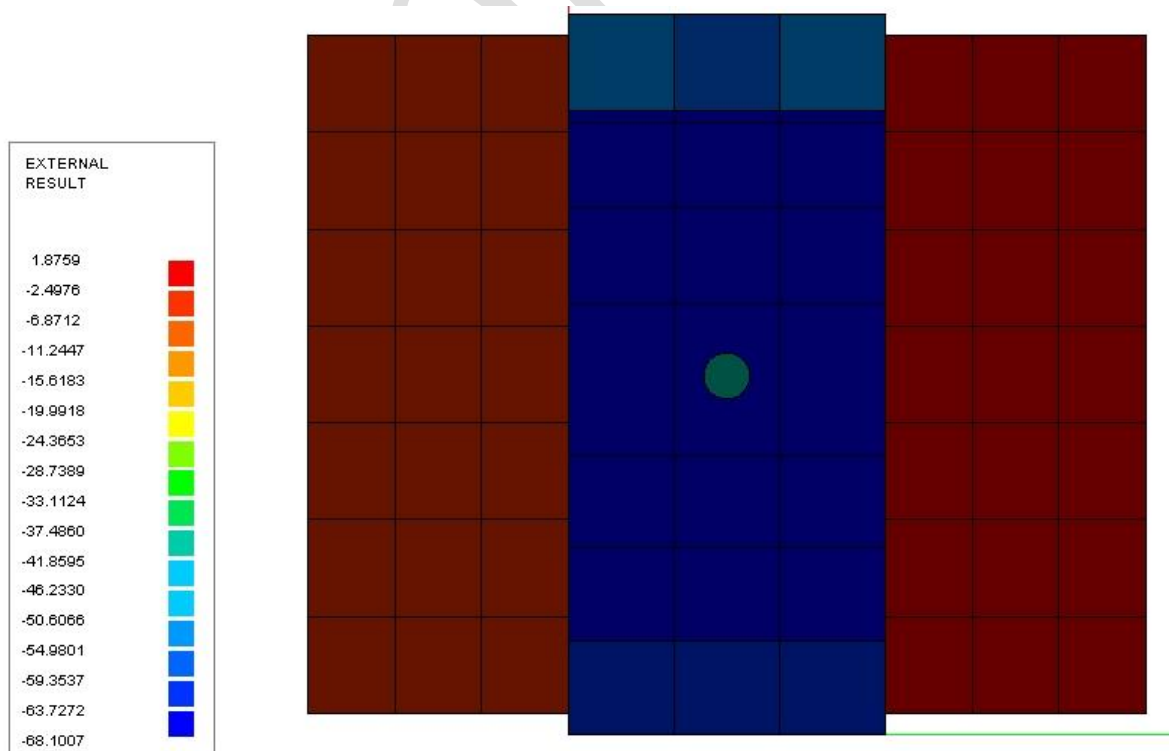


Figure 3-4 Temperature distribution on PW-Sat2 structure – rear view.

3.3 HOT CASE FOR INITIAL DESIGN WITHOUT RADIATORS

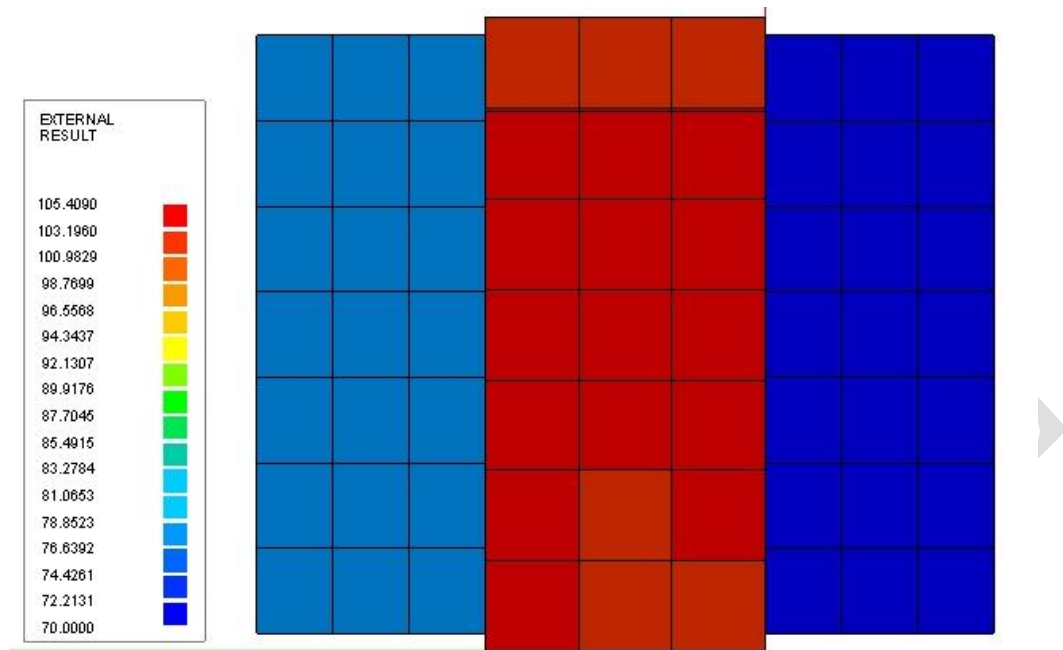


Figure 3-5 Temperature distribution on PW-Sat2 structure – front view

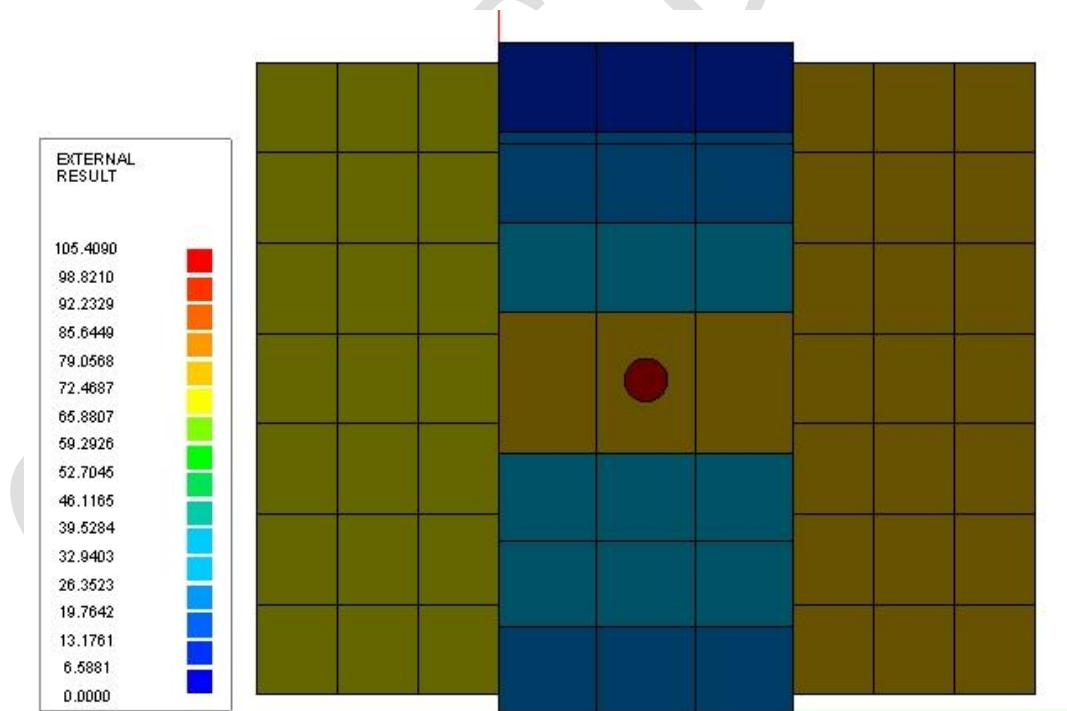


Figure 3-6 Temperature distribution on PW-Sat2 structure – rear view

3.5 COLD CASE FOR INITIAL DESIGN WITHOUT RADIATORS

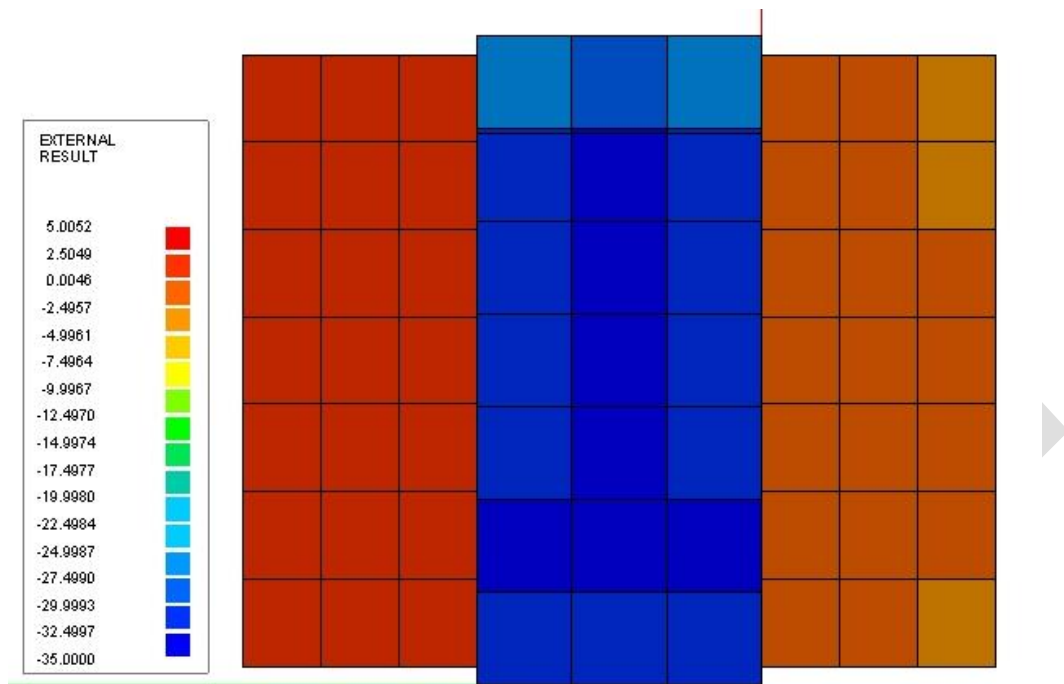


Figure 3-7 Temperature distribution on PW-Sat2 structure – front view

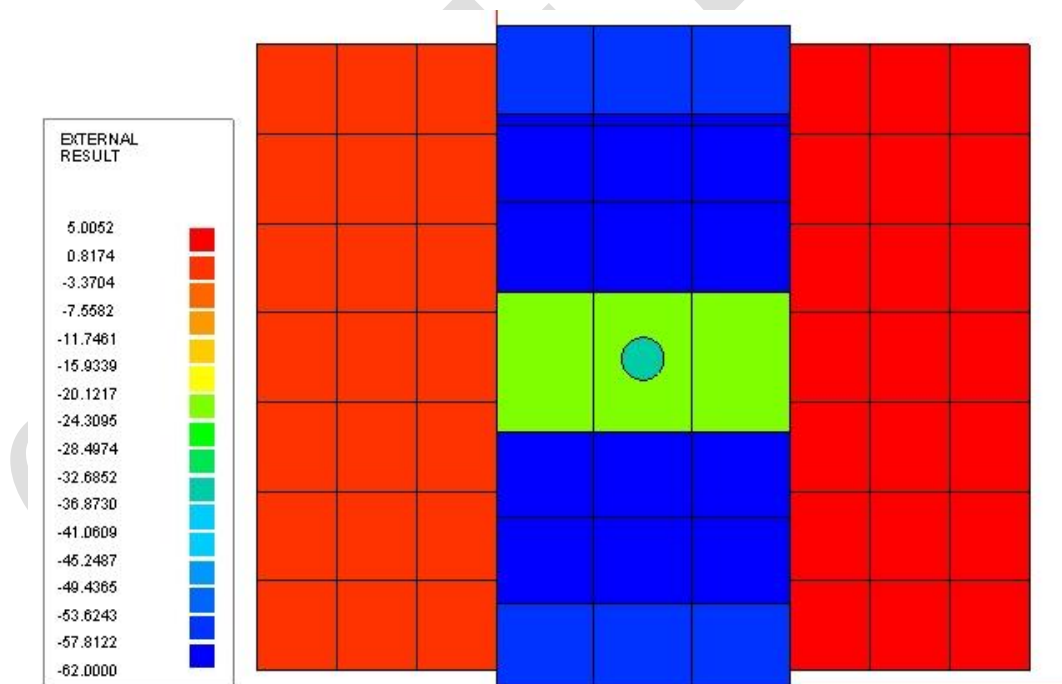


Figure 3-8 Temperature distribution on PW-Sat2 structure – rear view

3.7 HOT CASE FOR CHANGED DESIGN WITHOUT RADIATORS

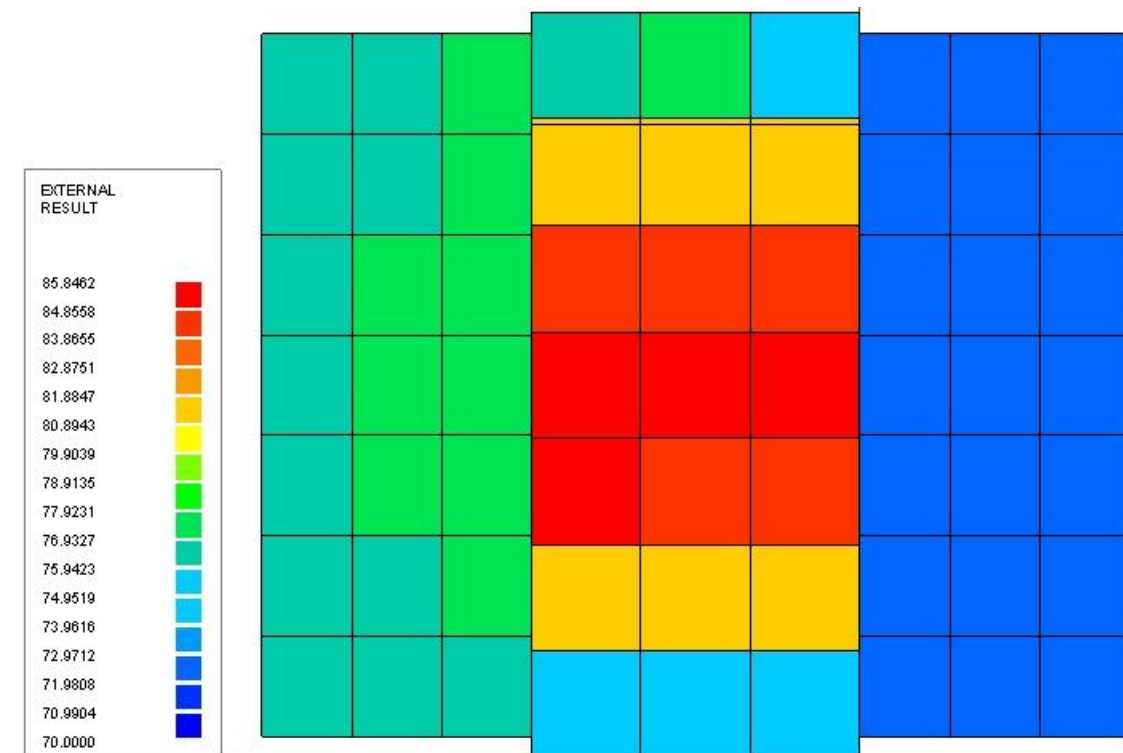


Figure 3-9 Temperature distribution on PW-Sat2 structure - front view

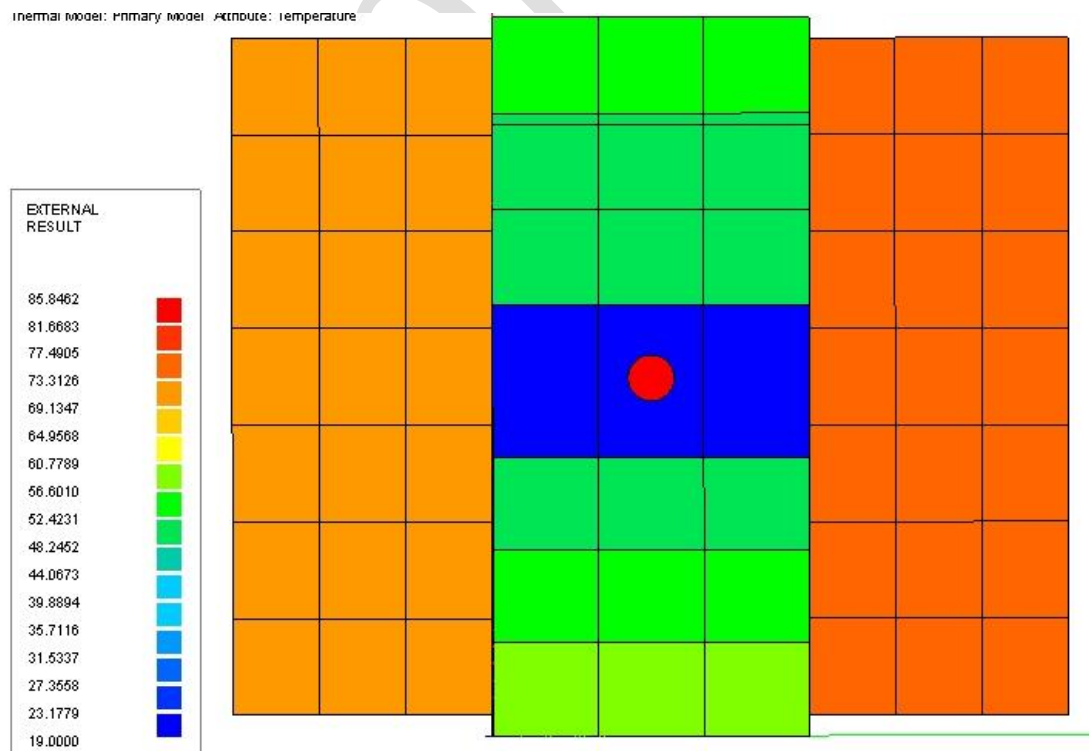




Figure 3-10 Temperature distribution on PW-Sat2 structure - rear view

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4 CONCLUSIONS

The calculations were performed for two extreme radiative cases – hot, where the S/C is constantly exposed to Sun radiation, and cold – where the S/C enters eclipse. Additionally 3 more cases were performed: two for hot and cold case without radiators and one hot case for front and rear walls material changed to Al7075 (from FR4) in order to increase heat conductivity across the S/C.

There were 2 objectives: first to check if it is possible to mount additional layer of solar cells at the other side of the Solar Panels. According to results shown in chapter 3 it is possible to apply them, since the difference in temperature is in average $\sim 5^{\circ}\text{C}$ and within standard acceptance temperature limits (usually 100°C). This is valid only for solar cells with emissivity assumed as in this analysis. Radiator is still suggested on the rear wall instead of MLI due to overall high temperatures..

Second objective was to check if the FR4 material used in front and rear wall of the S/C will conduct enough heat. As it can be seen from figure 3-1 and 3-2, temperatures are as high as 100°C and as low as 0°C where for cold case even below 65°C . Such values are not acceptable on structure where optical elements and electronics will be mounted. Aluminium alloy is expected solution in this case, since it performs better in excess heat conduction from front to the rear part of the S/C where radiator is placed, and decreases maximal temperature by over 20°C . This is, however, not a complete solution, and further analysis will have to be performed.