CRF (Centro Ricerche Fiat)

MADEin4

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MADEin4 T5.2.3 - Digital twin methodologies and collaborative applications for body and assembly shop floors modelling, simulation and validation
Partners: FCA-ITALY, POLITO, COMAU, BRI

CRF

Digital Twin methodology for energy modelling and management of body and assembly shop floors

Giulio Vivo - Federico Magnea

EMEA – SPW Research & Innovation – Factory Innovation

Digital Twin methodology for energy modelling and management of body and assembly shop floors

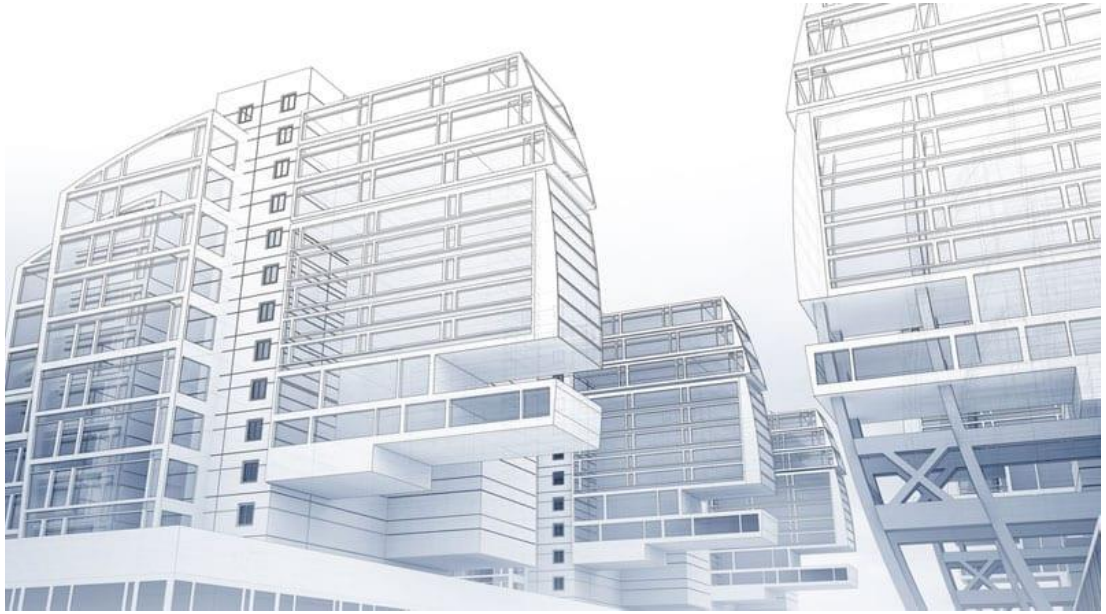
CRF in Task 5.2.3

The ***Digital Twin*** is a reliable copy, a virtual model, of a real object on which to make analysis and trials in order to avoid potential issues and/or mistakes that could generate relevant diseconomies in terms of costs and time wasted.

We can think of transferring this concept to a building as well, using the virtual model made available by the ***Building Information Modeling*** methodology. For example, after the construction of a building, or even an automotive plant, we can equip it with a series of sensors of various kinds, positioned appropriately in the different rooms and locations based on their functional characteristics:

- temperature sensors
- humidity sensors
- pressure sensors
- air quality sensor
- energy consumption control device
- electrical consumption
- control device
- brightness sensor

These sensors generate a significant amount of data, to be transferred in real time to the virtual building. The virtual building for its part, by analysing all these data, ***would be able to define the correct functioning*** of the systems and all the components at any time, in order to constantly maintain optimal behaviour, ensuring comfort and well-being.



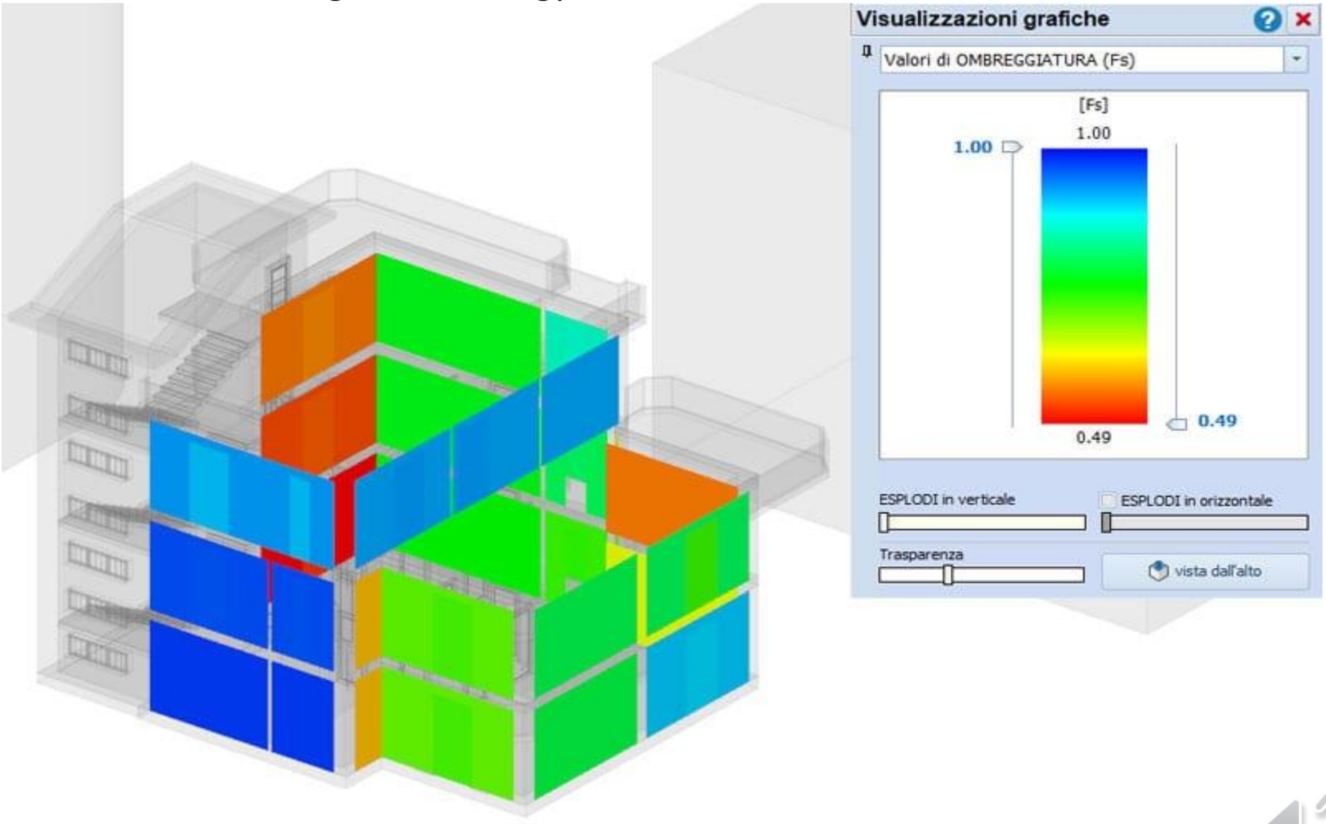
Digital Twin methodology for body and assembly shop floors modelling

CRF in Task 5.2.3

The main element, the keystone of all these innovations, is represented by the ***digital model on which to perform all the analyses***. We can think of creating a virtual model of the building that contains in addition to the geometric and structural information also all the energy related data and characteristics, such as systems, type of insulation, opaque envelope, glazed structures, energy inputs, climatic conditions, internal inputs, aspects and features of heating, cooling and ventilation. In this case we could talk about a true energy model of the building / plant system, which allows to exploit all the potential of Building Information Modelling methodology.

Therefore, it seems very appropriate to introduce in this digitalization context the acronyms ***BEM (Building Energy Management)*** *and* ***PEM (Process Energy Management)*** which identify the energy model of the building, enabling, as seen, the transfer of the digital twining approach to the field of heat engineering and energy performance. Such a model opens the doors to scenarios of energy management of any types, even the most innovative, in terms of:

- Design
- Implementation
- Control
- Management
- Maintenance



***BEM + PEM methodologies**: example of an energy efficiency solution*

CRF in Task 5.2.3

Description

- *Development and test of **Building Energy Management (BEM)** methodology to estimate the building consumption with integration of process loads using **Process Energy Management (PEM)** methodology.*
- *Energy simulations to evaluate the best **efficiency solution** in order to reduce the consumptions.*

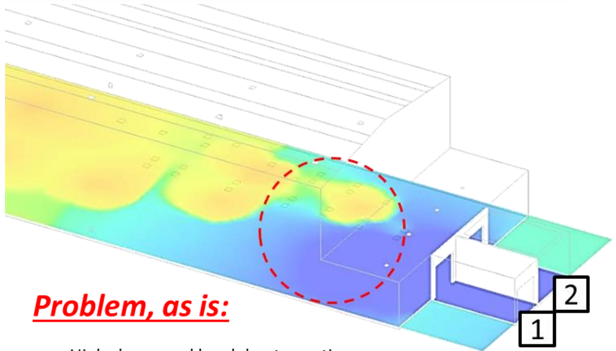
As is

- Lack of knowledge of the thermal behavior of the industrial buildings.
- Low diffusion of a common reference methodology for energy analysis.
- Lack of a tool to objectively analyze interventions on the buildings of the plant.

BEM + PEM solution

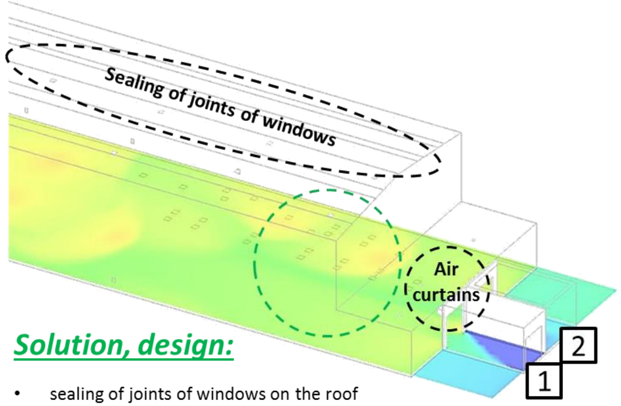
- ***BEM Methodology with PEM integration** for predictive and objective energy analysis* to identify the best solutions of maintenance, revamping and reduction of energy consumptions.
- Digital twin with *deterministic mathematical models* (no machine learning) *for **analysis aimed at predictive maintenance and quality control of working areas*** indoor temperatures for the well being of the workers

Case study: Finish Area of the AGAP plant



Problem, as is:

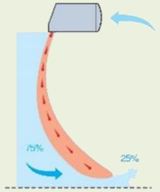
- High-depressed local due to suctions
- Cold air drafts througth external hatchbacks and elevator
- Drop of temperature to 10-12°C (h = 1,70 m)

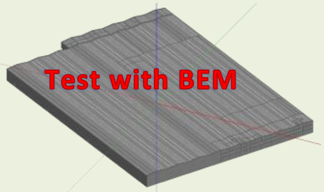


Solution, design:

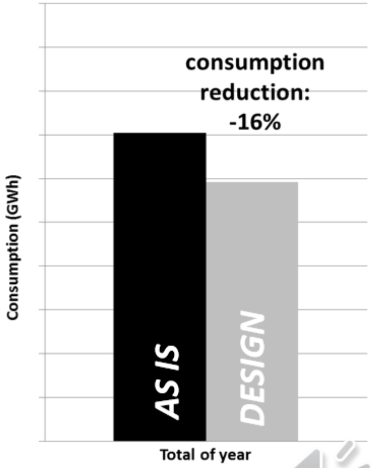
- sealing of joints of windows on the roof
- Installing of air curtains to pre-heat the flow
- Rise of temperature to 24 °C (h = 1,70 m)
- Possible reduction of CTA air supply temperatures

Solution: sealing of joints of windows on the roof + air curtains





Energy analysis results



Economic analysis and business case

DESIGN and ENERGY cost sources for B/C analysis		Heating energy consumption [GWh/year]	Heating energy and CO_2 emissions saving [%]	Payback time [years]
AS IS		AS IS	-	-
CASING AND STRUCTURE	Sealing of windows joints + air curtain	DESIGN	16	1,3

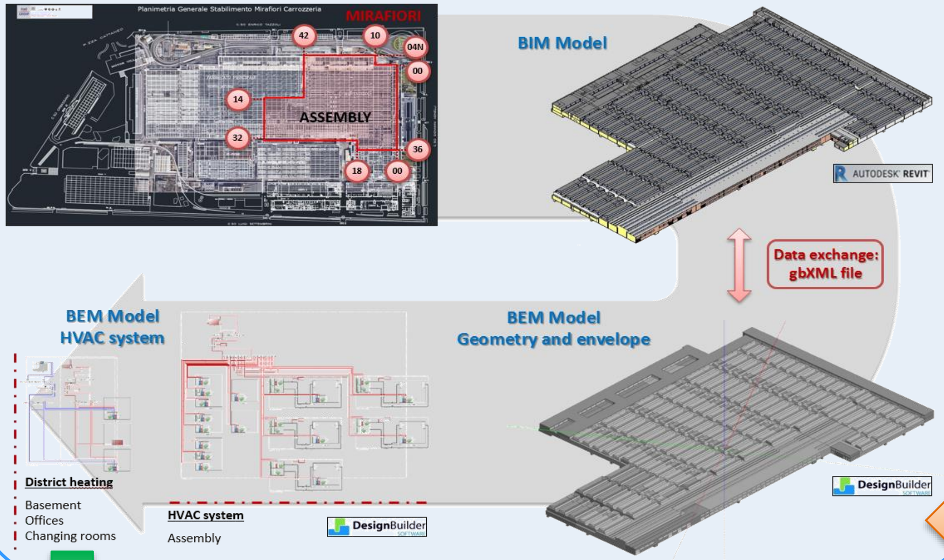
Note:

Example of an energy efficiency solution using BEM model to address a specific problem of a former model area (the Finish Area of the AGAP plant).

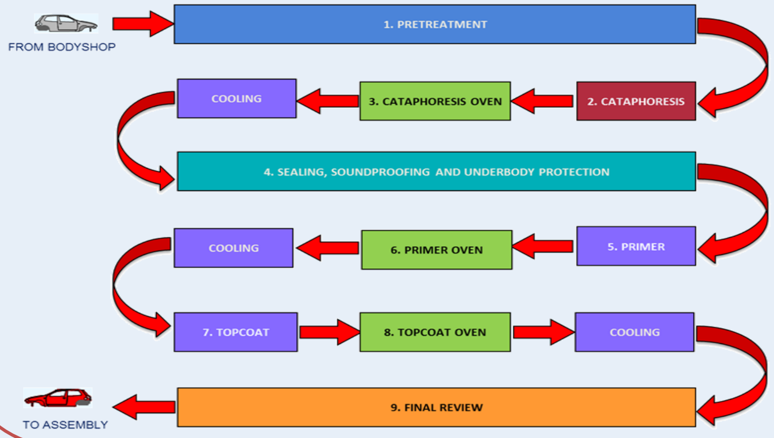
BEM + PEM methodologies: integration workflow in Task 5.2.3

Digital twining

1 Development of a BEM partial model of the building for the energetic analysis



2 Elaboration of process data with PEM methodology



Analytic calculation formulas:

Tanks

$$Q_{risc} = Q_{vol} + f_t\,(\Phi_m + \Phi_d - \Phi_{abs})\cdot 3{,}6$$

$$\Phi_{mant} = \Phi_h + \Phi_{eva} + \Phi_r + \Phi_{irr} + \Phi_{abs}$$

Ovens

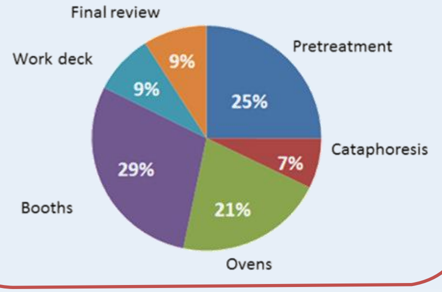
$$\Phi_{avv} = \Phi_a + \Phi_m$$

$$\Phi_{prod} = \Phi_d + \Phi_{irr} + \Phi_b + \Phi_m + \Phi_w$$

Electricity and compressed air

$$EE = P_n \cdot f_{inv} \cdot FC \cdot FU \cdot h$$

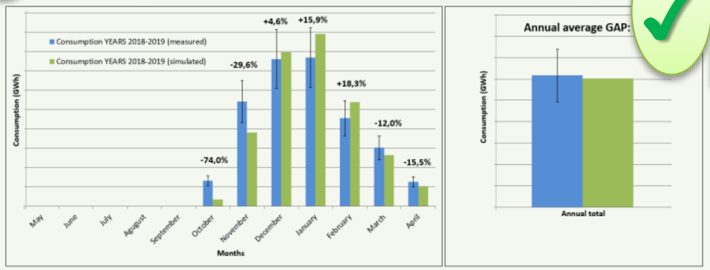
$$EE = V_n \cdot f_c \cdot FC \cdot FU \cdot h$$



3 Integration of BEM model (Building Energy Management) with PEM data (Process Energy Management)

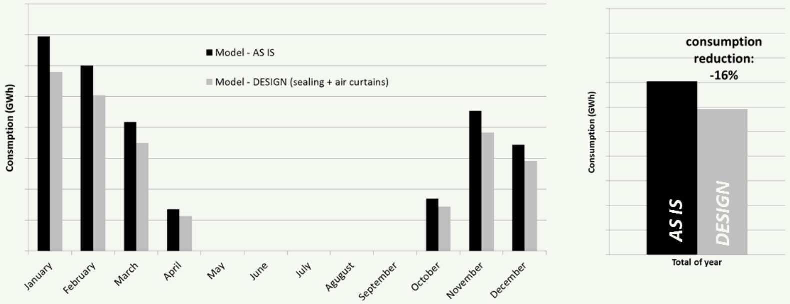
Output

4 Validation of BEM model



Mirafiori Assembly (%)	GAP model-real data [%]												
	May	June	July	Agugust	September	October	November	December	January	February	March	April	Total
GAP SIMULATION	-	-	-	-	-	- 74,0	- 29,6	4,6	15,9	18,3	- 12,0	- 17,5	- 2,4

5 Efficiency solution

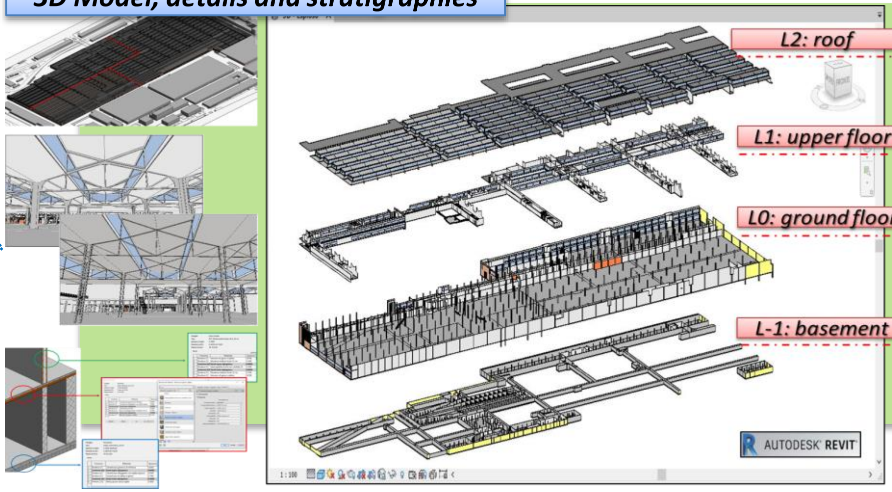


Phase 1: *BEM partial model of Mirafiori Paintshop* CRF in Task 5.2.3

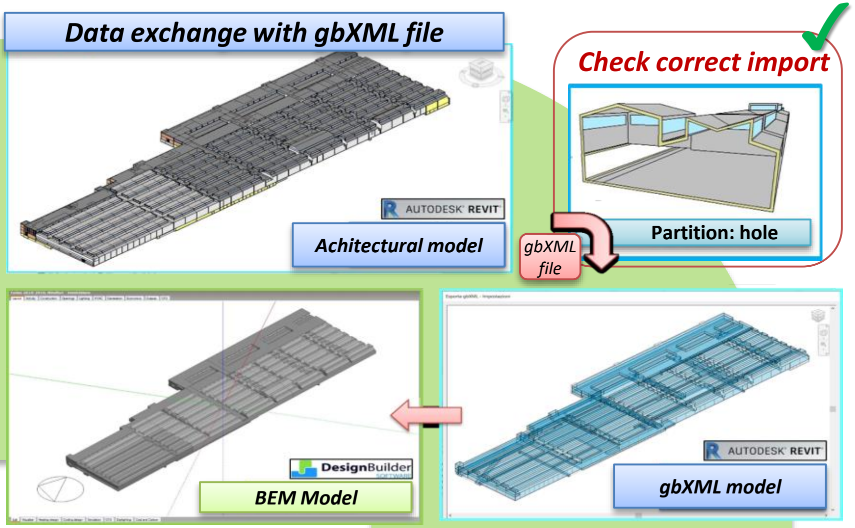
STARTING POINT: Input Data collection

- *Energy consumption for model validation*
- *Climatic file and Production data*
- *Thermal-stratigraphic data of the envelope*
- *Geometric-dimensional data*
- *HVAC system data*

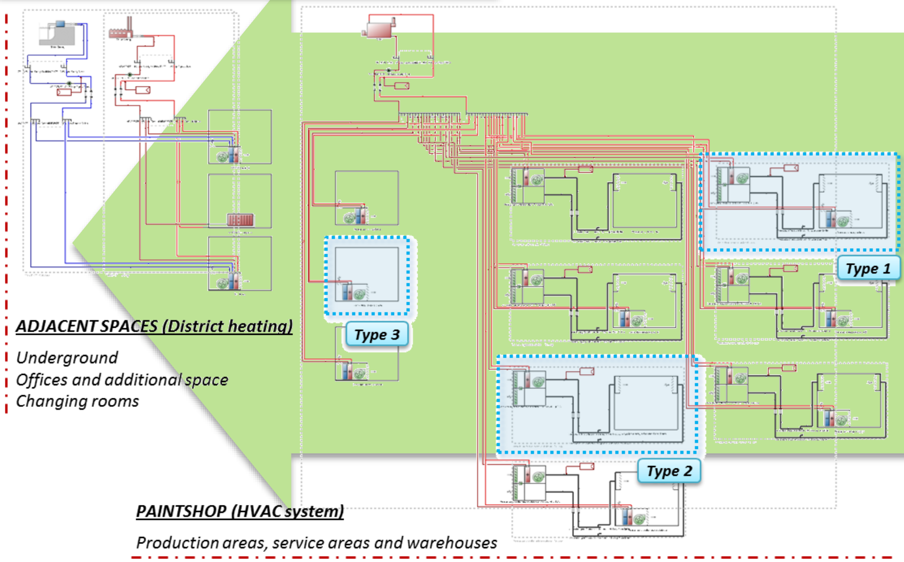
3D Model, details and stratigraphies



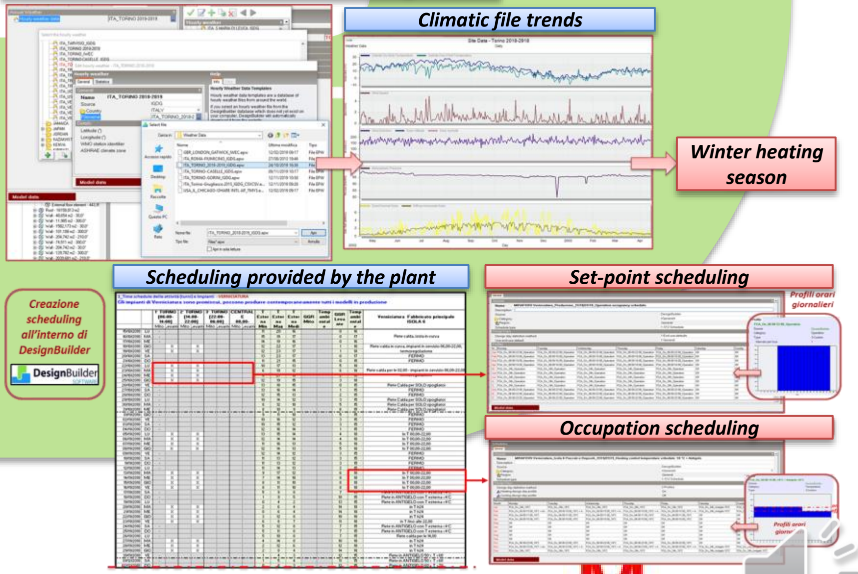
Data exchange with gbXML file



HVAC model for thermal zones

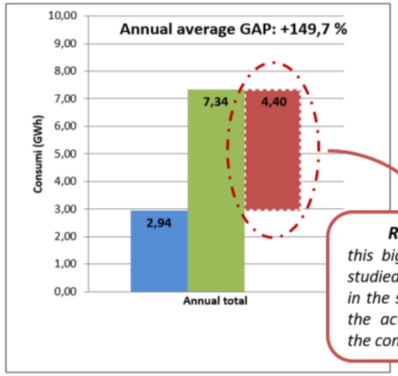


Climatic file and scheduling



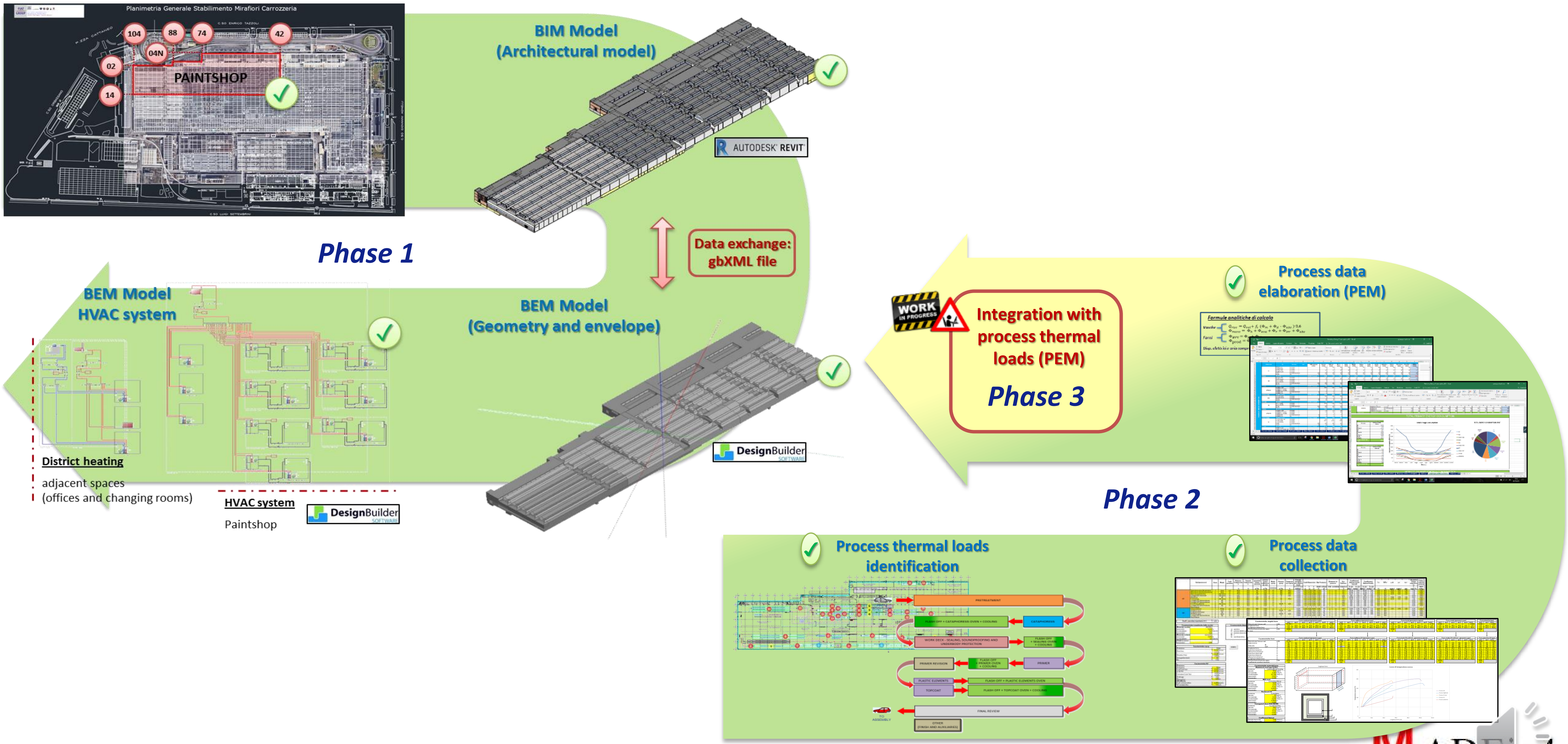
First output of BEM partial model

- *Real energy consumption*
- *Simulated energy consumption*
- *Simulation gap*



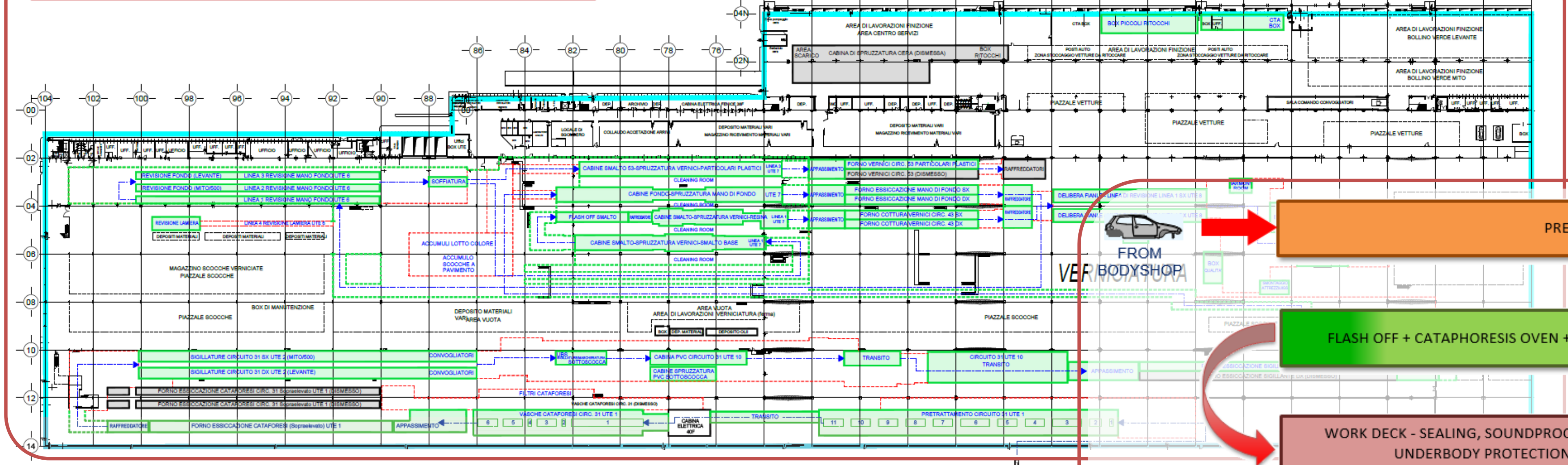
Remarks: *this big GAP will be studied and reduced in the second part of the activity creating the completed model*

***Phase 2**: BEM+PEM model workflow*



Phase 2: Paintshop process thermal loads identification

Model Area: Mirafiori Paintshop process line



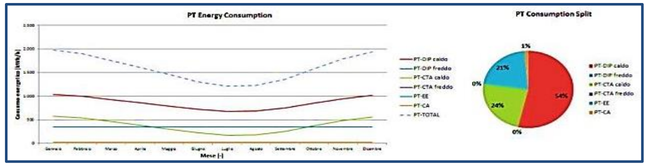
- **Studies about the process loads** of the painting line and **their position** within the building area.
- **Study about the type of process loads** along the process block chain of the production line.
- **Use of Process Energy Management (PEM)** to estimate thermal contribution of the process.

Analytic calculation formulas:

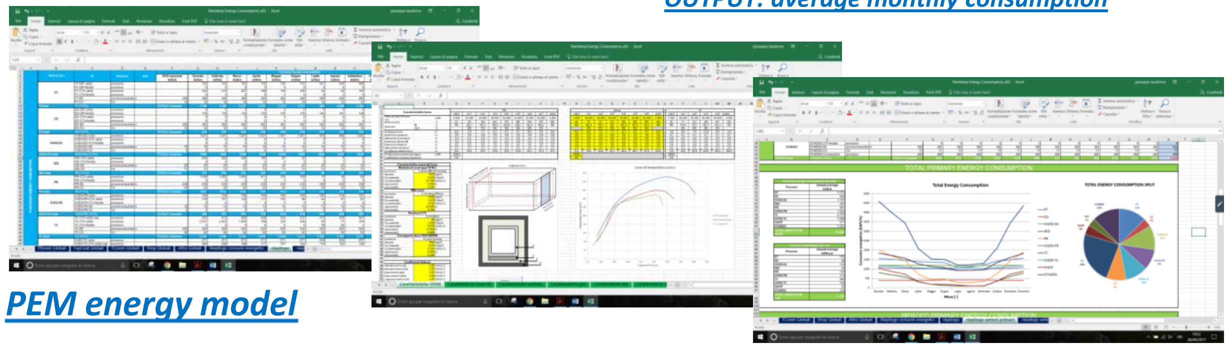
Tanks
$$Q_{risc} = Q_{vol} + f_t\,(\Phi_m + \Phi_d - \Phi_{abs})\cdot 3{,}6$$
$$\Phi_{mant} = \Phi_h + \Phi_{eva} + \Phi_r + \Phi_{irr} + \Phi_{abs}$$

Ovens
$$\Phi_{avv} = \Phi_a + \Phi_m$$
$$\Phi_{prod} = \Phi_d + \Phi_{irr} + \Phi_b + \Phi_m + \Phi_w$$

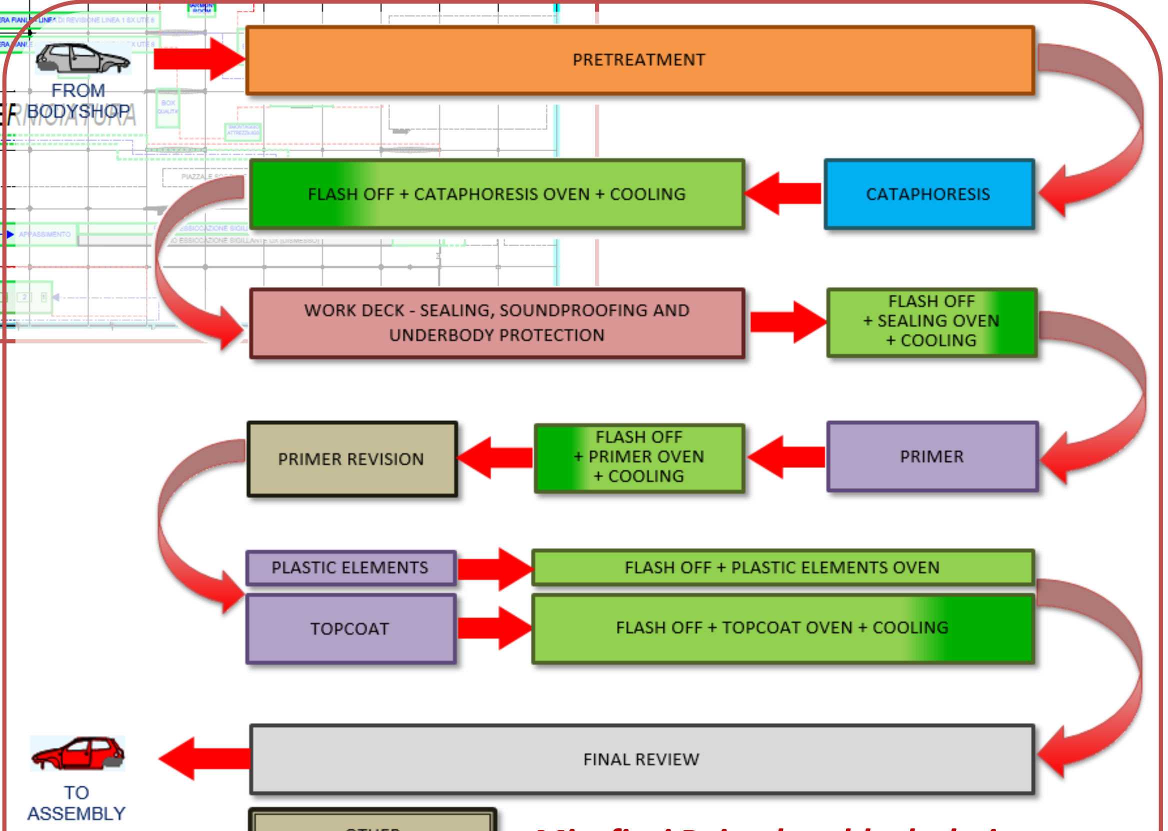
Elettricity and compressed air
$$EE = P_n \cdot f_{inv} \cdot FC \cdot FU \cdot h$$
$$EE = V_n \cdot f_c \cdot FC \cdot FU \cdot h$$



OUTPUT: average monthly consumption



PEM energy model



Mirafiori Paintshop block chain

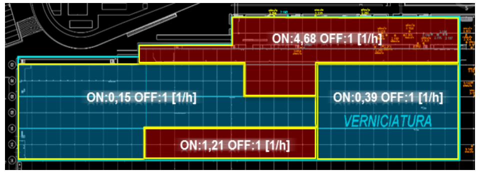
***Phase 2**: Paintshop process thermal loads identification*

CRF in Task 5.2.3

Process thermal contributions that affect the heating consumption of the building

1. AERAULIC BALANCE (without utilities volumes)

→ Reduction of cold air infiltrations from the outside

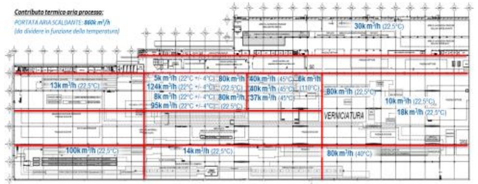


Expected output of the studies:

*Outdoor air exchange calculated with the balance between depression and overpressure of the indoor volume → **[1/h]***

2. THERMAL CONTRIBUTION OF PROCESS AIR FLOWS

→ Overpressure hot air from the booths and ovens to the building

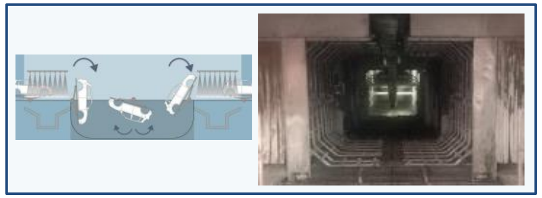


Expected output of the studies:

*Thermal power transferred from process to the building per floor area → **[W/m²]***

3. THERMAL CONTRIBUTIONS OF THE TANKS

→ Convective, conductive, radiative heat exchanges, etc.

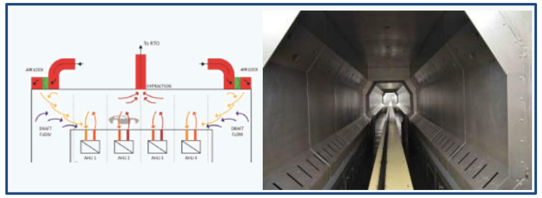


Expected output of the studies:

*Thermal power transferred from process to the building per floor area → **[W/m²]***

4. THERMAL CONTRIBUTIONS OF THE OVENS

→ Convective, conductive, radiative heat exchanges, etc.



Expected output of the studies:

*Thermal power transferred from process to the building per floor area → **[W/m²]***

5. THERMAL CONTRIBUTIONS OF THE BOOTHS

→ Convective heat exchanges through the dispersing surfaces

Expected output of the studies:

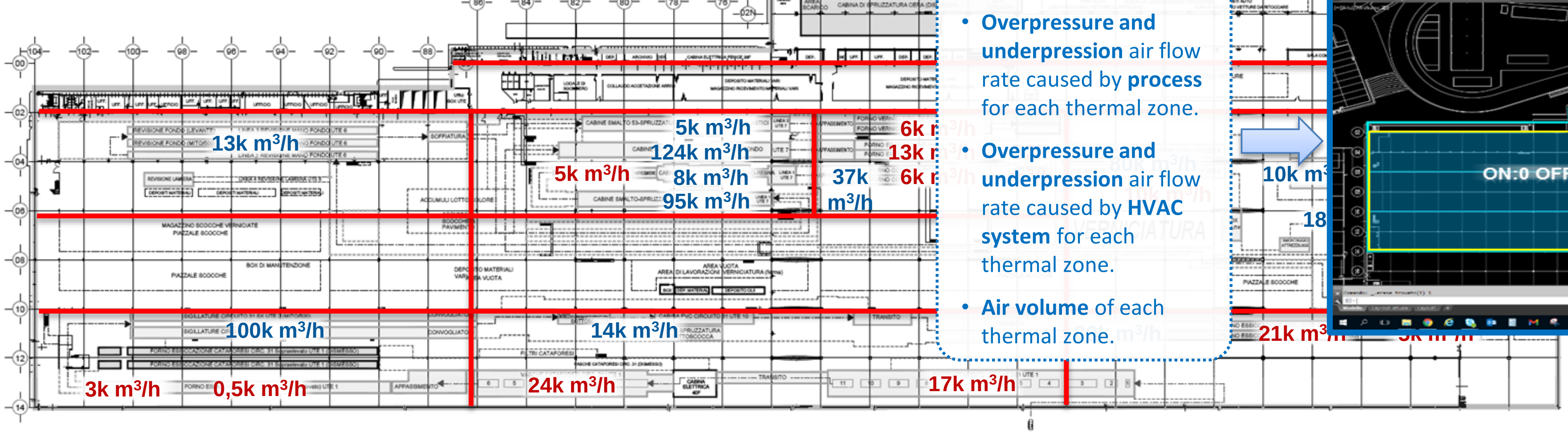
*Thermal power transferred from process to the building per floor area → **[W/m²]***

Phase 2: *Paintshop process thermal loads 1 and 2*

CRF in Task 5.2.3

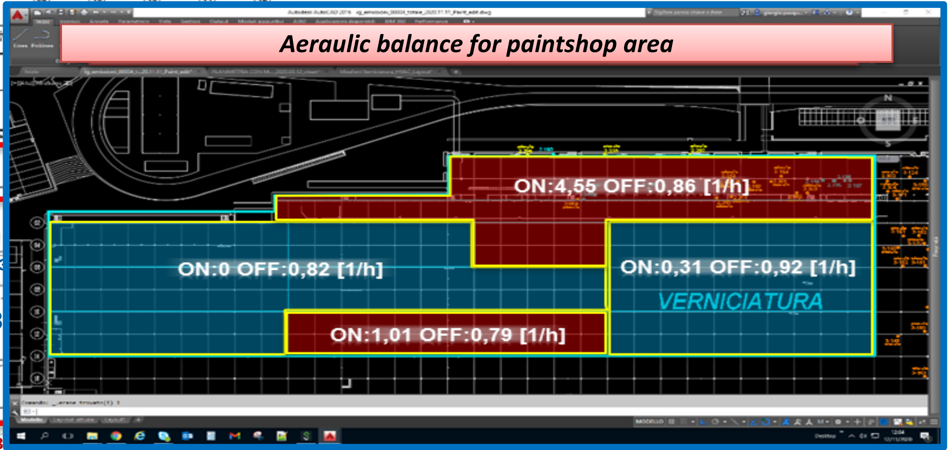
1 *AERAULIC BALANCE (without utilities volumes)*

Total overpressure: ***452k m³/h***



Excel analytical calculation based on:

- **Overpressure and underpression** air flow rate caused by **process** for each thermal zone.
- **Overpressure and underpression** air flow rate caused by **HVAC system** for each thermal zone.
- **Air volume** of each thermal zone.

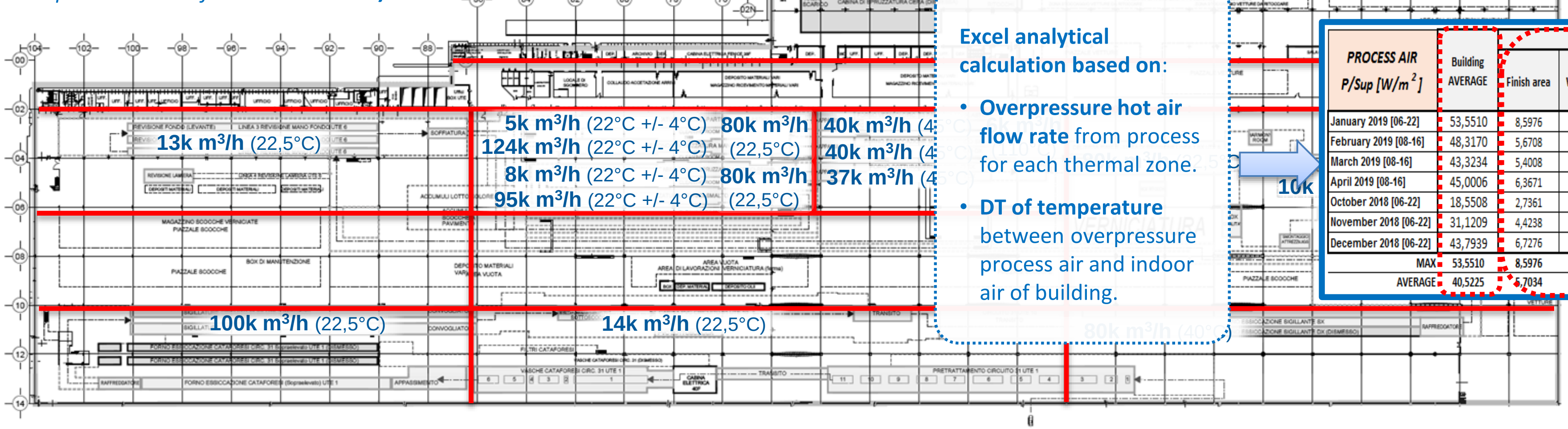


Outdoor air exchange rate with process ON or OFF:

- ***Thermal zones in depression***
- ***Thermal zones in overpressure***

2 *THERMAL CONTRIBUTION OF PROCESS AIR FLOWS*

Total process hot air flow rate: ***860k m³/h***



Excel analytical calculation based on:

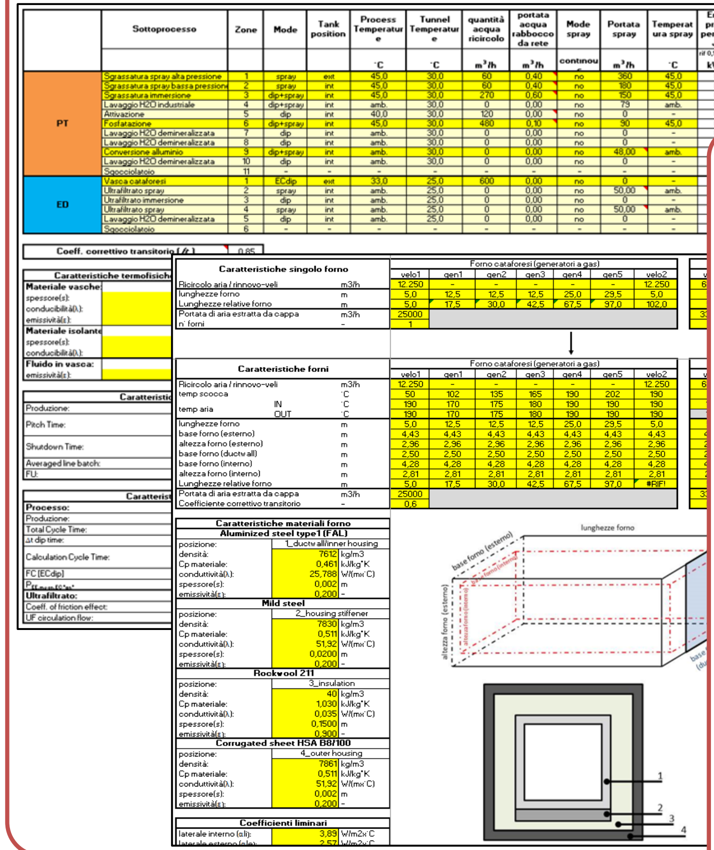
- **Overpressure hot air flow rate** from process for each thermal zone.
- **DT of temperature** between overpressure process air and indoor air of building.

PROCESS AIR P/Sup [W/m²]	Building AVERAGE	THERMAL ZONE									
		Finish area	Warehouse	Primer revision	Primer and topcoat	Primer and topcoat ovens	Quality revision	Storage place 1	Storage place 2	Cataphoresis and sealing ovens	Pretreatment and cataphoresis	sealing ovens
January 2019 [06-22]	53,5510	8,5976	0,0000	2,6201	345,7983	391,8067	9,4641	0,0000	0,0000	74,1366	5,5809	89,1990
February 2019 [08-16]	48,3170	5,6708	0,0000	2,6174	300,7455	372,5878	9,3554	0,0000	0,0000	64,1341	4,2269	83,4183
March 2019 [08-16]	43,3234	5,4008	0,0000	3,2114	245,5937	348,3733	11,3745	0,0000	0,0000	52,0697	4,2269	81,3520
April 2019 [08-16]	45,0006	6,3671	0,0000	4,0124	250,2767	351,3037	14,4966	0,0000	0,0000	53,2967	4,8138	85,9910
October 2018 [06-22]	18,5508	2,7361	0,0000	0,7641	32,5778	248,5389	1,4049	0,0000	0,0000	6,5667	0,6668	58,7483
November 2018 [06-22]	31,1209	4,4238	0,0000	2,2800	139,5872	297,9943	7,7092	0,0000	0,0000	28,9934	2,2388	69,0825
December 2018 [06-22]	43,7939	6,7276	0,0000	2,6173	257,2534	351,7941	9,3223	0,0000	0,0000	54,2630	3,8639	78,4036
MAX	53,5510	8,5976	0,0000	4,0124	345,7983	391,8067	14,4966	0,0000	0,0000	74,1366	5,5809	89,1990
AVERAGE	40,5225	5,7034	0,0000	2,5890	224,5475	337,4855	9,0181	0,0000	0,0000	47,6372	3,6597	78,0278

***Phase 2**: Paintshop process thermal loads* in Task 5.2.3

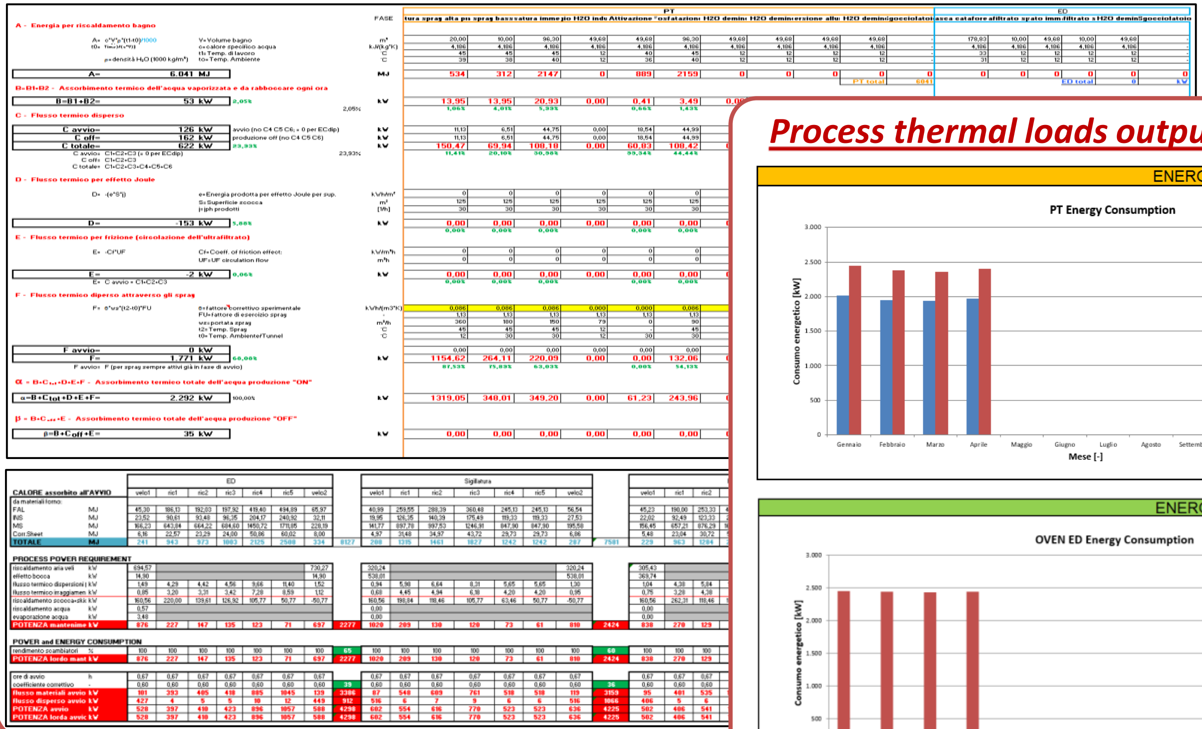
3 and 4 ***THERMAL CONTRIBUTIONS OF THE TANKS and OVENS***

Data collection



Data collection of tanks and ovens for PEM calculation

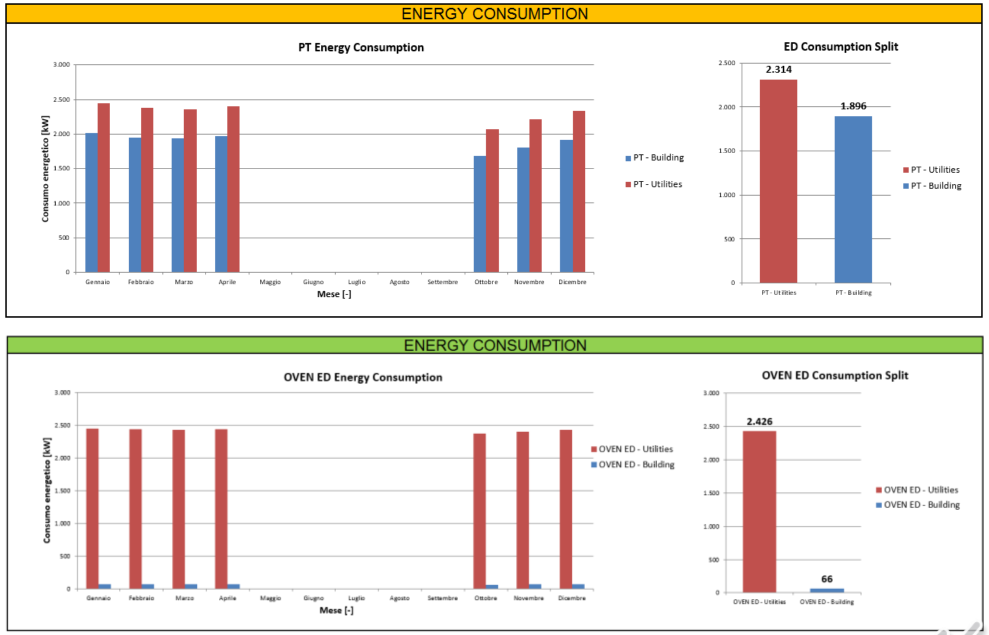
Data elaboration with PEM analytical model



Excel model with analytical heat transfer balance of PEM

Use of Process Energy Management (PEM) to estimate thermal contribution of the process in the building.

Process thermal loads output



Monthly average of thermal power from process to the building

Phase 2: *Paintshop process thermal loads*

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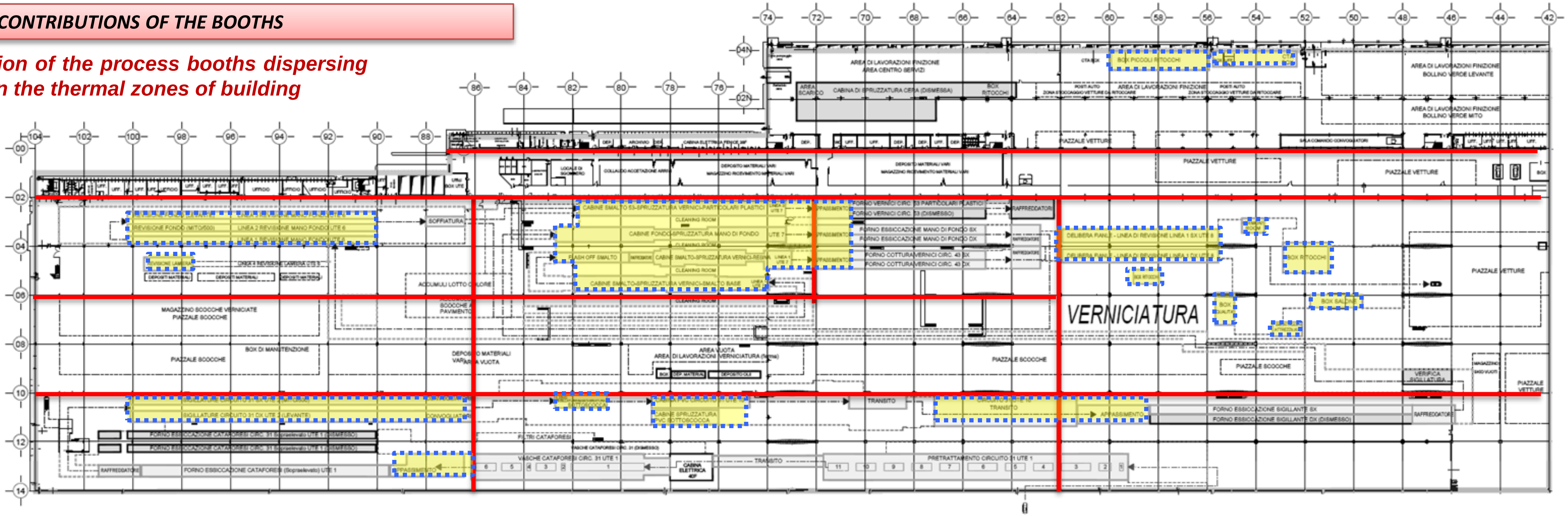
5 **THERMAL CONTRIBUTIONS OF THE BOOTHS**

Identification of the process booths dispersing surfaces in the thermal zones of building



Calculation of area of the process booths dispersing surfaces → ***Calculation of transmittance of the process booths dispersing surfaces*** → ***Calculation of power transferred to the building through the process booths dispersing surfaces, based on area [m²], transmittance [W/m²K] and DT[°C] between booths and building air temperature***

PAINTSHOP Finish area		
Booths roof surfaces	538	[m²]
Booths height	5	[m]
Booths wall length	167	[m]
Booths wall surfaces	837	[m³]

PAINTSHOP Warehouse		
Booths roof surfaces	0	[m²]
Booths height	0	[m]
Booths wall length	0	[m]
Booths wall surfaces	0	[m³]

PAINTSHOP Primer revision		
Booths roof surfaces	1.506	[m²]
Booths height	5	[m]
Booths wall length	321	[m]
Booths wall surfaces	1.604	[m³]

Transparent glass walls of the booths			
Element	s [m]	λ [w/mK]	R [m²K/W]
Internal resistance	-	-	0,130
Single glass	0,004	1,000	0,004
External resistance	-	-	0,040
Transmittance U [W/m²K]	5,75		

Roof of the booths			
Element	s [m]	λ [w/mK]	R [m²K/W]
Internal resistance	-	-	0,100
Sheet metal	0,001	0,800	0,001
EPS	0,050	0,040	1,250
Sheet metal	0,001	0,800	0,001
External resistance	-	-	0,100
Transmittance U [W/m²K]	0,69		

BOOTH LOSSES P/Sup [W/m²]	Building AVERAGE	THERMAL ZONE										
		Finish area	Warehouse	Primer revision	Primer and topcoat	Primer and topcoat ovens	Quality revision	Storage place 1	Storage place 2	Cataphoresis and sealing ovens	Pretreatment and cataphoresis	sealing ovens
January 2019 [06-22]	8,4538	4,5253	0,0000	6,3633	33,6175	38,8174	3,4574	0,0000	0,0000	27,5705	4,0256	8,0500
February 2019 [08-16]	7,5127	3,0026	0,0000	6,3567	29,4167	36,8875	3,4180	0,0000	0,0000	23,9381	3,0635	7,5500
March 2019 [08-16]	6,9750	2,8613	0,0000	7,7862	24,2365	34,4386	4,1489	0,0000	0,0000	19,5214	3,0635	7,3705
April 2019 [08-16]	7,5326	3,3665	0,0000	9,7058	24,6780	34,7360	5,2744	0,0000	0,0000	19,9723	3,4817	7,7729
October 2018 [06-22]	2,3507	1,4575	0,0000	1,8658	3,8292	24,1397	0,5166	0,0000	0,0000	2,5038	0,4894	5,3830
November 2018 [06-22]	4,8099	2,3483	0,0000	5,5428	14,1611	29,2827	2,8203	0,0000	0,0000	10,9629	1,6340	6,2972
December 2018 [06-22]	6,9137	3,5545	0,0000	6,3566	25,3351	34,7857	3,4060	0,0000	0,0000	20,3272	2,8040	7,1138
MAX	8,4538	4,5253	0,0000	9,7058	33,6175	38,8174	5,2744	0,0000	0,0000	27,5705	4,0256	8,0500
AVERAGE	6,3640	3,0166	0,0000	6,2825	22,1820	33,2982	3,2917	0,0000	0,0000	17,8280	2,6517	7,0768

Planned steps:

- ✓ 1 - Development of a BEM partial model of the building for energy analysis
- ✓ 2 - Elaboration of process data with PEM methodology
- WORK IN PROGRESS 3 - Integration of BEM model with PEM data
- To do: 4 - Validation of BEM complete model