ETICS with vacuum insulation panels for retrofitting buildings from the great Swedish housing program “Miljonprogrammet”

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Robust and Durable Vacuum Insulation Technology for Buildings

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Why the Swedish ”Million program”?

We have to deal with the existing building stock - to meet the “20-20-20” targets of the EU-commission related to climate and energy

In Sweden, about 21% of the energy use can be related to the heat losses through the climatic envelopes of buildings

The Swedish “Million Program” units built in the period between 1965 and 1974

A U-value of about 0,6 $Wm^{-2}K^{-1}$ on average for external walls

Rinkeby, Stockholm

Fittja, Stockholm

Skärholmen, Stockholm

Tensta, Stockholm

Objectives

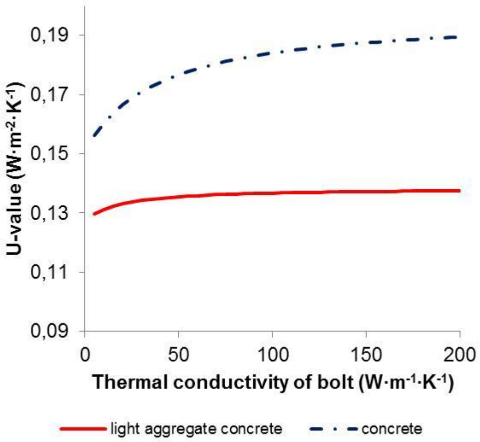
- To propose a new and robust VIP technical solution for the great Swedish Million dwelling program
- To investigate the influence of various design factors on the resulting U-value
- To simulate heat and moisture conditions.
- To compare theoretical assessments and in situ measurements of thermal performance
- To carry out a full scale measurement in a climatic chamber to investigate the influence of thermal bridges of a wall construction with exterior VIPs

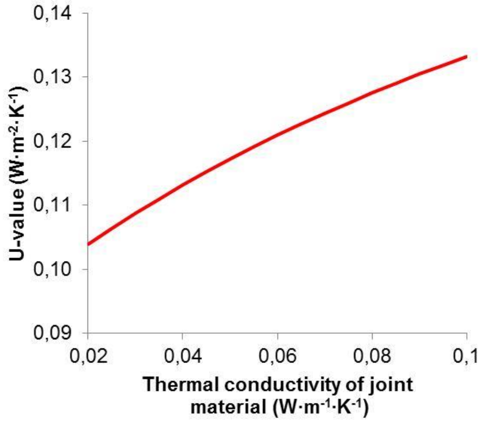
Method

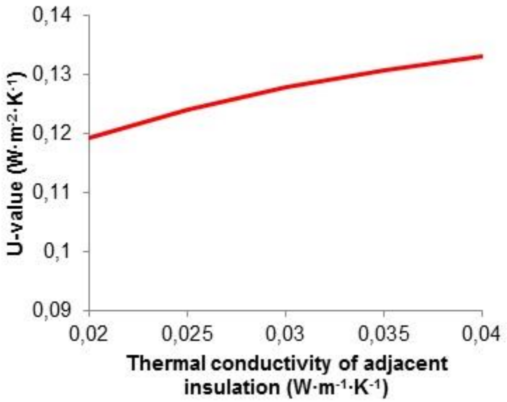
- *A parametric study of the impact of the thermal conductivity of the joints of the panels and the adjacent insulation layer as well as the material of the fasteners*
- *A 3-dimension COMSOL simulation of heat transfer through the construction*
- *A 2 dimensional transient modeling of vapor diffusion with COMSOL allowing for sorption in the material as well as enhanced moisture transport at high relative humidity.*

Hovsjö, an example of a housing project in the "Million Program"

Parametric pre-study







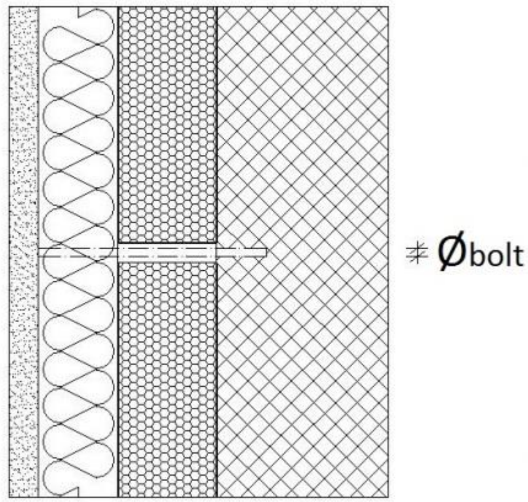
- *The material with a high thermal resistance at the VIP joints has a* ***significant influence*** *on the thermal bridges. Going from a value of 0.10 to 0.02 W $m^{-1}K^{-1}$ will give a reduction that amounts to about* ***30%*** *of the total density of heat loss*

- *The influence of improving the outer insulation layer does also have a measurable effect on the heat flux, although somewhat smaller.*

VIP technical solution

2D och 3D dynamic simulations with Comsol Multiphysics®

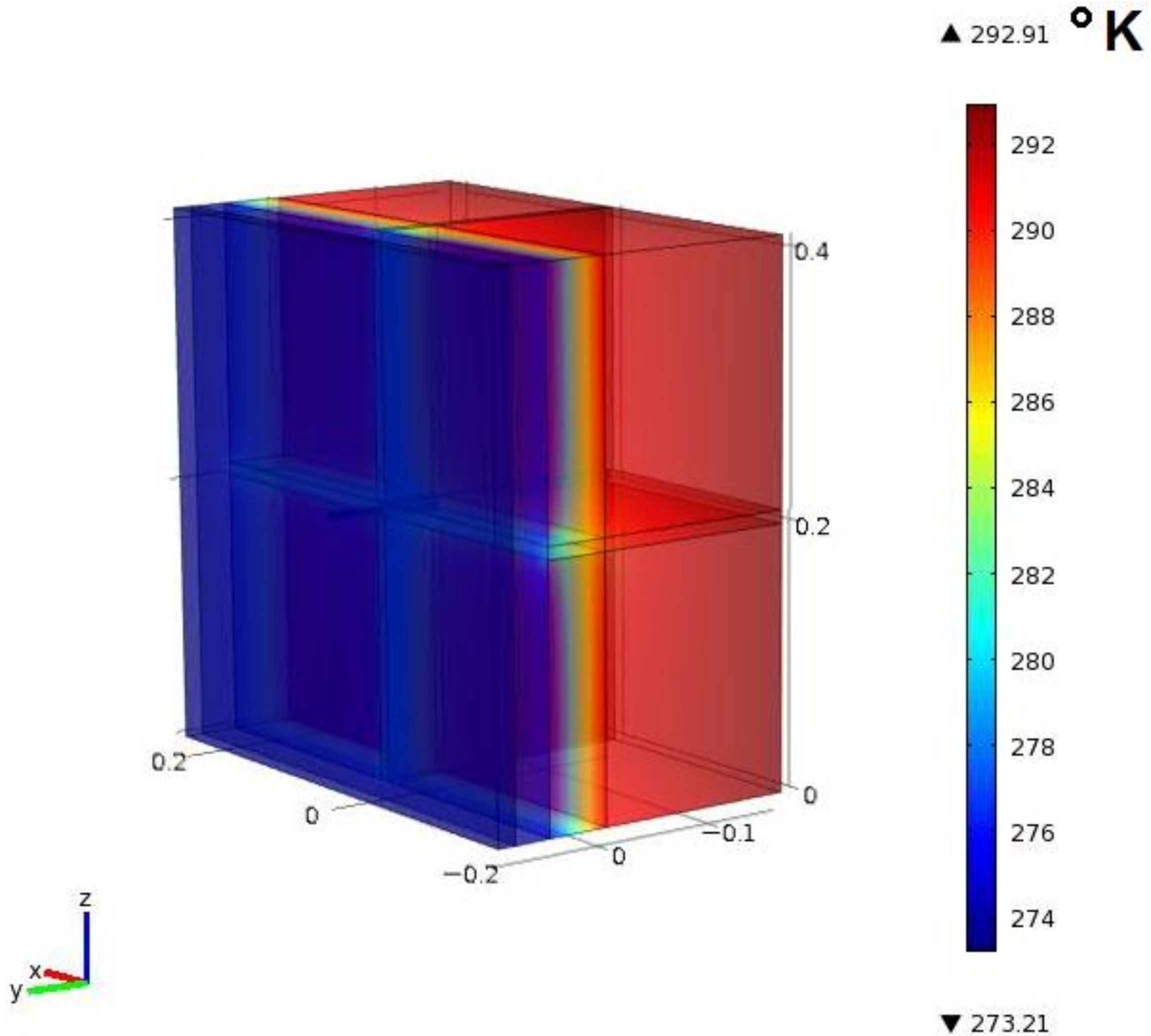
- *The average hourly values for outdoor temperature and relative humidity are retrieved from an International weather for energy calculation (IWEC) climate file for Stockholm, 2012*
- *The indoor temperature and relative humidity are as defined by EN 15026*



15 RENDERING
45 MINERAL WOOL
50 VIP , WITH A 10 MM JOINT BETWEEN PANELS
160 LIGHT AGGREGATE CONCRETE

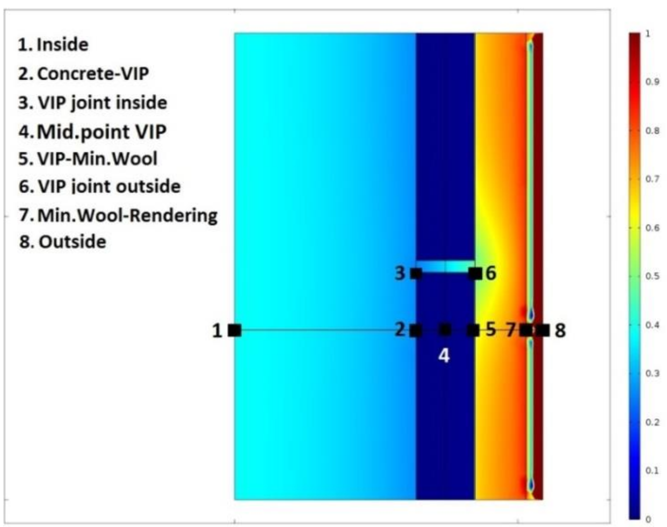
ALL DIMENSIONS IN MM

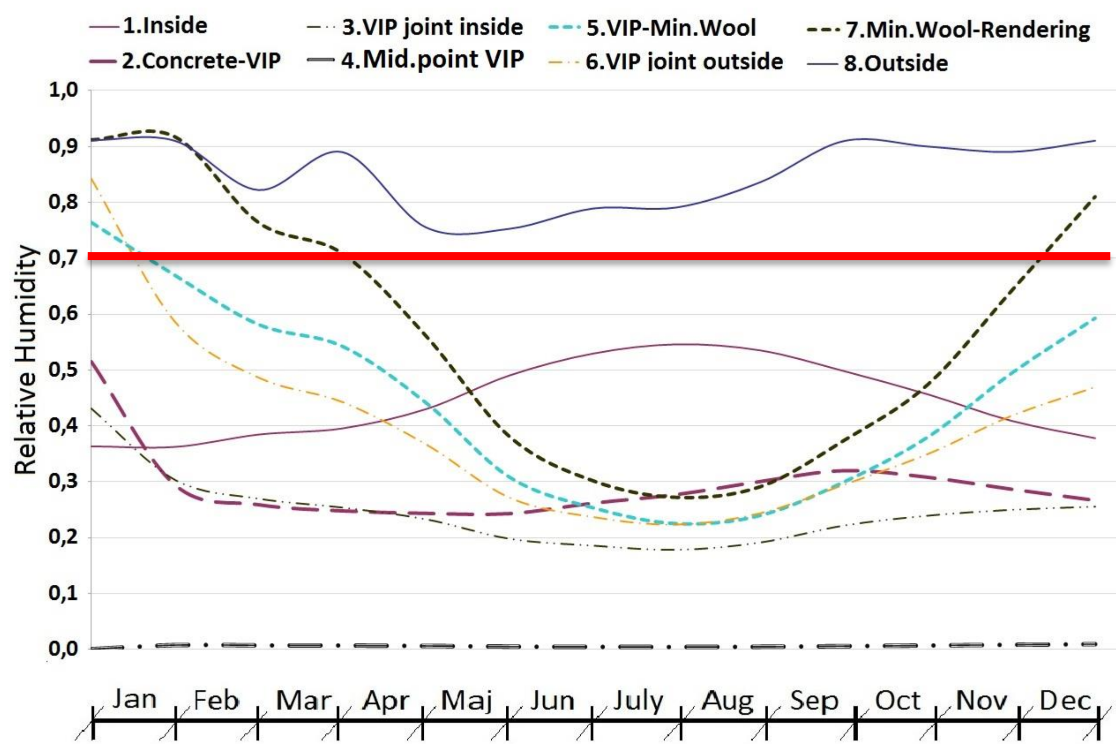
Simulated heat transport



Moisture transport

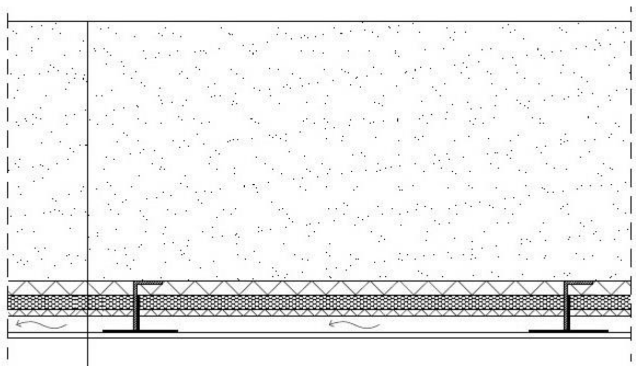
The relative humidity distribution in wall construction in the long term, extreme conditions.





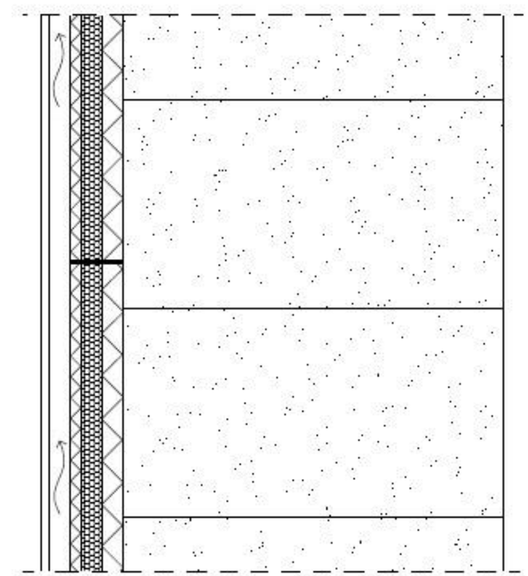
A new VIP mounting system

- *Facade components are standard and available at market.*
- *The VIP sandwiches were glued to the outside of the wall structure, by the means of an adhesive (hydraulically setting mortar)*
- *A 3 mm thick L-profile plus a T-profile (stainless steel) provides a flexible ventilating air gap between the façade board and the structure*



Facade system (Horizontal section)
365 mm Light aggregate concrete
20 mm EPS-Panels
20 mm Vacuum Insulation Panels (VIPs)
10 mm EPS-Panels

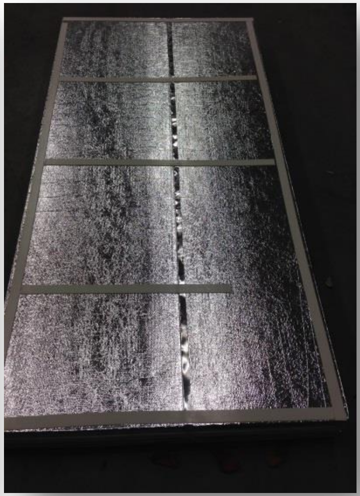
70 mm L-Shaped stainless steel sheet
20 mm Airgap
12 mm Facade boards
3 mm Rendering

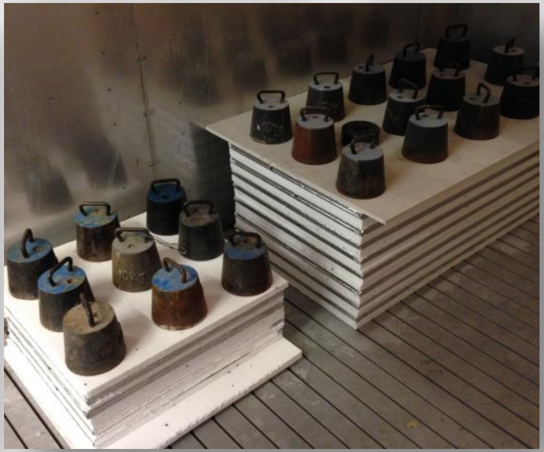


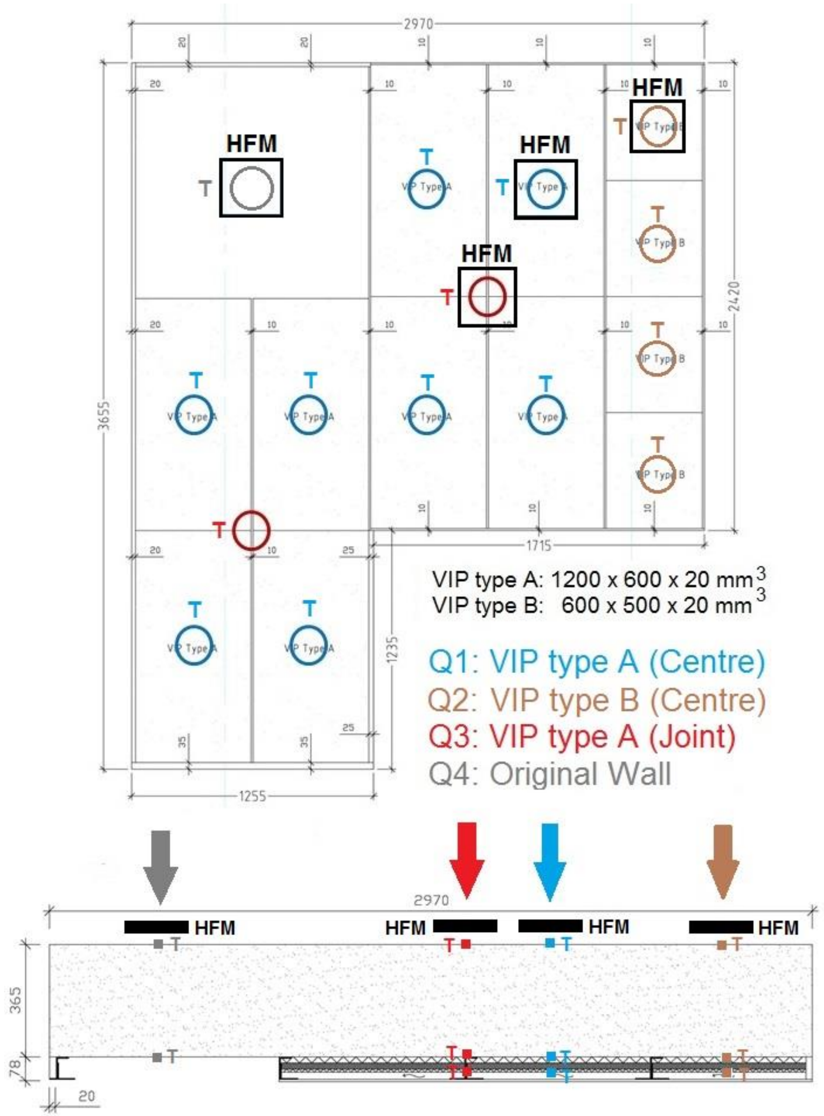
Vertical section

Full scale laboratory measurement





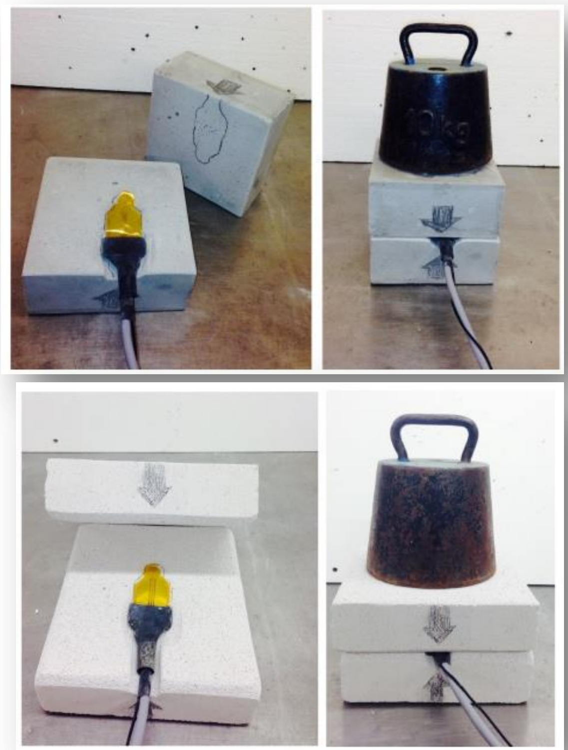



Facade system (Horizontal section)

- *The heat flow meter (HFM) sensors were mounted in different positions on the interior surface*
- *80 temperature sensors, Copper/Constantan as well as Chromel/Alumel thermocouple were installed at various coordinates in the plane of the wall and at the material layer boundaries*

Calculated centre-of-panel U-value

The TPS technique (TPS 2500S-ISO/DIS 22007-2.2) used to evaluate the thermal properties of the materials used in the wall



Material	**d (mm)**	**λ (W m^{-1}K^{-1})**	**Standard deviations**	**Source**	**R (m^{2}K W^{-1})**
Aerated concrete blocks	365	0.118	±0.000223	TPS	3.09
Hydraulically setting mortar	2	0.959	±0.000234	TPS	0.002
EPS	20	0.0329	±0.0000156	TPS	0.608
VIP_{centre}	20	0.0042	-	Manufacturer	4.76
EPS	10	0.0329	±0.0000156	TPS	0.304
R_{si}	-	-		Standard value	0.14
R_{se}	-	-		Standard value	0.04
R_{wall}	-	-		-	8.944
Calculated U-value (W m^{-2}K^{-1})	417			**Before retrofitting**	**0.305**
				After retrofitting	**0.112**

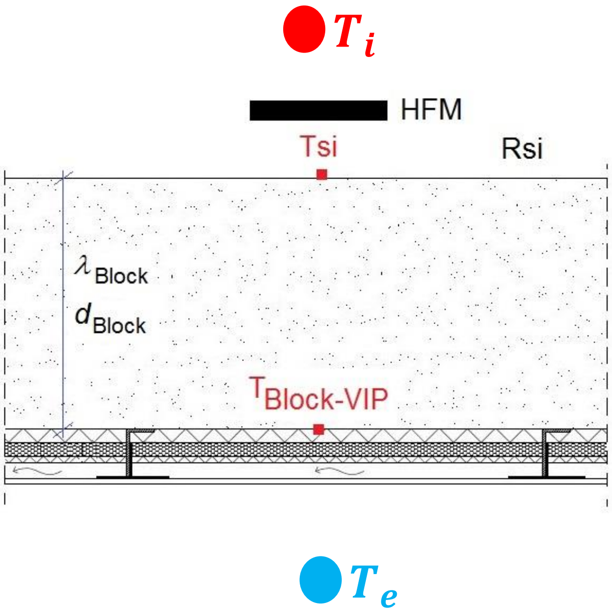
Measured Centre-of-Panels U-value

Centre-of-Panels U-value using Thermocouples and reference material

$$\frac{\lambda_{Block}}{d_{Block}}(T_{si} - T_{Block\ -VIP}) = U_{wall}\,(T_i - T_e)$$

Centre-of-Panels U-value by using Thermocouples and HFM sensors

$$\frac{(T_i - T_{si})}{R_{si}} = q_{HFM} = U_{wall}\,(T_i - T_e)$$



Measured effective U-value

Effective U-value by thermography investigations

$$q_{tot} = U_{centre-of-panel} \cdot \Delta T + \Psi \cdot \frac{P}{A} \cdot \Delta T$$

$$\frac{\frac{T_e - T_{se,VIPcentre}}{R_{se}}}{\frac{T_e - \overline{T_{se}}}{R_{se}}} = \frac{U_{centre-of-panel} \cdot (T_i - T_e)}{U_{effective} \cdot (T_i - T_e)}$$

T_e: Outside air temperature

T_i: Inside air temprature

$\overline{T_{se}}$: Average outside wall surface temperature

$T_{seVIPcentre}$: Outside wall surface temperature at coordinate of the centre-of-panel

R_{se}: Wall surface thermal resistance at exterior side

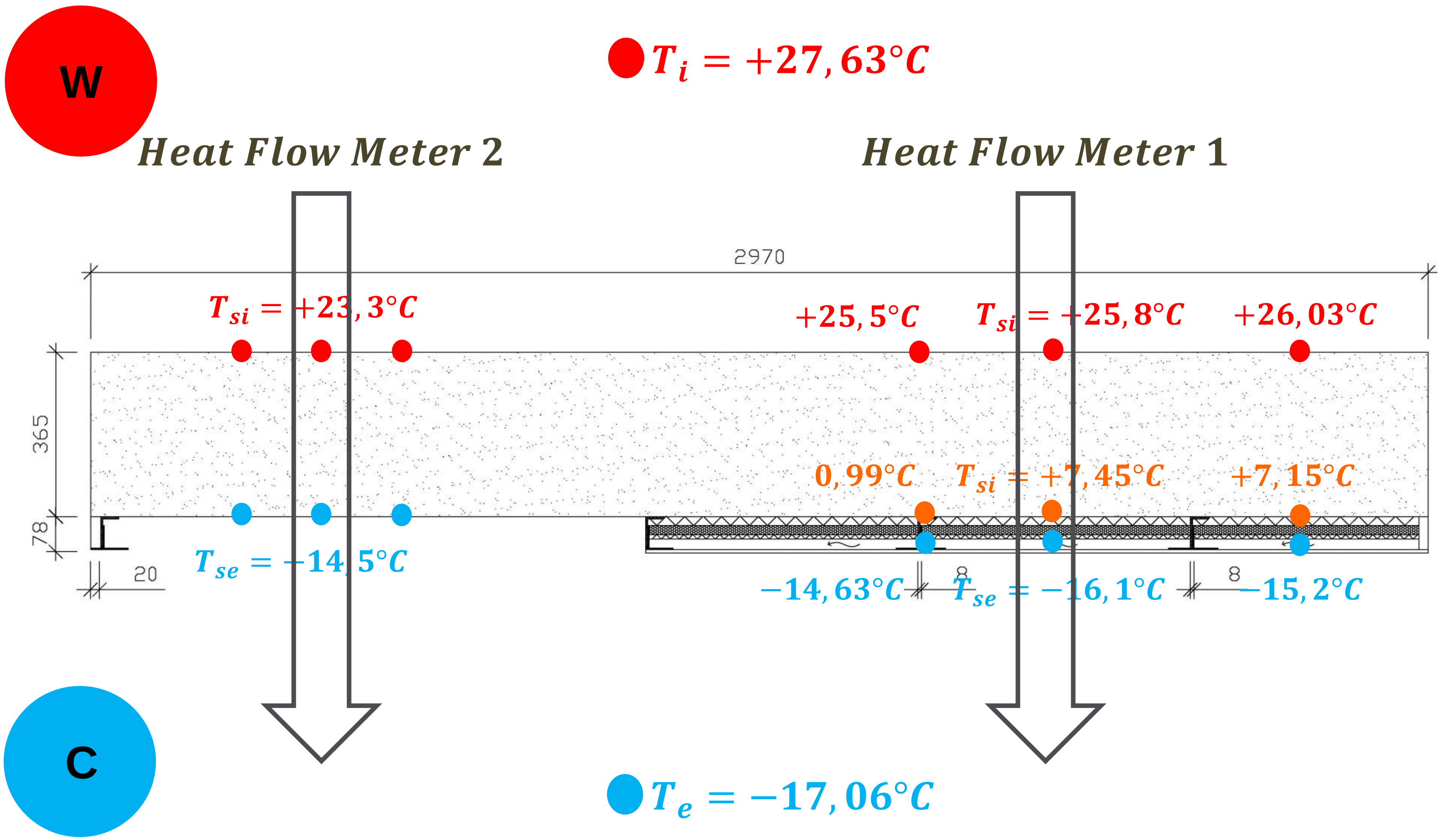
$U_{centre-of-panels}$: Thermal transmittance of the wall at coordinate of the centre-of-panels

$U_{effective}$: Effective thermal transmittance of the wall

Climatic Condition

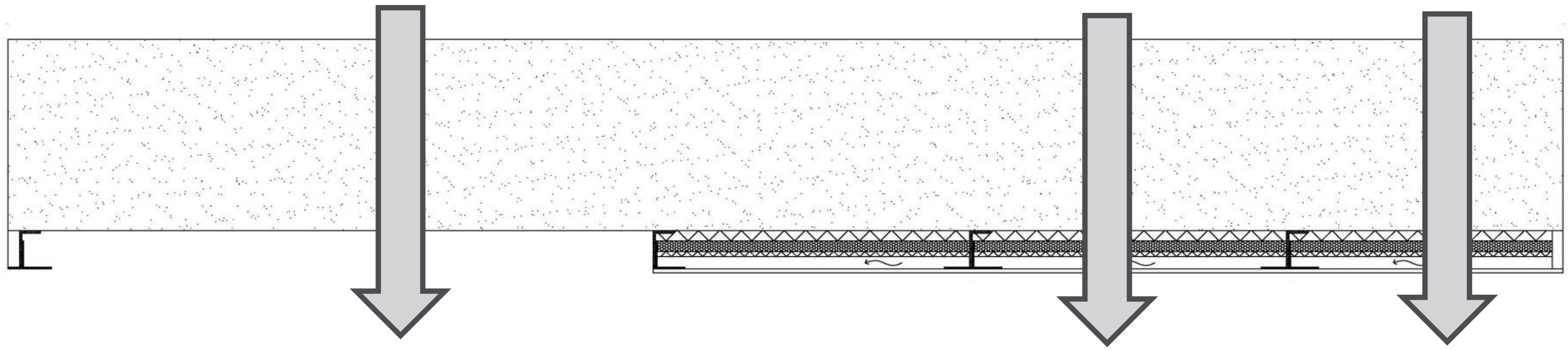
Climate sequences	Measuring time (Hours)	Colder side		Warmer side	
		T_e (℃)	RH_{ea} (%)	T_i (℃)	RH_{ea} (%)
Climatic time sequence No.1	410	-5		22-24	
Climatic time sequence No.2	860	-15	45 – 73	23-28	6.7–25.5
Climatic time sequence No.3	2030	-20		23-28	

Measured temperatures



Centre-of-Panels U-values

$R_{si} = 0{,}24\ (m^2 \cdot K)/W$



Calculated:	0.305	0,112	$W/(m^2 \cdot K)$
Measured: (T-sensors)	0.275	0,121 – 0.136	$W/(m^2 \cdot K)$
Measured : (HFM)	0.323	0,17	$W/(m^2 \cdot K)$

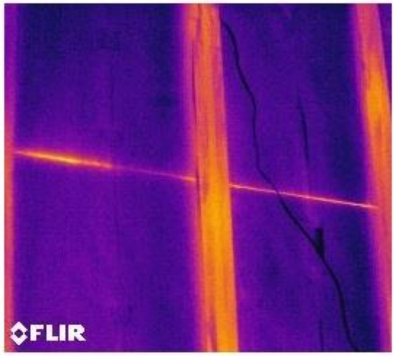
Taking into account an addition standard thermal resistance of a ventilated air gap

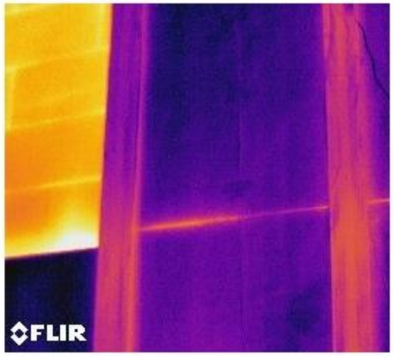
Calculated:	0.29	0,109	$W/(m^2 \cdot K)$
Measured: (T-sensors)	0.26	0,118 – 0.132	$W/(m^2 \cdot K)$
Measured : (HFM)	0.3	0,165	$W/(m^2 \cdot K)$

Effective U-value

Measured temperatures:

Placement	VIP No. 5-8	
	VIP_{centre} 1200×600 mm^2	VIP_{joint} 1200×600 mm^2
Inside air temperature (°C)	28.83	
Interior surface temperature(°C)	25.62	25.52
Concrete blocks -VIP(°C)	6.89	0.58
Exterior surface temperature(°C)	-15.31	-13.31
Outside air temprature (°C)	-16.87	





A comparison of the U-values and λ-values:

	[W/(m²·K)]		[mW/(m·K)]
Calculated $U_{centre-of-panel}$	0,112	According to manufacturer $\lambda_{centre-of-panel}$	4,2
Measured $U_{centre-of-panel}$	0,132	Measured $\lambda_{centre-of-panel}$	≈7
Measured $U_{effective}$	0,154	Measured $\lambda_{effective}$	≈10,9

Conclusions

- *Use material with relatively low thermal conductivity at the joints have a significant impact on the resulting U value.*

- *Thermal conductivity of the adjacent insulation next to the VIP's have a measurable effect on the heat flow, while the choice of materials for the mounting (e.g. screws) have a smaller effect on the resulting U value compared to the effect of the material in the joints and adjacent insulation.*

- *Relative humidity calculation shows that the location of the VIP on the outside does not a moisture problem to the construction.*

- *There is no risk of high relative humidity at the joints.*

- *VIPs is a very competitive solution to renovate the construction of the Swedish "Million Program".*

- *This study demonstrates a robust, effective, simple and fast system for external mounting of the VIPs, an improved centre-of-panels thermal transmittance of the wall, in the range of 0.118-0.132* $W\ m^{-2}K^{-1}$ *as well as a low effective thermal conductivity for the VIPs of 10,9* $mW\ m^{-1}K^{-1}$*, are reached.*

Thanks for your kind attention!