National Technical University of Athens

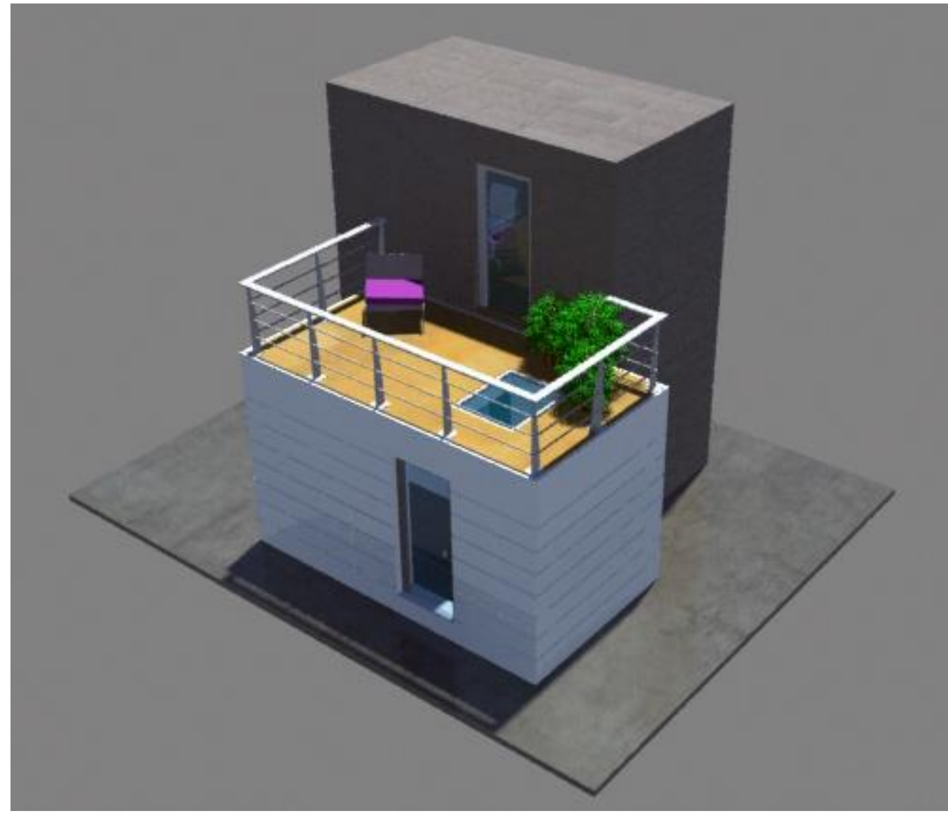
Thermal Performance of a Steel Skeleton / Drywall Building Insulated with Vacuum Insulation Panels

I.D. Mandilaras*[a],D.A. Kontogeorgos[a], I.A. Atsonios[a], C. Stark[b], S. Vidi[b], D. Marity[c], D. Seiler[c], D. Herfurth[d], M.A. Founti[a]

[a]*National Technical University of Athens, School of Mechanical Engineering, Lab. of Heterogeneous Mixtures and Combustion Systems*
[b]*Bayerisches Zentrum fur Angewandteenergieforschung ZAE EV, Am Galgenberg 87, 97074, Wuerzburg, Germany*
[c]*Haring Nepple AG, Hebelstrasse 75, 4056 Basel, Switzerland*
[d]*KNAUF GIPS GK, AM Bahnhof 7, 97346 Iphofen,Germany*

IVIS2015
12th International Vacuum Insulation Symposium - September 19 – 21, 2015, NUAA, Nanjing, P.R. China

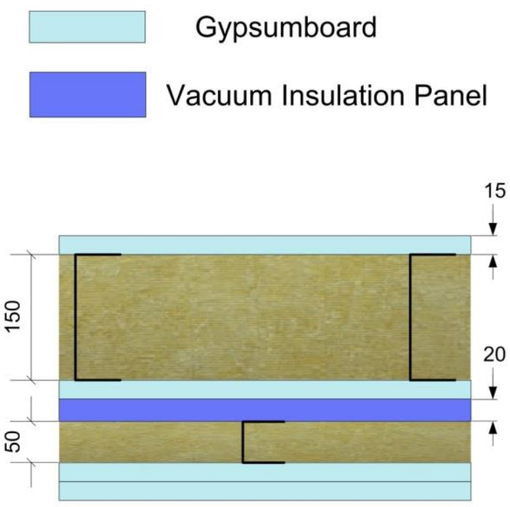
- Lightweight steel framed/drywall building systems
  - Fast construction
  - Simplified erection (prefabricated modules)
  - Low weight (seismic performance)
- Use of VIPs
  - Thermal performance
  - High degree of energy efficiency



Building Concept - ELISSA
http://elissaproject.eu/

- Minimization of the heat transfer (losses) through the wall, using VIPs
- VIPs placed in the "middle" of the wall, thus protected
- Possibility of flexible facade because of VIPs in the middle
- Strong thermal bridges because of the steel construction (high difference between thermal conductivities of steel and insulation)
- Increased risk of condensation and mould growth

Lightweight drywall



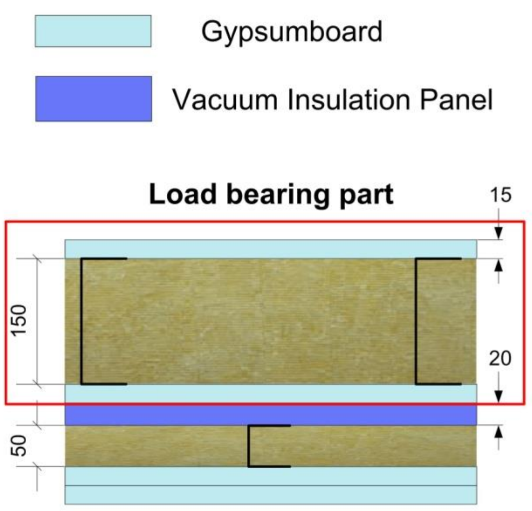
U-value: 0.15 W/m²K
Density: 35 kg/m²
Thickness: 280 mm

IVIS 2015

National Technical University of Athens

- Minimization of the heat transfer (losses) through the wall, using VIPs
- VIPs placed in the "middle" of the wall, thus protected
- Possibility of flexible facade because of VIPs in the middle
- Strong thermal bridges because of the steel construction (high difference between thermal conductivities of steel and insulation)
- Increased risk of condensation and mould growth

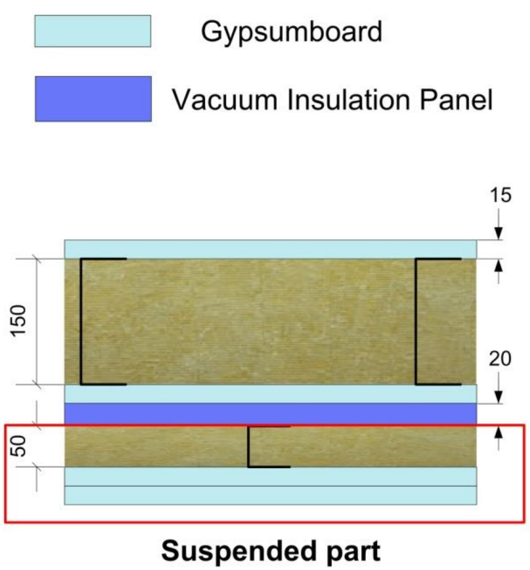
Lightweight drywall



National Technical University of Athens

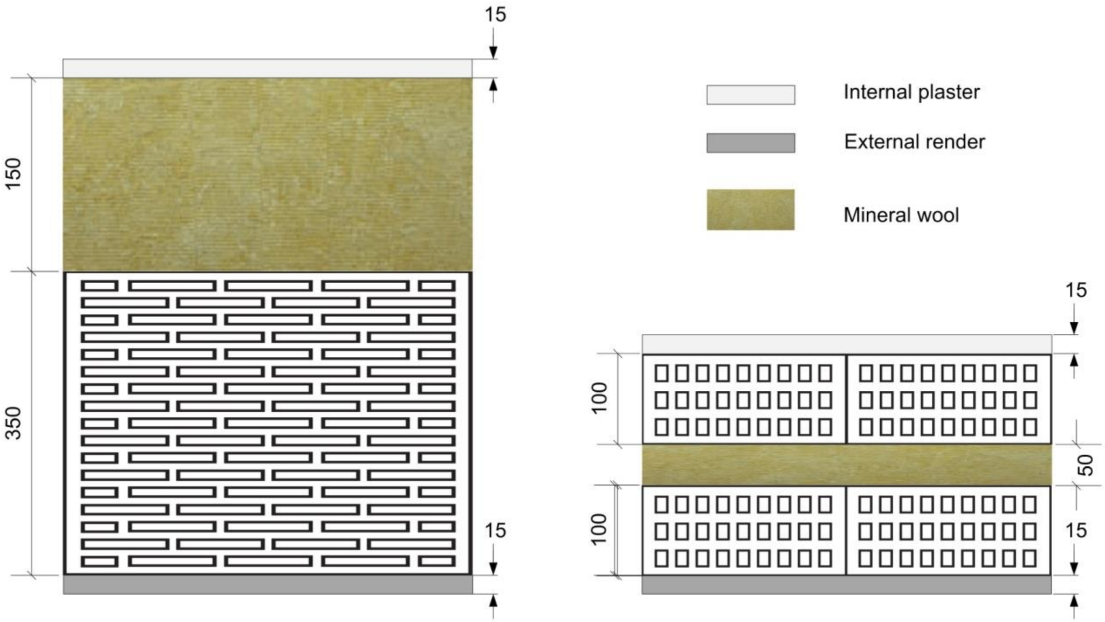
- Minimization of the heat transfer (losses) through the wall, using VIPs
- VIPs placed in the “middle” of the wall, thus protected
- Possibility of flexible facade because of VIPs in the middle
- Strong thermal bridges because of the steel construction (high difference between thermal conductivities of steel and insulation)
- Increased risk of condensation and mould growth

Lightweight drywall



National Technical University of Athens

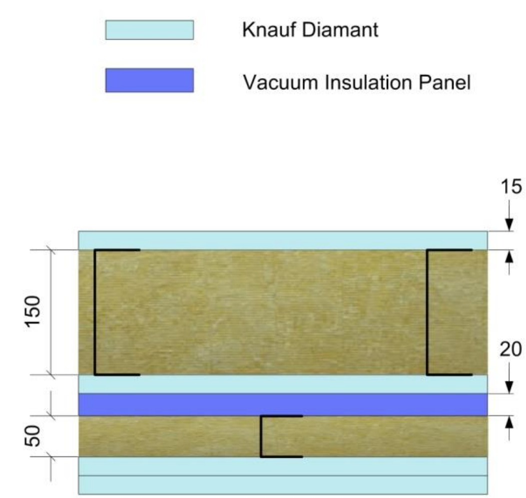
Brick Walls



U-value: 0.15 W/m²K
Density: 360 kg/m²
Thickness: 530 mm

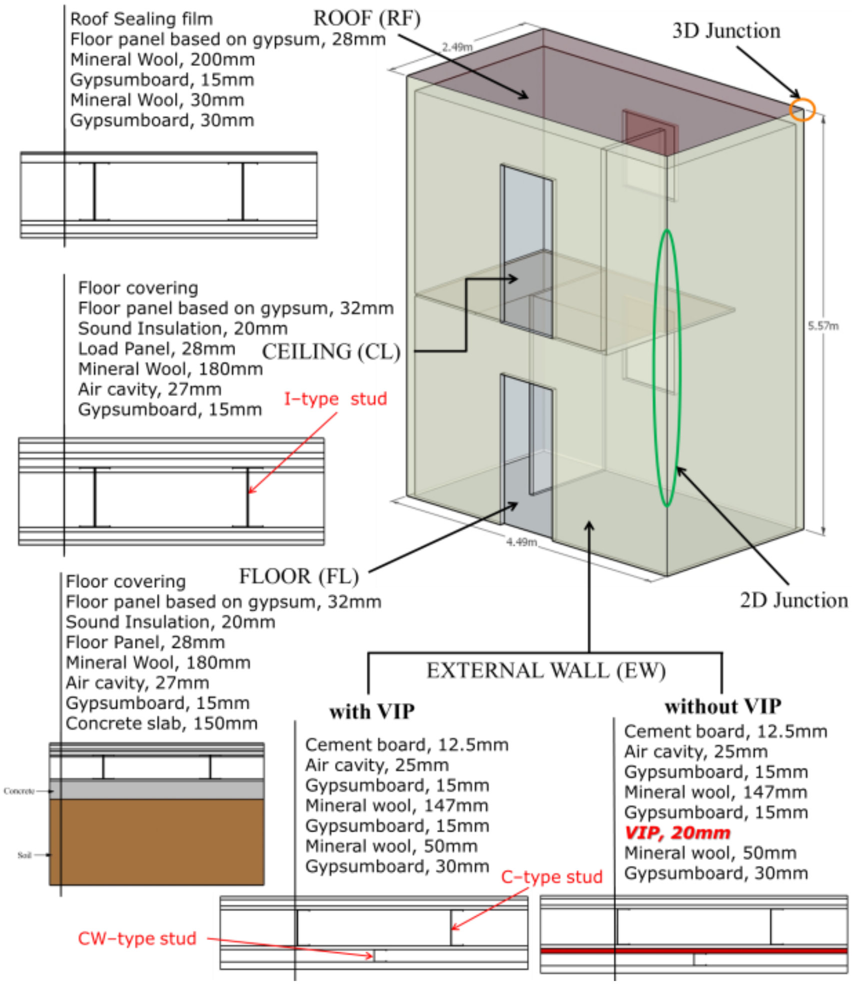
U-value: 0.42 W/m²K
Density: 270 kg/m²
Thickness: 280 mm

Lightweight drywall



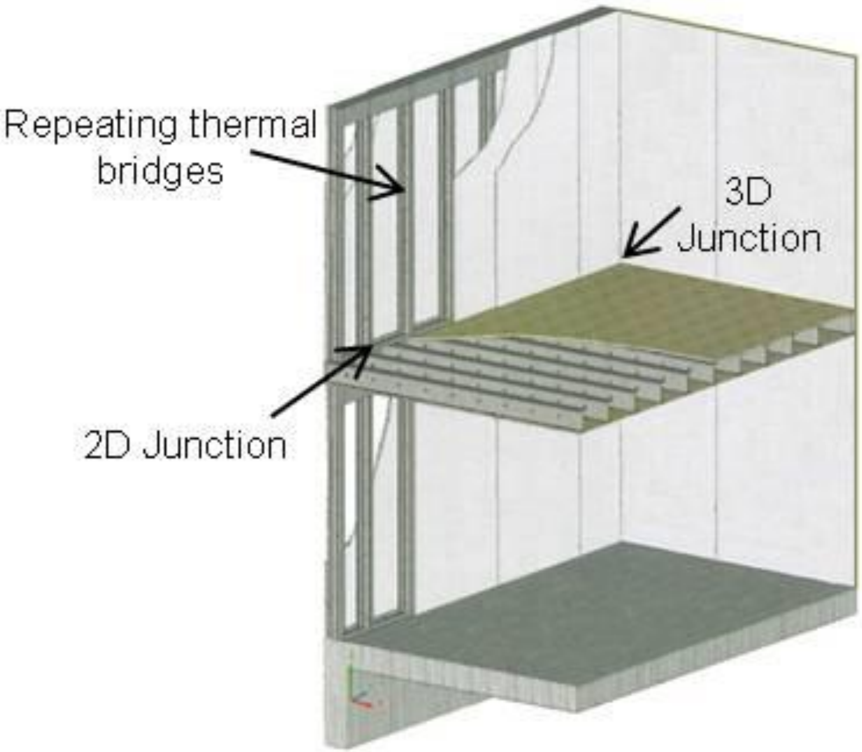
U-value: 0.15 W/m²K
Density: 35 kg/m²
Thickness: 280 mm

- Thermal bridges analysis
  - Two storey building
- Construction
  - Lightweight steel framed construction based on a cavity wall system
  - Metal skeleton founded on a cement base
  - Drywall system envelope anchored on the steel skeleton
- Drywall system
  - Materials anchored on three different types of metal studs (i.e. C, CW and I)
  - Additional VIP layer placed in the internal side of the External Walls



Schematic diagram of the configuration of the building elements

- Methodology based on ISO 10211
  - Separate analysis of the repeating and non-repeating thermal bridges
- Thermal bridges
  - **<u>Repeating</u>**: Metal studs at the middle part of the building elements
  - **<u>Non-repeating</u>**: Two- and Three- dimensional junctions between the building elements



Schematic diagram of the repeating and non-repeating thermal bridges

Transmission Heat Transfer Coefficient

$$H_D = \sum_i f_i A_i U_i + \sum_k f_k l_k \Psi_k + \sum_j f_j \chi_j$$

Variable	Description
f_i	Factor of temperature correction of the building part I
A_i	Area of element i of the building envelope
U_i	Thermal transmittance of the clear element i of the building (center of wall)
f_k	Factor of temperature correction of the linear thermal bridge k
L_k	Length of linear thermal bridges k
Ψ_k	Linear thermal transmittance of linear thermal bridges
f_j	Factor of temperature correction of the point thermal bridge j
χ_j	Point thermal transmittance of the point thermal bridge j

National Technical University of Athens

- Calculation of the individual thermal transmittances of each configuration
- Calculations are based on CFD simulations
  - ANSYS CFX
  - Boundary Conditions
    - **Inner side**: T_{in}=20°C, h_{in}=7.69W/m^{2}K
    - **Outside**: T_{out}=-10°C, h_{out}=20W/m^{2}K
    - **Soil**: T_{soil}=-10°C

Linear thermal transmittance

$$\psi = L_{2D} - \sum_{j=1}^{N_j} U_j l_j$$

Point thermal transmittance

$$\chi = L_{3D} - \sum_{i=1}^{N_i} U_i \mathrm{A}_i - \sum_{j=1}^{N_j} \psi_j l_j$$

***L_{2D}**: thermal coupling coefficient obtained from a 2D calculation of the component separating two environments being considered*

***L_{3D}**: thermal coupling coefficient obtained from a 3D calculation of the 3D component separating two environments being considered*

Hygro-thermal analysis

$$f_{Rsi} = \frac{T_{si} - T_{out}}{T_{in} - T_{out}}$$

T_{si}: Minimal internal surface temperature
f_{Rsi}: Temperature factor indicating potential mold growth

- **Mold growth** → f_{Rsi}<0.7 (relative humidity on a surface higher than 80% for several days, *DIN 4108-2)*
- **Simulations**→**HEAT3** commercial software
- **Boundary Conditions**
  - T_{out}=-5°C, R_{out}=0.04m^{2}K/W
  - T_{in}=20°C, R_{in}=0.25m^{2}K/W
  - RH_{in}=50%
  - T_{soil}=10°C

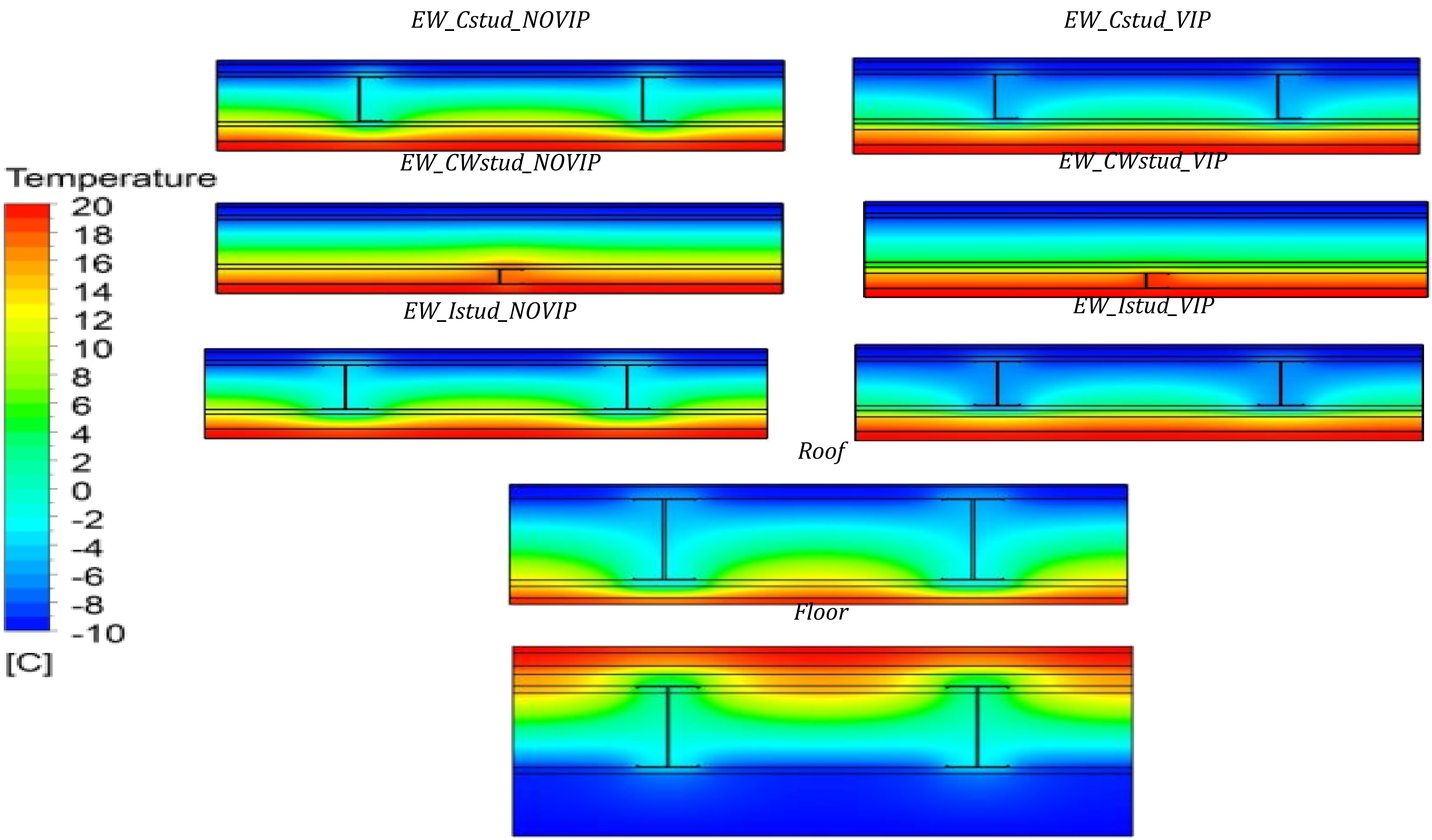
National Technical University of Athens

- Introduction
- Description of the Building
- Methodology
- Results & Discussion
- Conclusions & Outlook

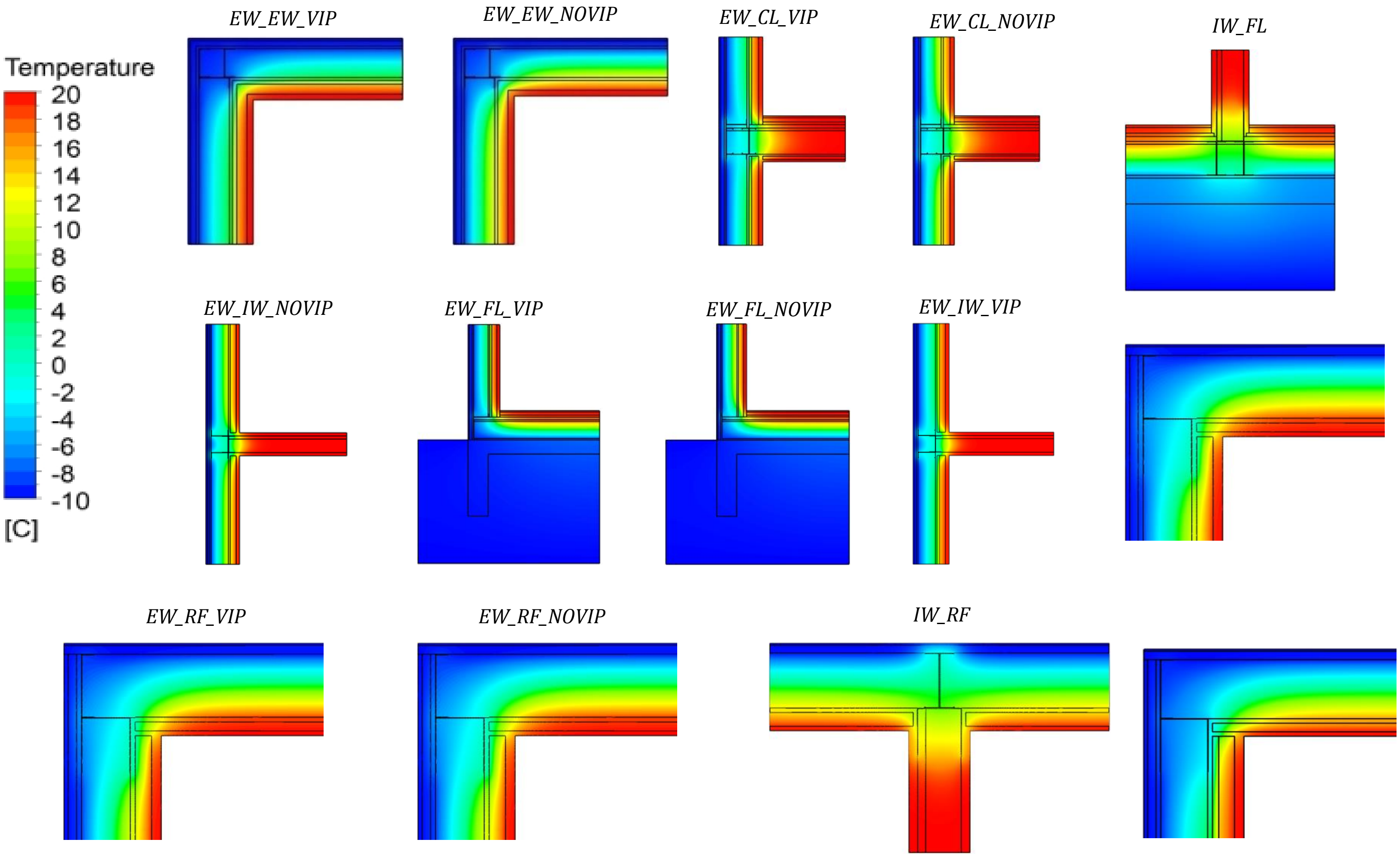
- Evaluation of the thermal bridges with and without the additional VIP layer
- Thermal Bridges
  - 8 cases → Impact of metal studs at the center part of walls
  - 14 two-dimensional intersections between the building elements
  - 12 three-dimensional junction between the building elements
- **Output**: Individual and overall contribution of the thermal bridges on the total heat transmittance

- Evaluation of the thermal bridges with and without the additional VIP layer
- Thermal Bridges
  - 8 cases → Impact of metal studs at the central part of walls
  - 14 two-dimensional intersections between the building elements
  - 12 three-dimensional junction between the building elements
- **Output**: Individual and overall contribution of the thermal bridges on the total heat transmittance

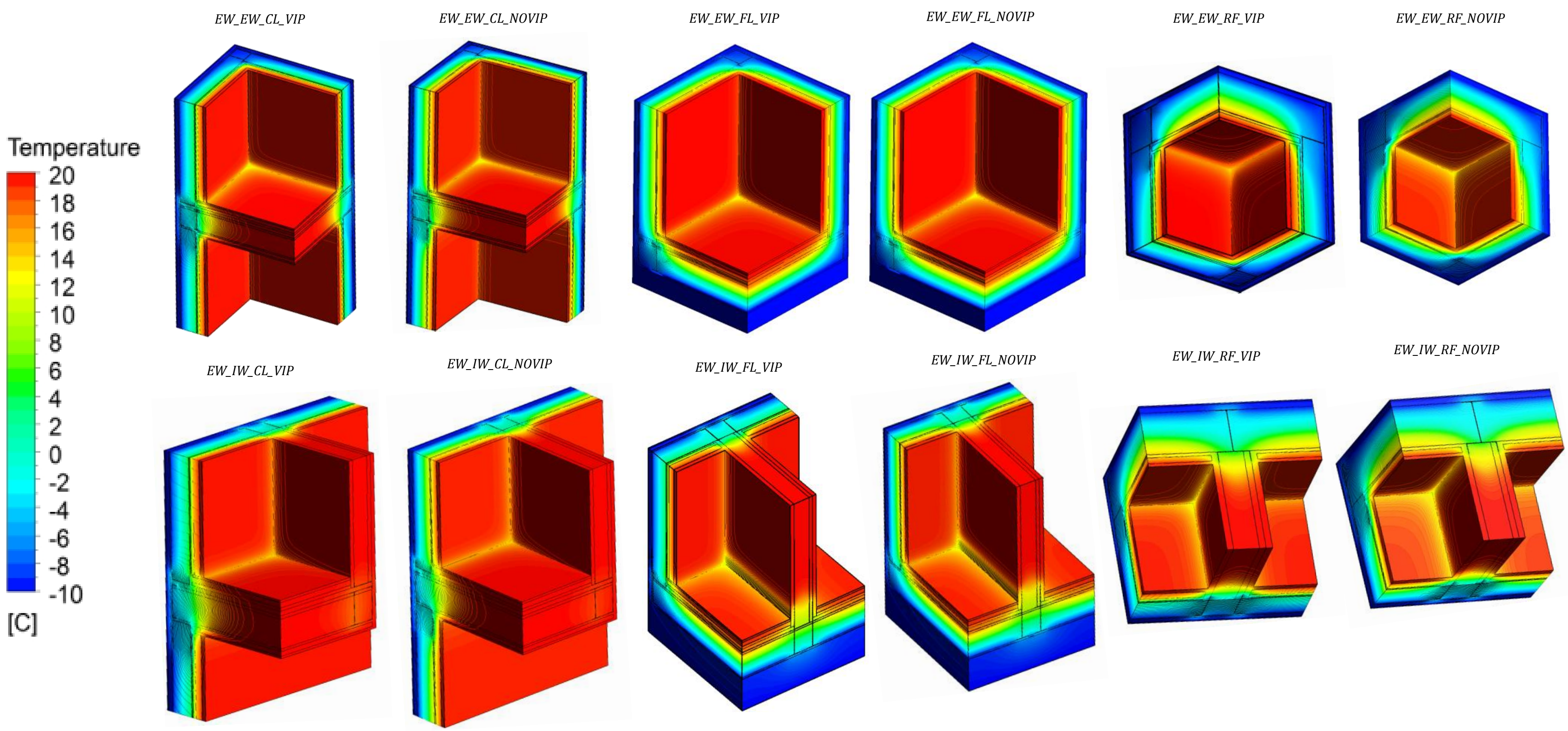
National Technical University of Athens



- Evaluation of the thermal bridges with and without the additional VIP layer
- Thermal Bridges
  - 8 cases → Impact of metal studs at the center part of walls
  - 14 two-dimensional intersections between the building elements
  - 12 three-dimensional junction between the building elements
- **Output**: Individual and overall contribution of the thermal bridges on the total heat transmittance

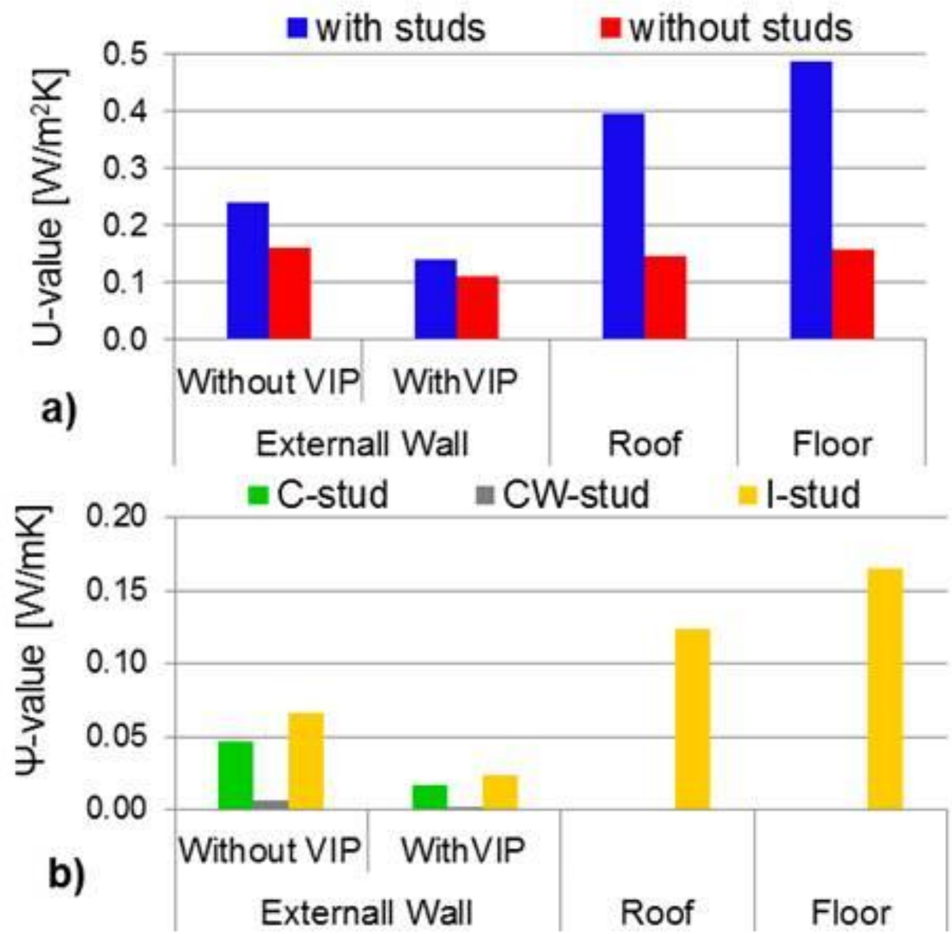

EW_EW_VIP
EW_EW_NOVIP
EW_CL_VIP
EW_CL_NOVIP
IW_FL
Temperature
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
[C]
EW_IW_NOVIP
EW_FL_VIP
EW_FL_NOVIP
EW_IW_VIP
EW_RF_VIP
EW_RF_NOVIP
IW_RF

- Evaluation of the thermal bridges with and without the additional VIP layer
- Thermal Bridges
  - 8 cases → Impact of metal studs at the center part of walls
  - 14 two-dimensional intersections between the building elements
  - 12 three-dimensional junction between the building elements
- **Output**: Individual and overall contribution of the thermal bridges on the total heat transmittance


EW_EW_CL_VIP
EW_EW_CL_NOVIP
EW_EW_FL_VIP
EW_EW_FL_NOVIP
EW_EW_RF_VIP
EW_EW_RF_NOVIP
Temperature
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
[C]
EW_IW_CL_VIP
EW_IW_CL_NOVIP
EW_IW_FL_VIP
EW_IW_FL_NOVIP
EW_IW_RF_VIP
EW_IW_RF_NOVIP

Center Part of Walls

- External Wall
  - Clear wall (without studs)
    - *Without VIP*: **U=0.16W/m²K**
    - *With VIP*: **U=0.11W/m²K**
    - VIP contribution: **31% decrease**
  - Metal studs
    - *Without VIP*: **50% U-value increase**
    - *With VIP*: **27% U-value increase**
  - Overall VIP contribution: **~42% U-value decrease**
- Roof
  - Repeating thermal bridges: **~169% U-value increase**
- Floor
  - Repeating thermal bridges: **~210% U-value increase**

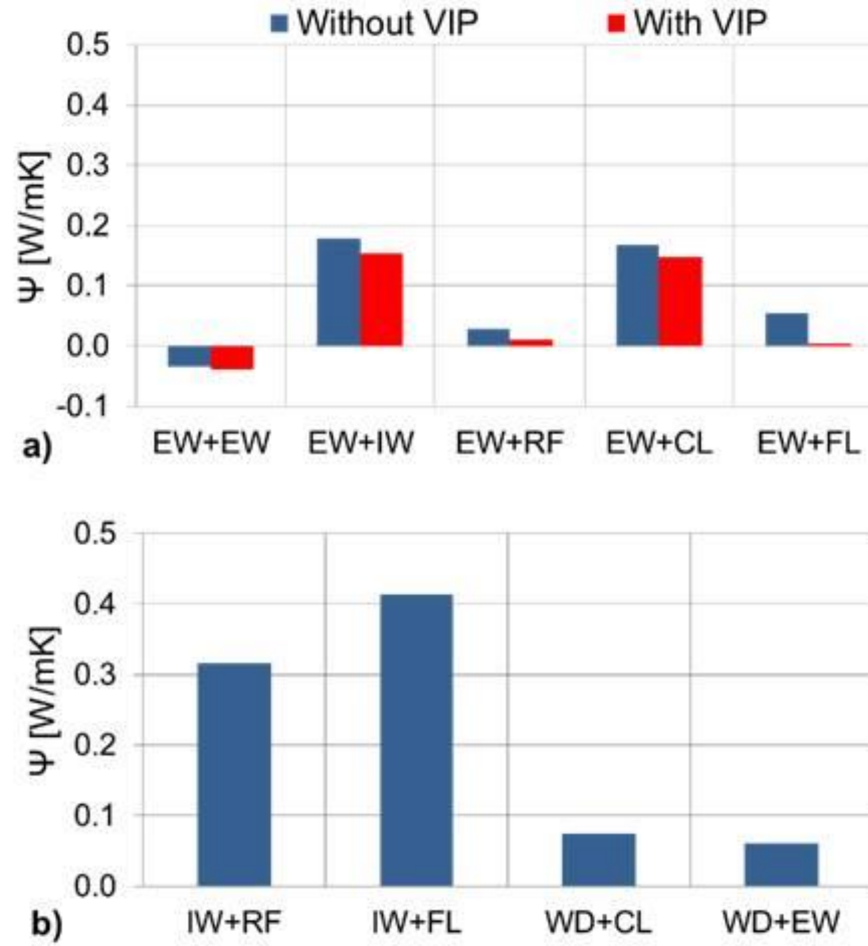


Impact of repeating thermal bridges on (a) the U-value of the building element and (b) the linear thermal transmittance of metal studs

National Technical University of Athens

2D Junctions

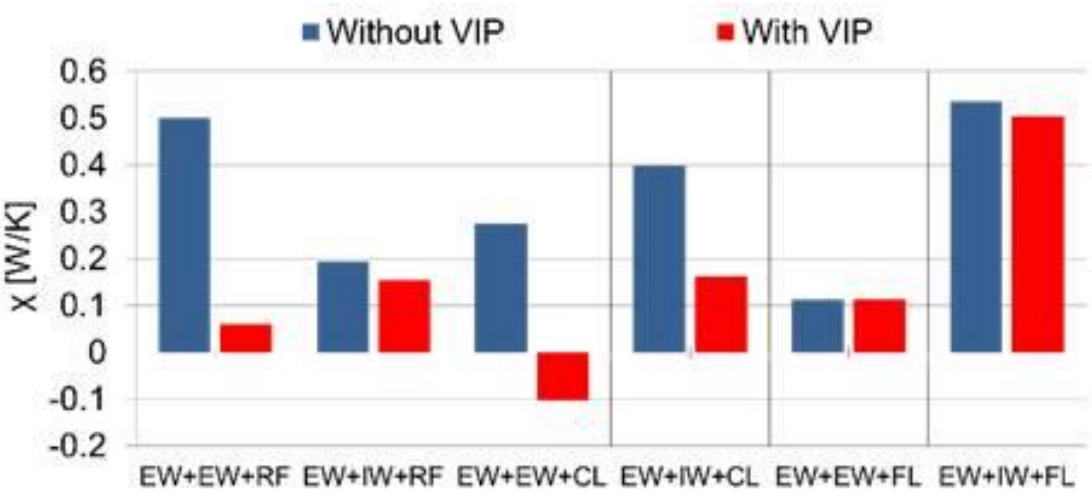
- VIP layer
  - Reduces the impact of the 2D junctions
  - Linear Thermal Transmittance: **12% to 92% reduction** (depending on the type of intersection)
- Most important thermal bridges
  - Junctions that include the floor, the roof and the internal wall
  - Needs design modifications to reduce



The linear thermal transmittance of all 2D junctions. (a) Junctions where all elements include VIPs and (b) junctions where only one of the elements include VIPs

3D Junctions

- VIP layer
  - Improves the thermal performance of the 3D thermal bridges
  - Up to **138% reduction** of the point thermal transmittance

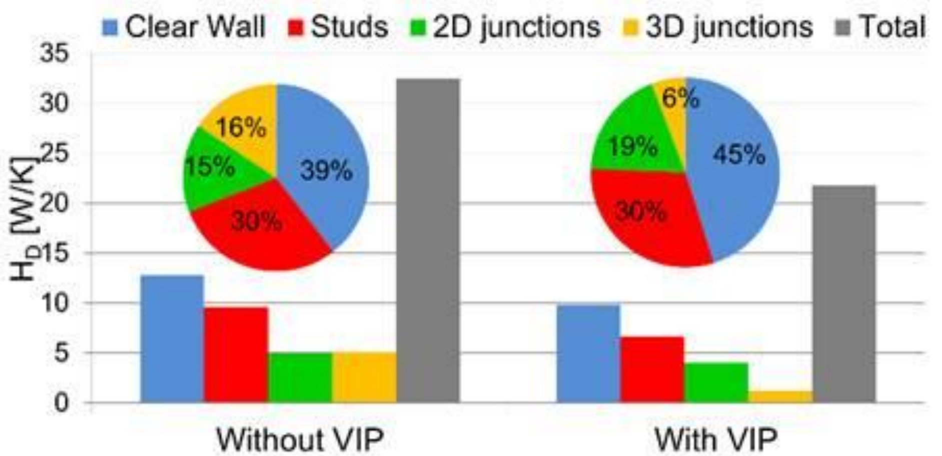


Impact of VIP on the point thermal transmittance of all 3D junctions

National Technical University of Athens

Overall thermal performance

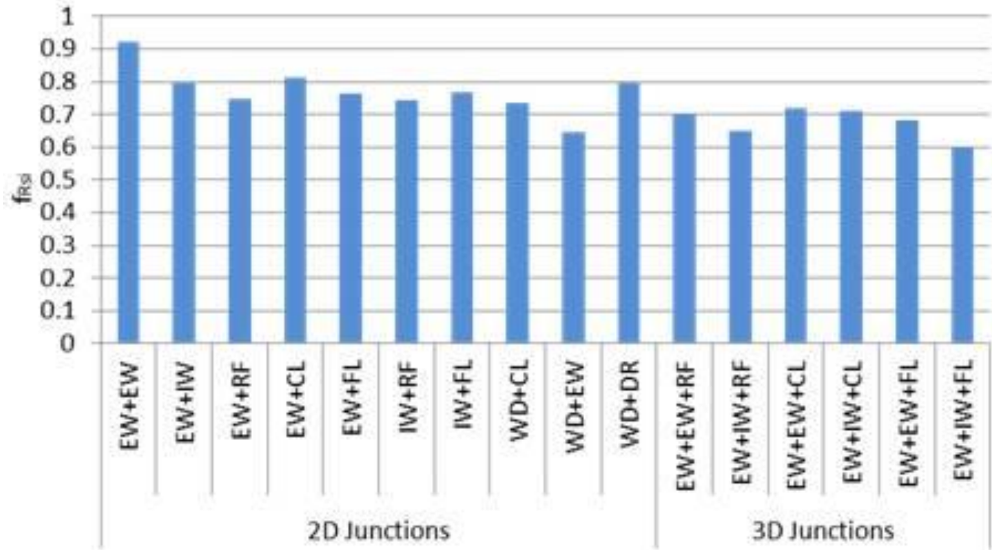
- VIP layer → Total thermal transmittance, H_D: **~33% reduction**
- Metal studs: ~30% contribution to the overall thermal transmittance
- Impact of 2D and 3D junctions
  - *Without VIP*: 31%
  - *With VIP*: 25%



Impact of thermal bridges on the overall thermal transmittance at the two cases

Hygro-thermal analysis

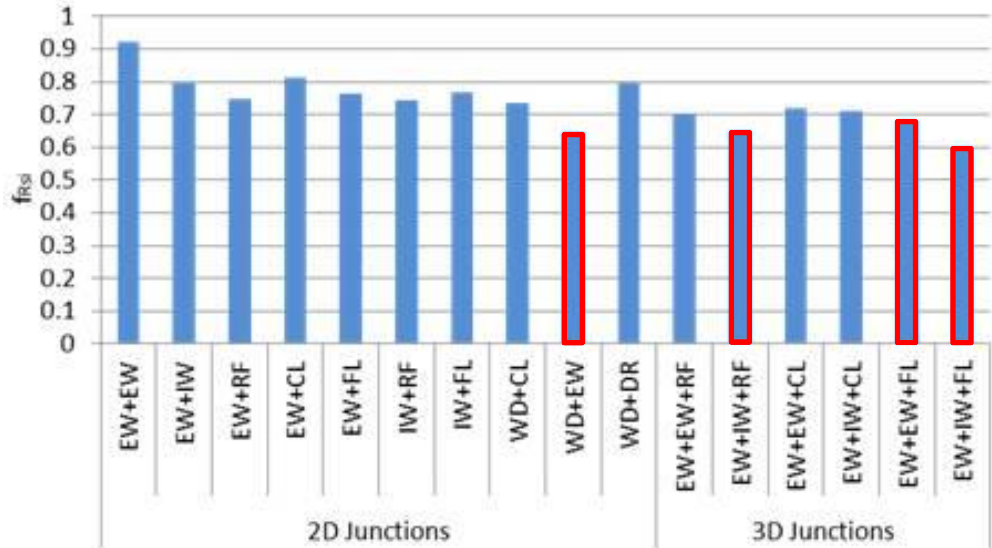
- Middle part of building elements
  - Mold growth is not expected (f_{Rsi}>0.7)
  - VIP layer increases temperature factor by 14%
- Case with VIP layer
  - **2D junctions**
    - No condensation risk
    - Condensation risk: intersection between the window frame and the external wall
  - **3D junctions**
    - mold growth is possible
    - Lowest factor: intersection between external wall – internal wall – floor



Temperature factor of non repeating thermal bridges configurations at the case with VIP

Hygro-thermal analysis

- Middle part of building elements
  - Mold growth is not expected (f_{Rsi}>0.7)
  - VIP layer increases temperature factor by 14%
- Case with VIP layer
  - **2D junctions**
    - No condensation risk
    - Condensation risk: intersection between the window frame and the external wall
  - **3D junctions**
    - mold growth is possible
    - Lowest factor: intersection between external wall – internal wall – floor



Temperature factor of non repeating thermal bridges configurations at the case with VIP

- Introduction
- Description of the Building
- Methodology
- Results & Discussion
- Conclusions & Outlook

- Summary of work
  - Metal framed lightweight drywall building envelope
  - Impact of thermal bridges on the overall thermal transmittance
  - Installation of additional VIP layer on the inner side of the external wall
  - Thermal bridges analysis
    - Repeating: metal studs of the center part of walls
    - Non-repeating: 2D & 3D junctions

- Conclusions
  - Overall contribution of the thermal bridges on the thermal transmittance: 55%-61%
  - Contribution of:
    - Metal frame of the building, ~30% (highest)
    - 2D junctions, ~15%-19%
    - 3D junctions, ~6%-16% (should be taken into account and not be neglected)
  - Additional VIP layer
    - Reduction of the overall thermal transmittance, ~33%
    - Reduction of the impact of the non-repeating thermal bridges, ~6%
    - Reduction of linear and point thermal transmittances up to 130%

National Technical University of Athens

QUESTIONS

Thank you for your attention

SHARE YOUR THOUGHTS

Acknowledgements

The authors acknowledge the financial support of the European Commission in the frame of the FP7-2013-NMP-ENV-EeB project ‘ELISSA’ (www.elissaproject.eu)