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BIM-based building physics modelling of ventilated façade systems



The structure of this presentation

- Introduction, importance of the topic
- Research questions
- Methodology
 - Simplified method
 - BIM to BPM workflow summary
 - Numerical model
- Result assessment
- Conclusion

Introduction, importance

- **Reduction of the energy consumption** in the construction industry with all means necessary
- Ventilated facades are a common system to **improve the thermal envelope's performance** of a building
- Calculating the thermal transmittance of such structures is not straightforward, due to **thermal bridging**
- Source of additional losses: changes in geometry and inhomogeneities



Aim of this research

- To explore, whether the simplified, everyday-used methods are “close enough” to determine the total thermal transmittance of ventilated facade systems
- What is the difference between the results of a full numerical simulation and the simplified method?
- Demonstrate a use case for detailed BIM models for building physics modelling by isolating the effects of particular subsystems

$$\Delta U_{TB,simp} = U_{w,corr} * (1 + \chi) - U_{w,corr}$$

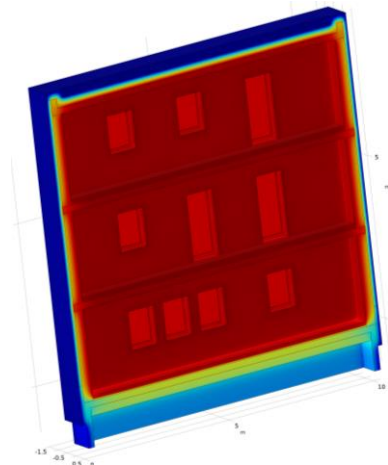
$$\Delta U_{f,simp} = \alpha * \frac{n_{db} * A_f * \lambda_f}{d_0} * \left(\frac{R_1}{R_{th}}\right)^2$$

$$\Delta U_{b,simp} = n_{fixed} * \chi_{fixed} + n_{sliding} * \chi_{sliding}$$

$$U_{w,tot,simp} = (U_w + \Delta U_{TB,simp} + \Delta U_{f,simp} + \Delta U_{b,simp})$$

“simplified” method

VS.



numerical model
(4 cases, 3 assessment methods)



Simplified method - thermal bridging (ΔU_{TB})

- The geometry data is taken from the BIM model for the calculations.
- The correction term for thermal bridges are obtained based on the Hungarian regulation (7/2006 gov. decree)
 - The simplified method for considering thermal bridges is to **evaluate the length of thermal bridges** (adjoining building elements with the wall)
 - The total length is 98.65 m in the modelled building, which divided by the internal surface area of the wall gives 1.41 m/m² specific quantity
 - **30% increase is necessary due to thermal bridges (χ)**

$$\Delta U_{TB,simp} = U_{w,corr} * (1 + \chi) - U_{w,corr}$$



Simplified method - brackets ($\Delta U_{b,simp}$) and dowels ($\Delta U_{f,simp}$)

- The correction term $\Delta U_{f,simp}$ regarding of the dowels **can be calculated using ISO 6946**

$$\Delta U_{f,simp} = \alpha * \frac{n_{db} * A_f * \lambda_f}{d_0} * \left(\frac{R_1}{R_{th}} \right)^2$$

- For obtaining correction terms of the brackets, **we used the Hilti thermal bridge catalogue**, from which we included both fixed ($\chi_{fixed} = 0,0534 \text{ W/K}$) and sliding ($\chi_{sliding} = 0,0336 \text{ W/K}$) brackets fixed on masonry (quantities for n_{fixed} and $n_{sliding}$ are obtained from the Archicad model)

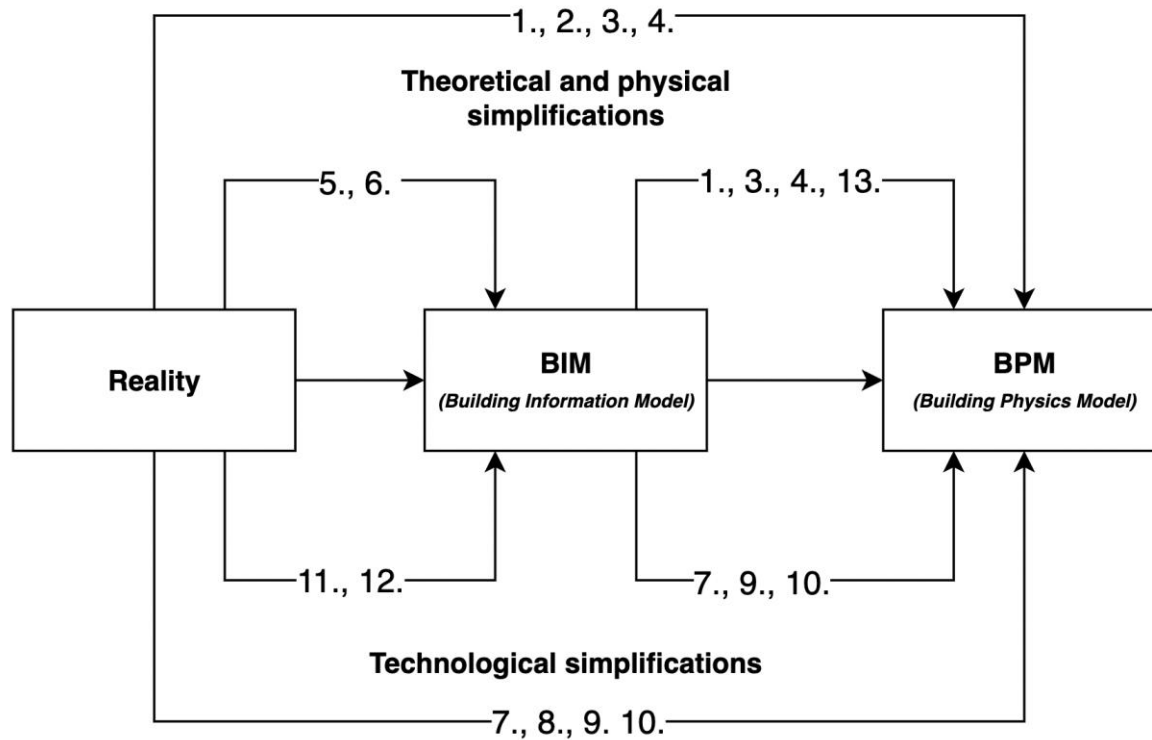
$$\Delta U_{b,simp} = n_{fixed} * \chi_{fixed} + n_{sliding} * \chi_{sliding}$$

- Therefore, **the calculation of the façade's total thermal transmittance** using simplified methods is the following:

$$U_{w,tot,simp} = U_w + \Delta U_{TB,simp} + \Delta U_{f,simp} + \Delta U_{b,simp}$$



Modelling reality, simplifications - the BIM to BPM workflow



1. Adequacy of space boundaries
2. Validity of boundary conditions
3. Computational simplifications
4. Use of standards and its simplifications
5. Geometric simplifications
6. Perfectly executed structures
7. FEA compatible model assumed to be airtight
8. Steady-state physics
9. Only heat conduction occurs
10. Planar internal surfaces used for U-value calculation
11. Materials modelled using simple geometry and equivalent thermal conductivity
12. Construction inaccuracies are neglected
13. Neglecting facade cladding and air movement in the ventilated gap

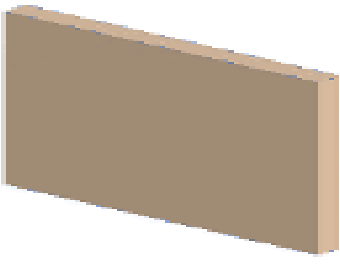


Current openBIM to BPM workflow

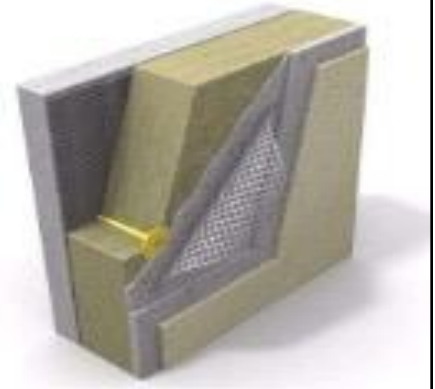
Step	Software	Description
1.	Archicad 25	Modelling geometry
2.		Metadata
3a.		Creating IFC translator
3b.		Exporting IFC
4.	GeometryGym (plugin, Rhinoceros)	Importing IFC
5.	Rhino 7	Checking model, cleaning model
6.	Rhino 7	Exporting STEP file
7.	COMSOL Multiphysics 5.6	Importing STEP file
8.		Organising geometry
9.		Creating domains
10.		Meshing
11.		Creating materials, assigning building physics properties, boundary conditions
12.		Simulation
13.		Exporting results
14.	COMSOL (simpler queries); Excel, Matlab, Mathematica, Anaconda, Grasshopper, stb. (complex queries)	Evaluation
15.		



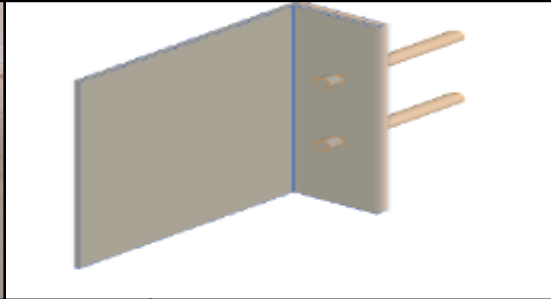
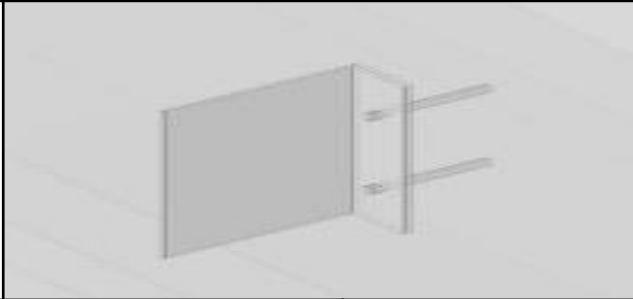
Modelled elements and their respective Level of Detail

	reality		BIM model (Archicad)		BPM model (Comsol)	
thermal break						
	<i>LOG</i>	<i>LOI</i>	<i>LOG</i>	<i>LOI</i>	<i>LOG</i>	<i>LOI</i>
	infinite	infinite	350	manufacturer, product, density, thermal cond., spec. heat	350	thermal cond.
ceramic block			homogeneous layer		homogeneous layer	
	<i>LOG</i>	<i>LOI</i>	<i>LOG</i>	<i>LOI</i>	<i>LOG</i>	<i>LOI</i>
	infinite	infinite	350	manufacturer, product, density, thermal cond., spec. heat	350	thermal cond.

Modelled elements and their respective Level of Detail

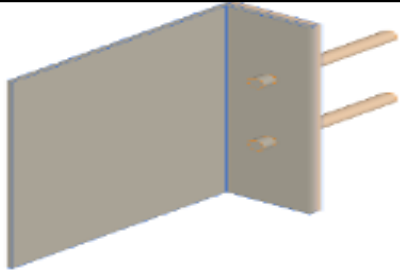
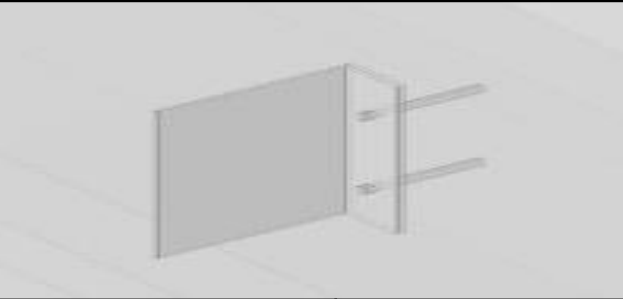
	reality		BIM model (Archicad)		BPM model (Comsol)	
thermal insulation			homogeneous layer		homogeneous layer	
	<i>LOG</i>	<i>LOI</i>	<i>LOG</i>	<i>LOI</i>	<i>LOG</i>	<i>LOI</i>
	infinite	infinite	350	manufacturer, product, density, thermal cond., spec. heat	350	thermal cond.
dowel						
	<i>LOG</i>	<i>LOI</i>	<i>LOG</i>	<i>LOI</i>	<i>LOG</i>	<i>LOI</i>
	infinite	infinite	350	manufacturer, product, density, thermal cond., spec. heat	350	thermal cond.

Modelled elements and their respective Level of Detail

	reality		BIM model (Archicad)		BPM model (Comsol)	
bracket						
	LOG	LOI	LOG	LOI	LOG	LOI
	infinite	infinite	350	manufacturer, product, density, thermal cond., spec. heat	350	thermal cond.
bracket fix						
	LOG	LOI	LOG	LOI	LOG	LOI
	infinite	infinite	350	manufacturer, product, density, thermal cond., spec. heat	350	thermal cond.

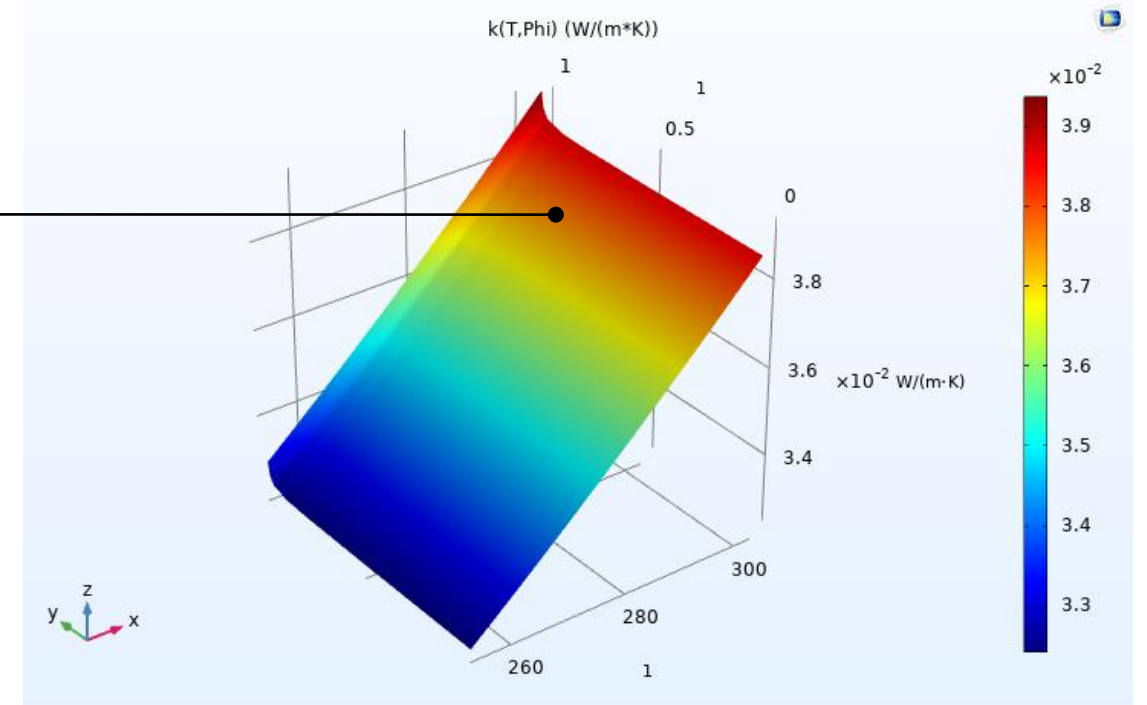
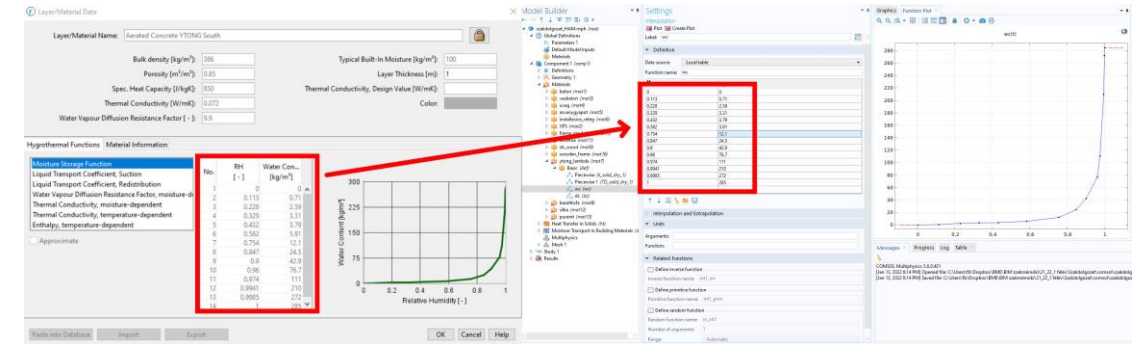
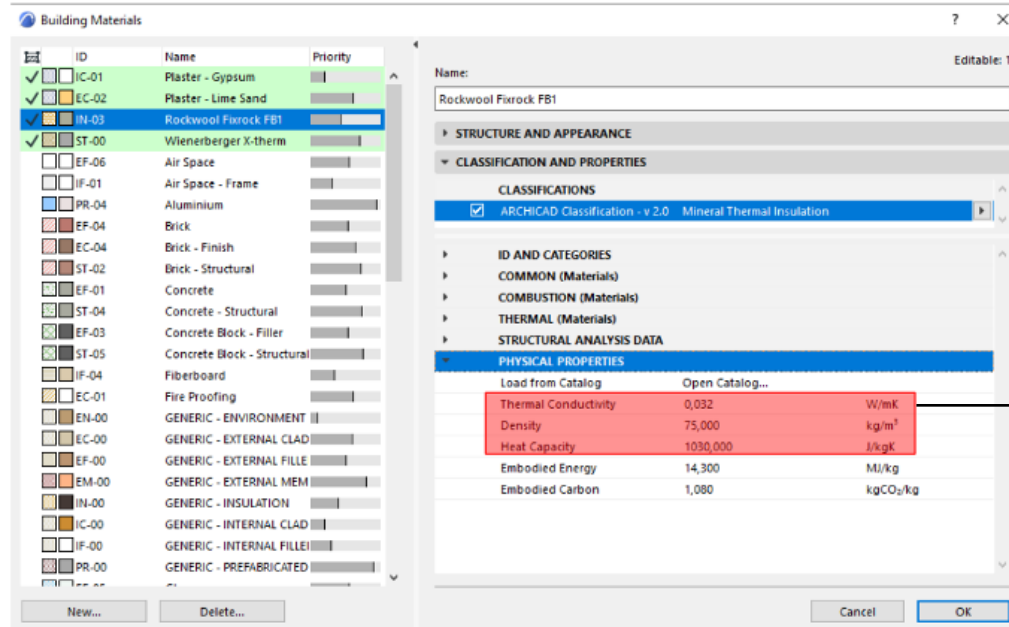


Modelled elements and their respective Level of Detail

	reality		BIM model (Archicad)		BPM model (Comsol)	
bracket						
	LOG	LOI	LOG	LOI	LOG	LOI
	infinite	infinite	350	manufacturer, product, density, thermal cond. , spec. heat	350	thermal cond.
bracket fix						
	LOG	LOI	LOG	LOI	LOG	LOI
	infinite	infinite	350	manufacturer, product, density, thermal cond., spec. heat	350	thermal cond.



The data granularity problem



Example for the necessary data granularity (**dependance of thermal conductivity on temperature and rel. humidity**). Mapping the WUFI “moisture storage function” to COMSOL’s “water content”.

Differentiation base of “cases” - isolating subsystem effects

Dowel



used for

fixing the thermal insulation to the wall construction

how many?

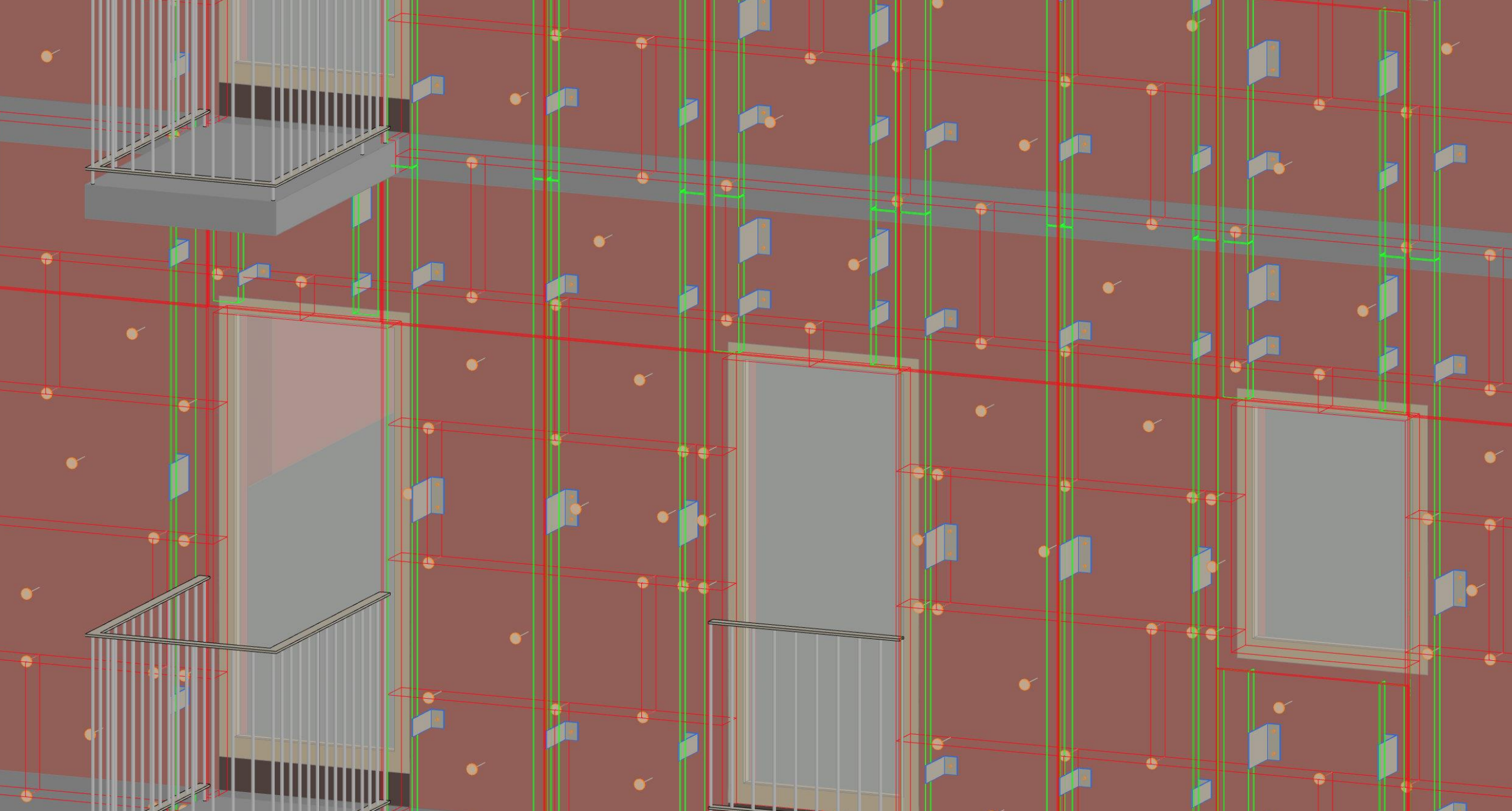
444 pieces

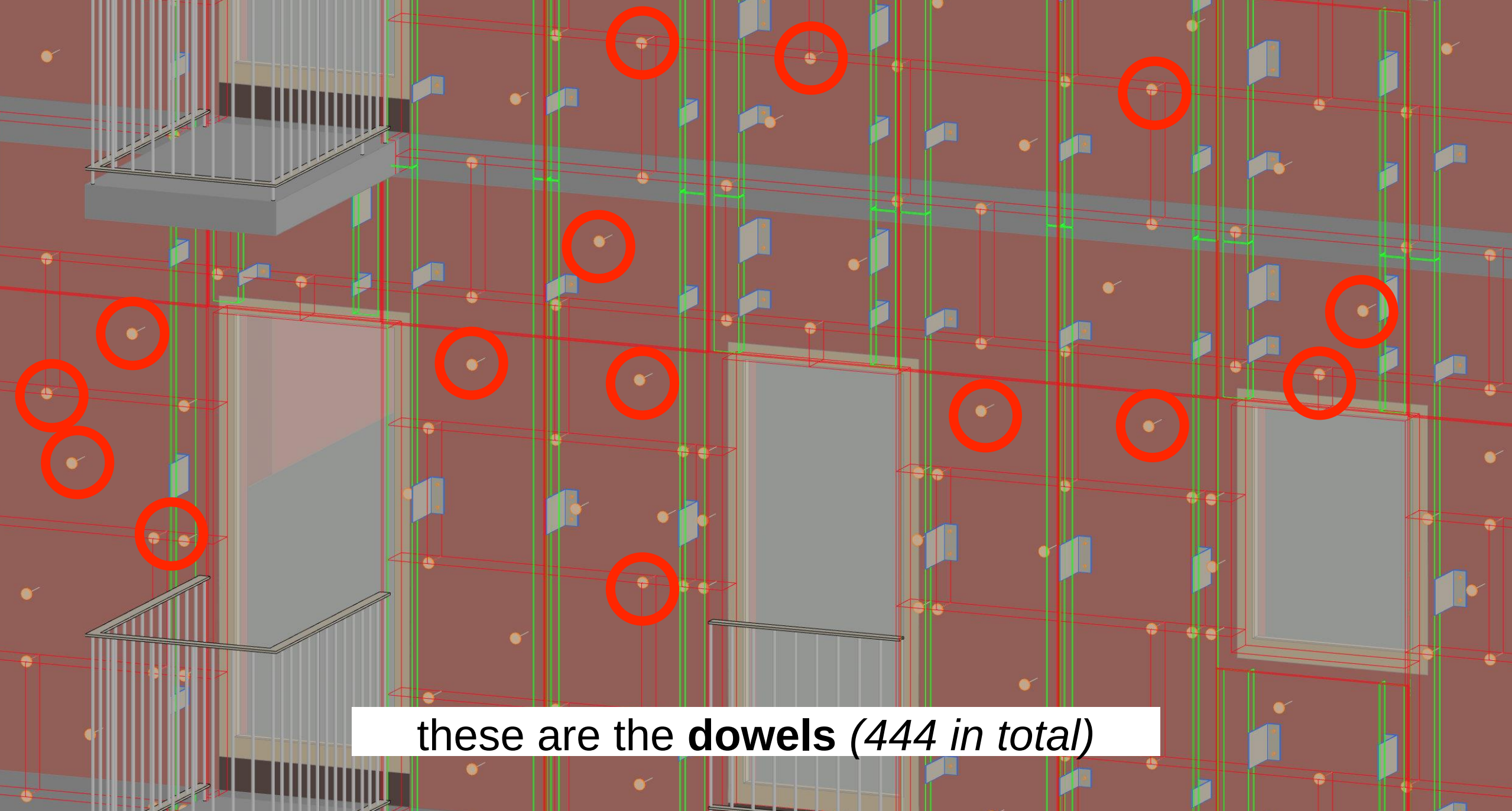
Bracket



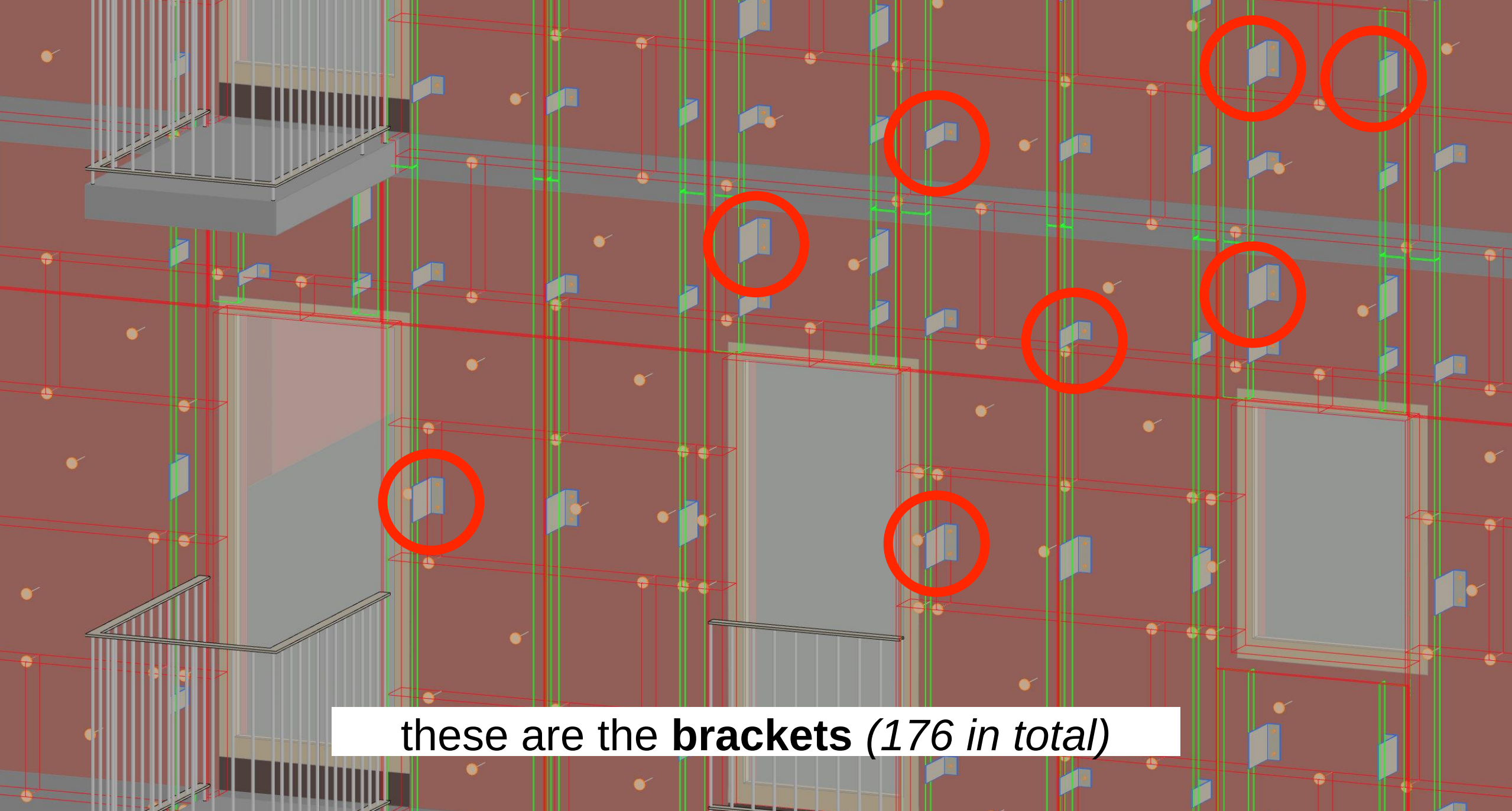
fixing the facade system to the load-bearing construction (bracket+anchors+thermal break)

69 fixed + 107 movable





these are the **dowels** (*444 in total*)



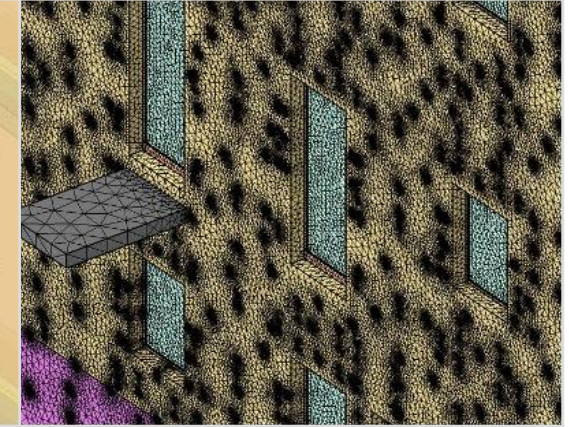
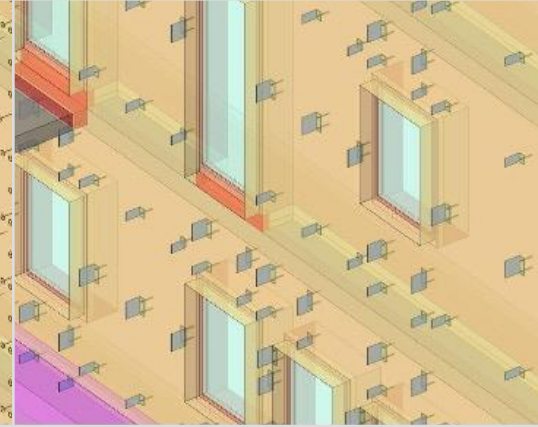
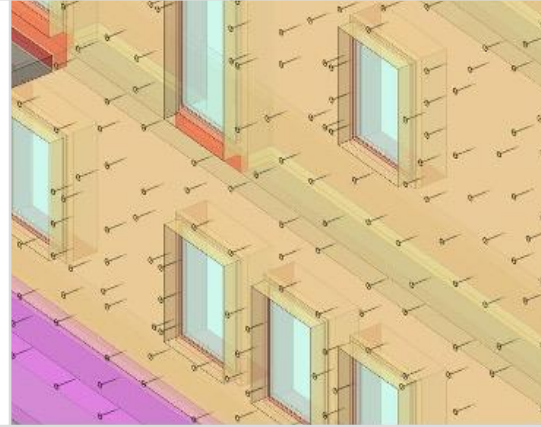
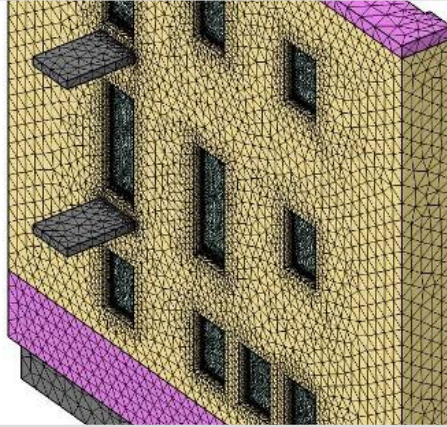
these are the **brackets** (*176 in total*)

Baseline Case 01

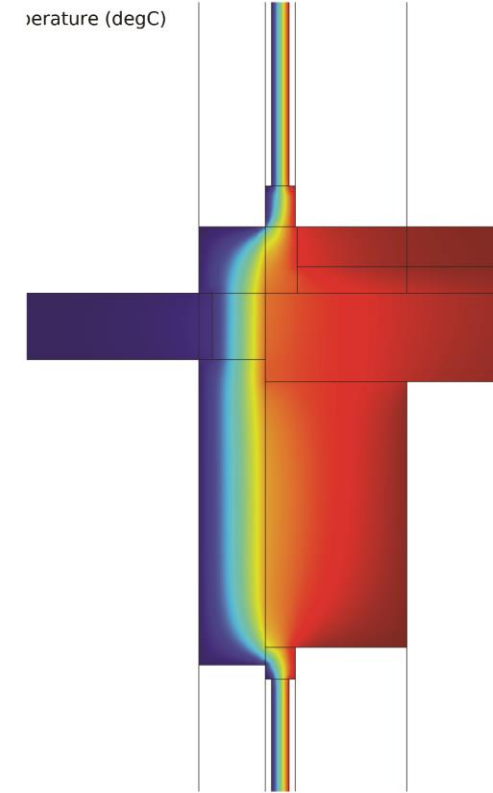
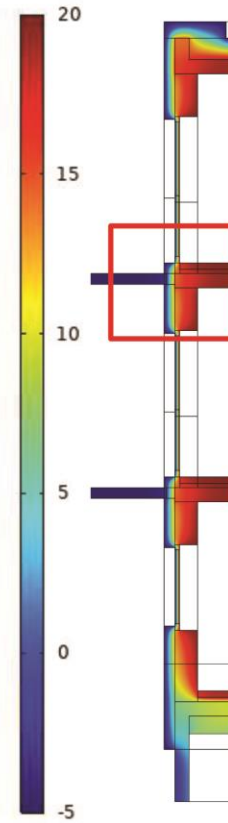
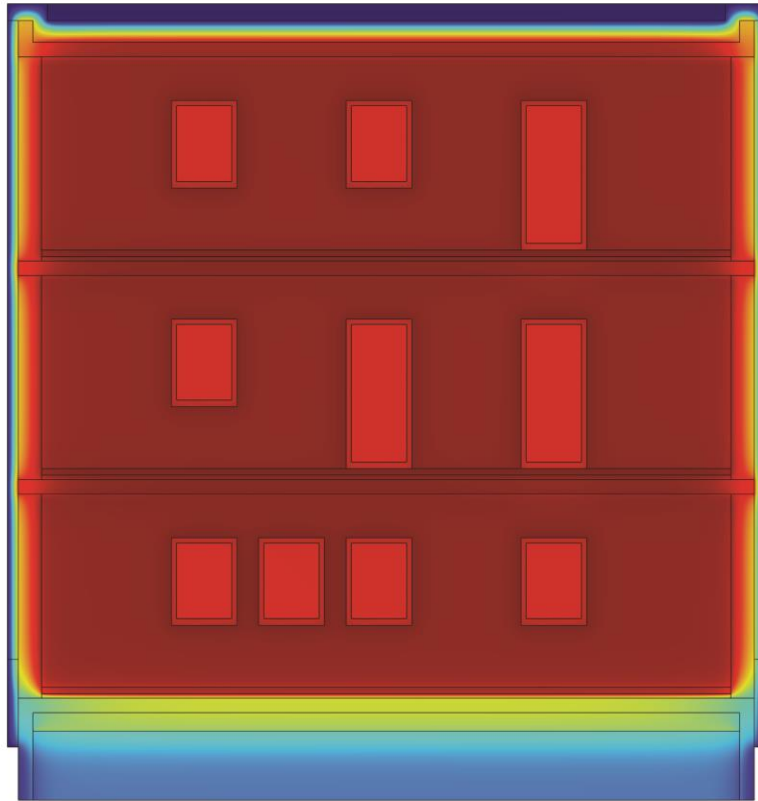
Dowels-only Case 02

Brackets-only Case 03

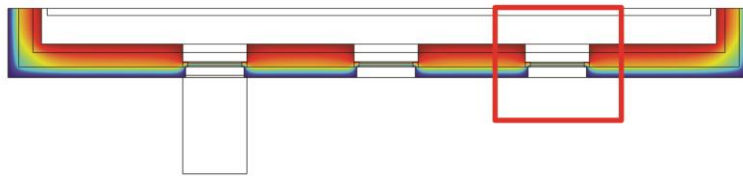
FULL model Case 04



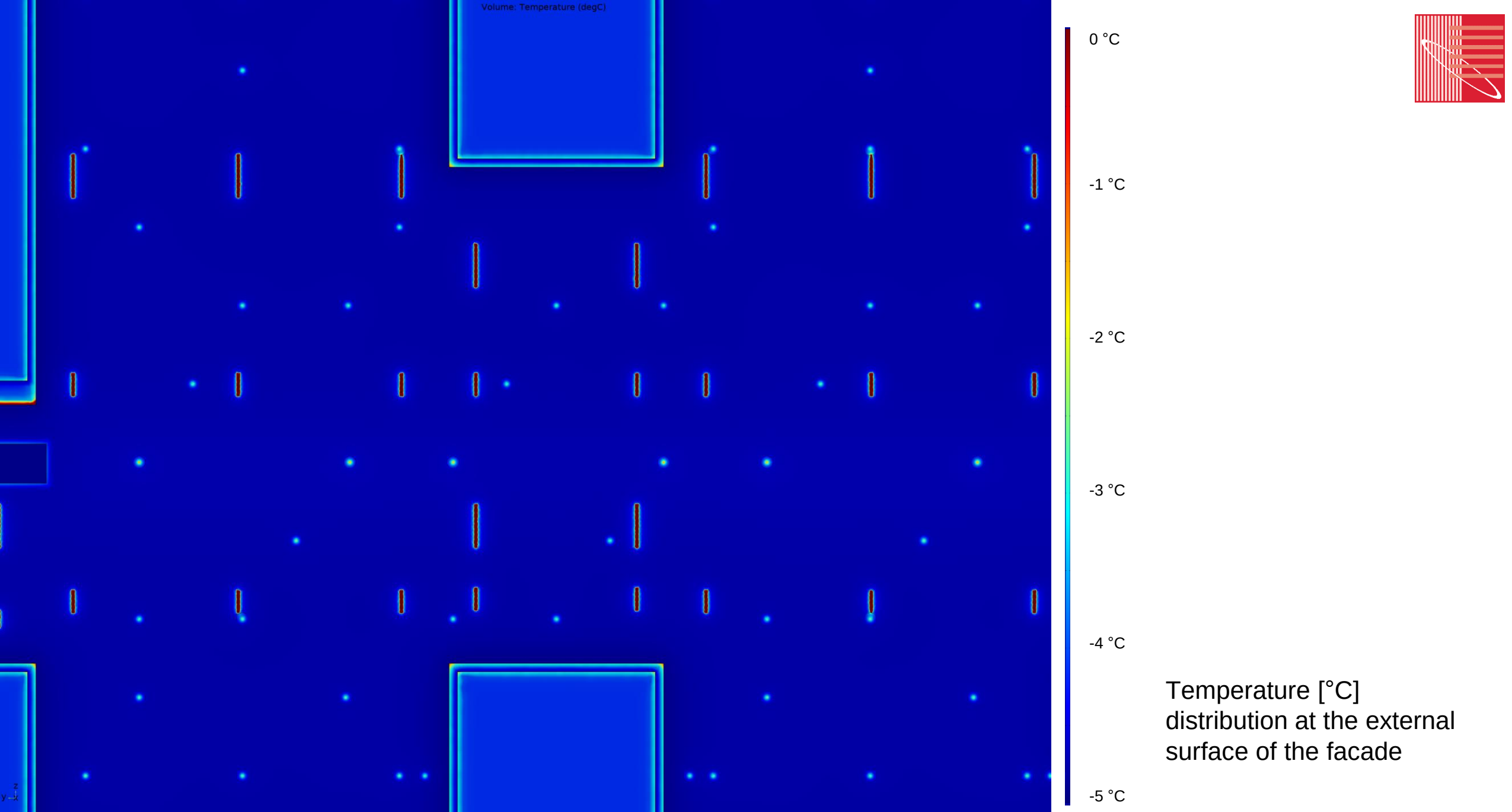
base geometry	✓	✓	✓	✓
dowels	✗	✓	✗	✓
brackets	✗	✗	✓	✓
use case	isolate the effects of geometrical thermal bridging (adjoining edges, inhomogenities)	isolate the effects of the thermal insulation fixes (point-like effects)	isolate the effects of the load-bearing structure of the facade system	calculate the total thermal transmittance based on the numerical model
correction factor calc,	$\Delta U_{TB,sim} = (Q_1 - A_r U_r - A_b U_b - A_w U_w - A_{wd} U_{wd}) / A_w$	$\Delta U_{f,sim} = (Q_2 - Q_1) / (A \cdot \Delta T)$	$\Delta U_{b,sim} = (Q_3 - Q_1) / (A \cdot \Delta T)$	$\Delta U_{fs,sim} = (Q_4 - Q_1) / (A \cdot \Delta T)$

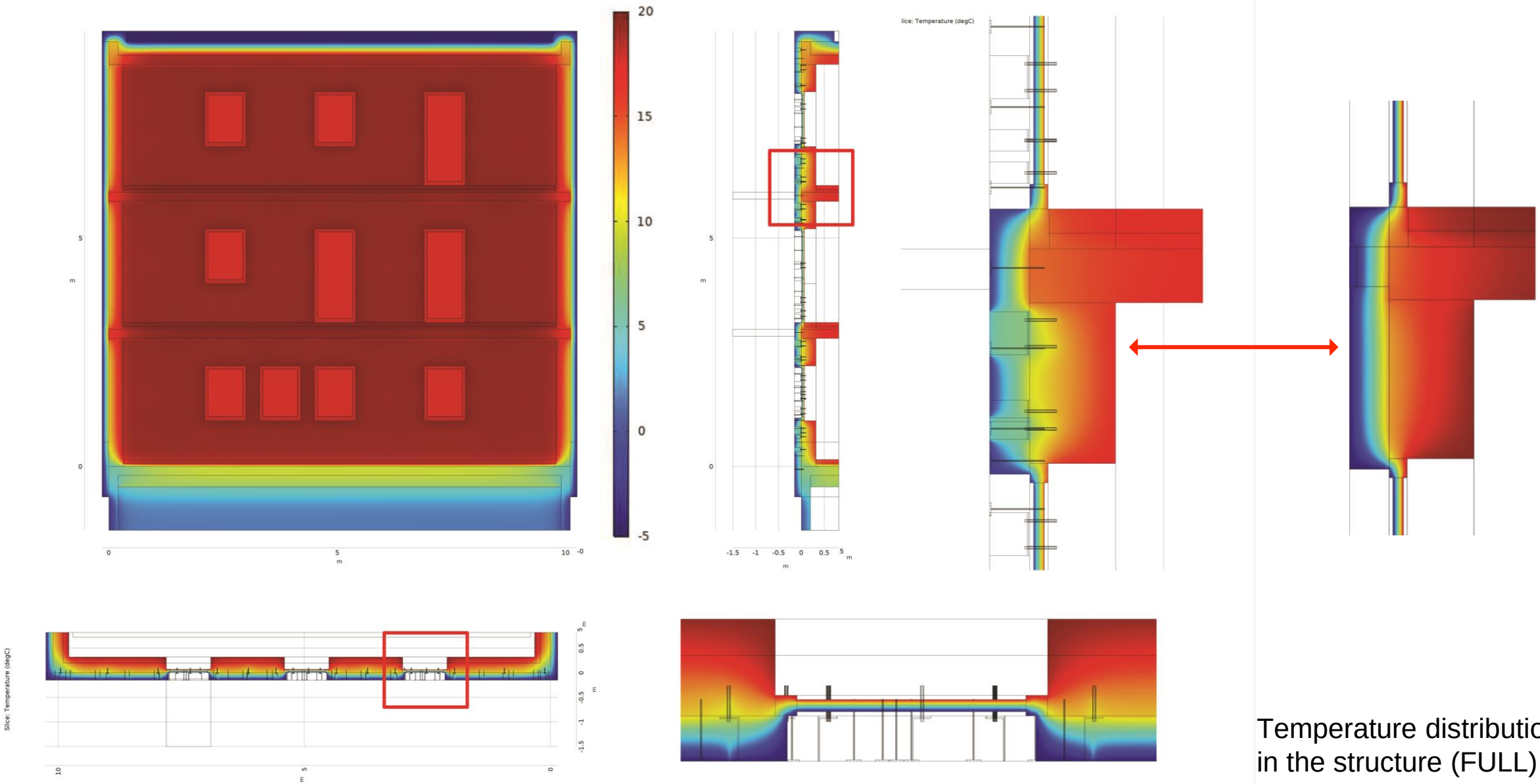


Slice: Temperature (degC)

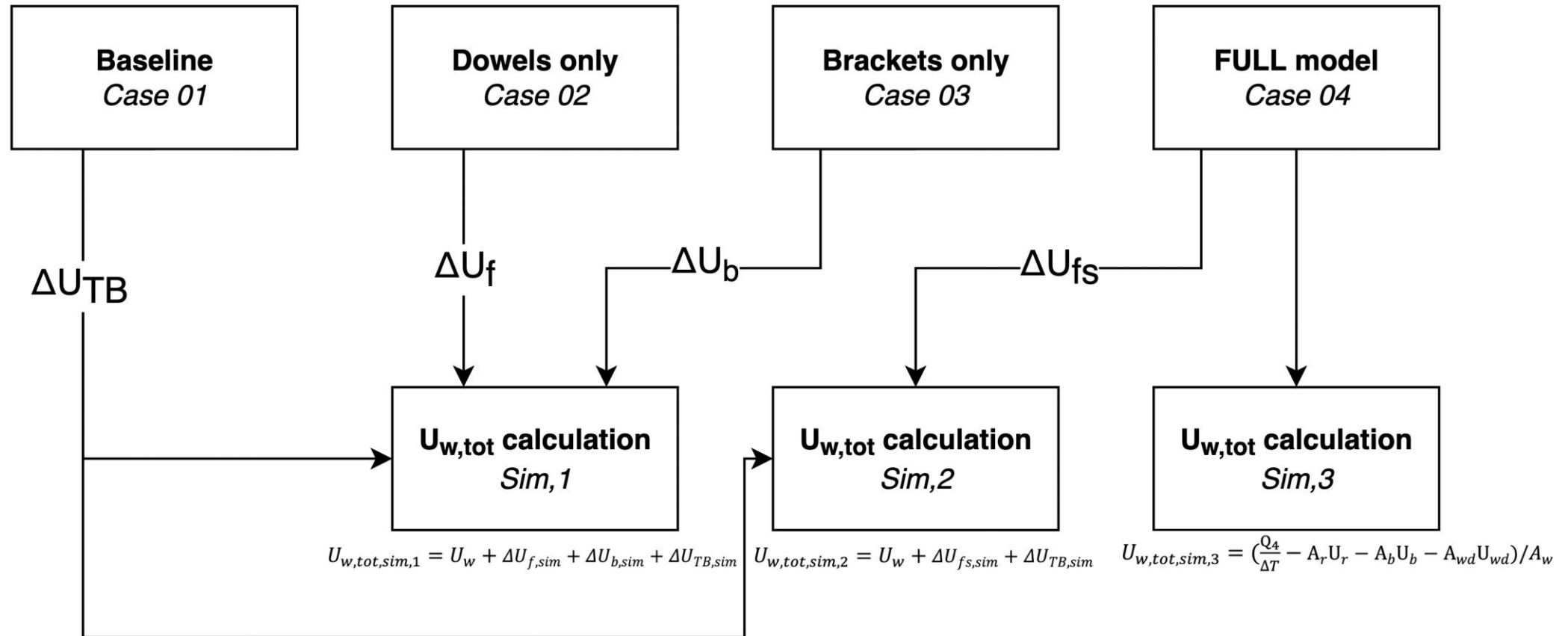


Temperature distribution,
in the structure (BASE)





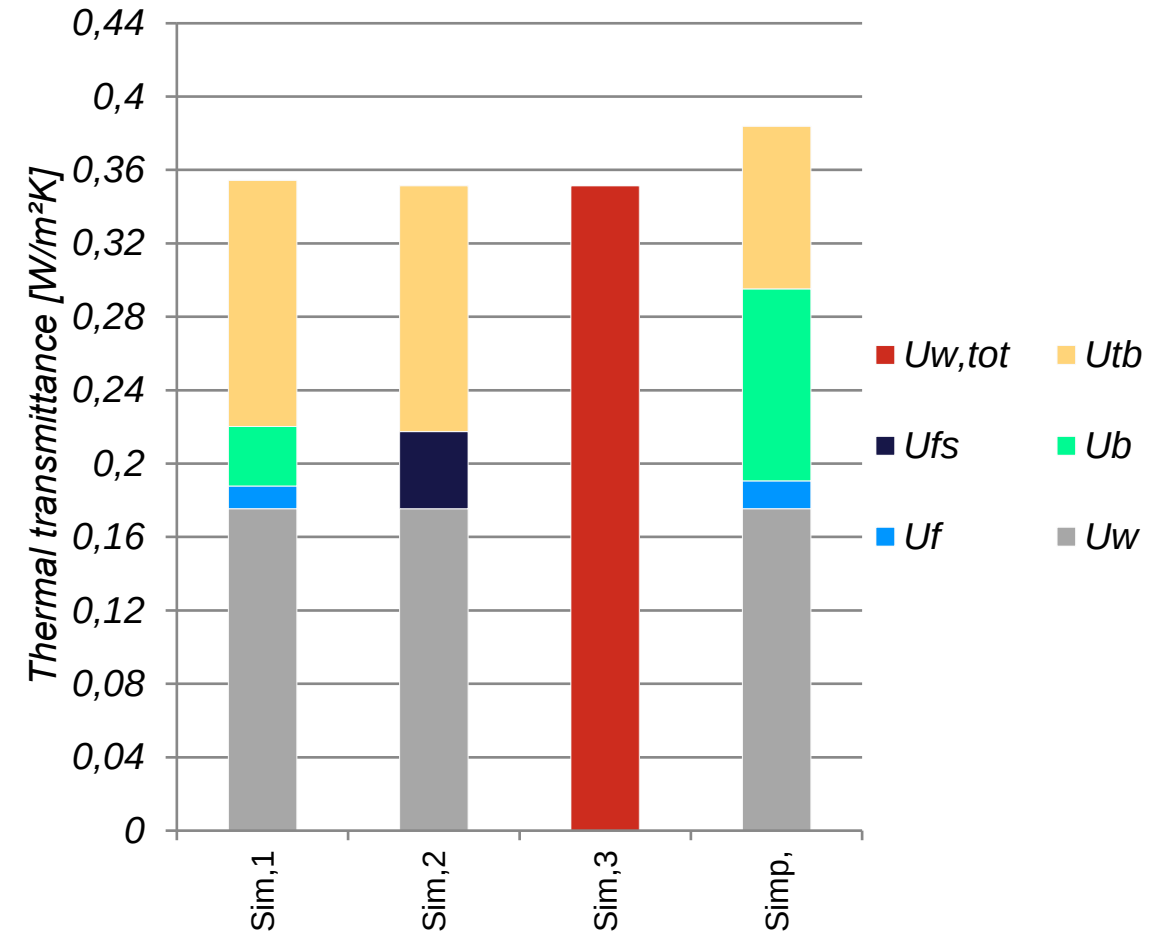
Correction factor assignment





Result assessment

Refer to Eq, (8-10,) in the paper	Simulated results			Simplified calculation (W/m ² K)	Diff. (simp. vs. num. model)
	Sim,1 (W/m ² K)	Sim,2 (W/m ² K)	Sim,3 (W/m ² K)		
U _w	0,1754	0,1754	-	0,1754	
ΔU _f	0,0124	-	-	0,0151	21,77%
ΔU _b	0,0325	-	-	0,1047	222,15%
ΔU _{fs}	-	0,0420	-	-	n.d.
ΔU _{w,corr}	0,2203	0,2174	-	0,2952	-34,89%
ΔU _{TB}	0,134	0,134	-	0,0886	-33,88%
U_{w,tot}	0,3543	0,3514	0,3514	0,3838	
Diff.	-8,33%	-9,22%	-9,22%	Base	





Result assessment - difference in correction factors

Refer to Eq, (8-10,) in the paper	Simulated results			Simplified calculation (W/m²K)
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ΔU_{TB}	0,134	0,134	-	0,0886
$U_{w,tot}$	0,3543	0,3514	0,3514	0,3838

Diff. -8,33% -9,22% -9,22% Base

Diff.
(simp. vs.
num. model)

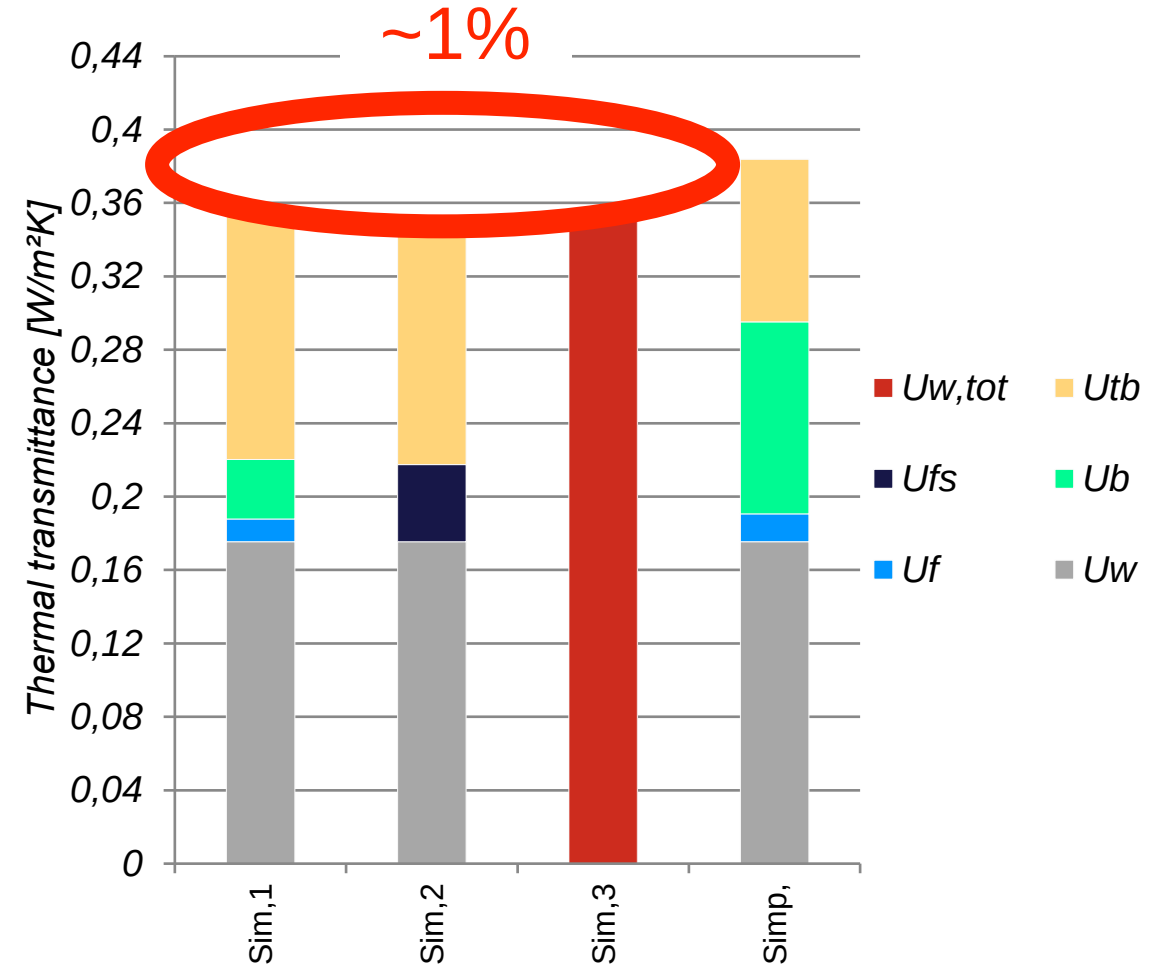
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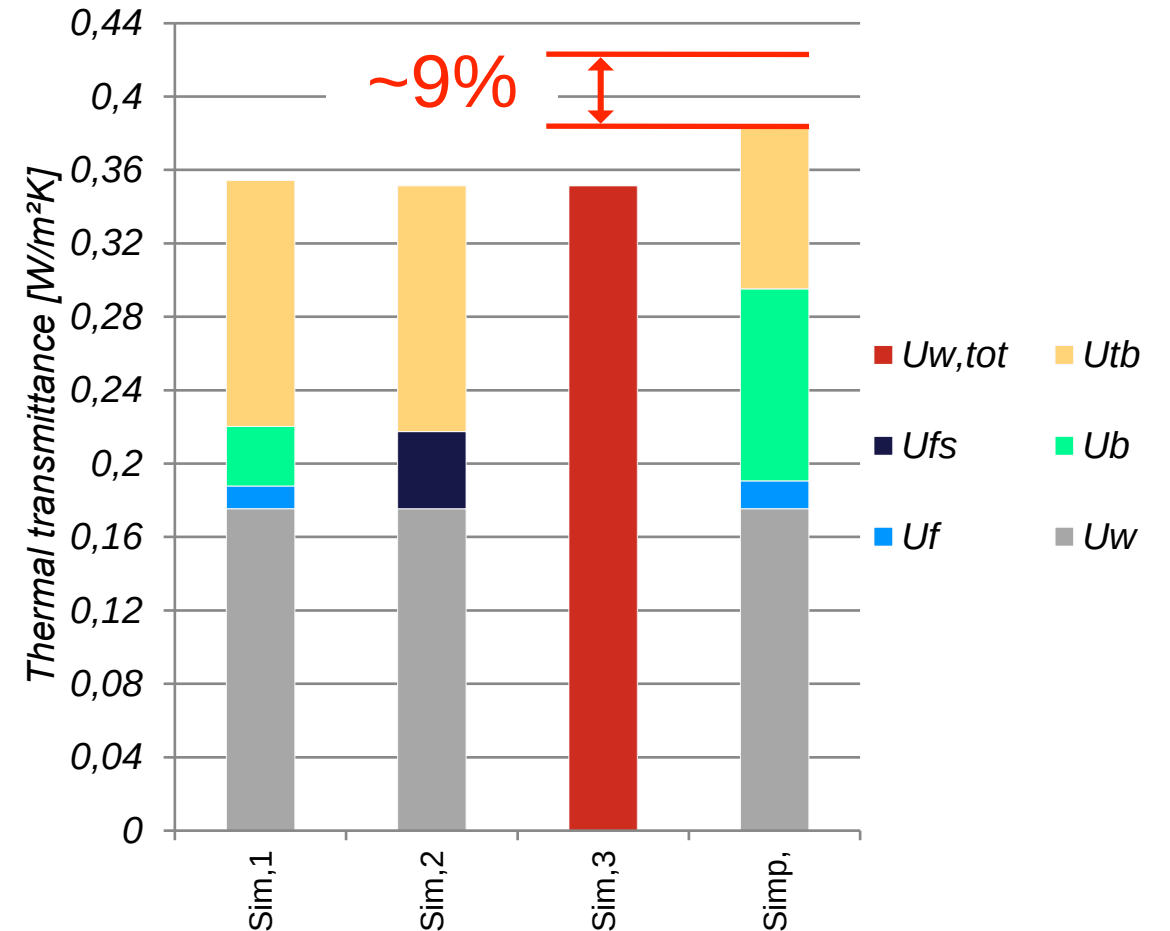
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222,15%

n.d.

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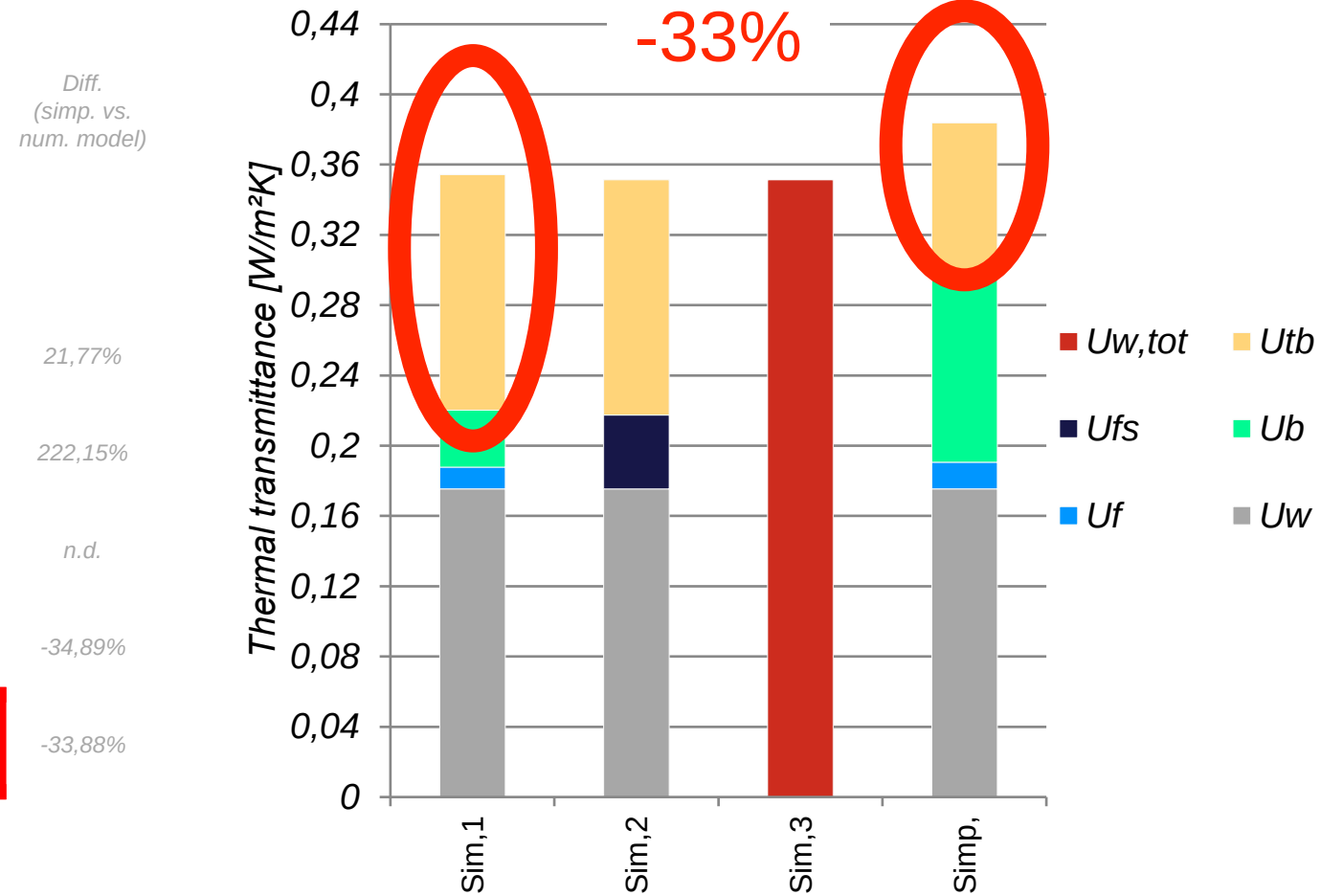
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Result assessment - difference in correction factors

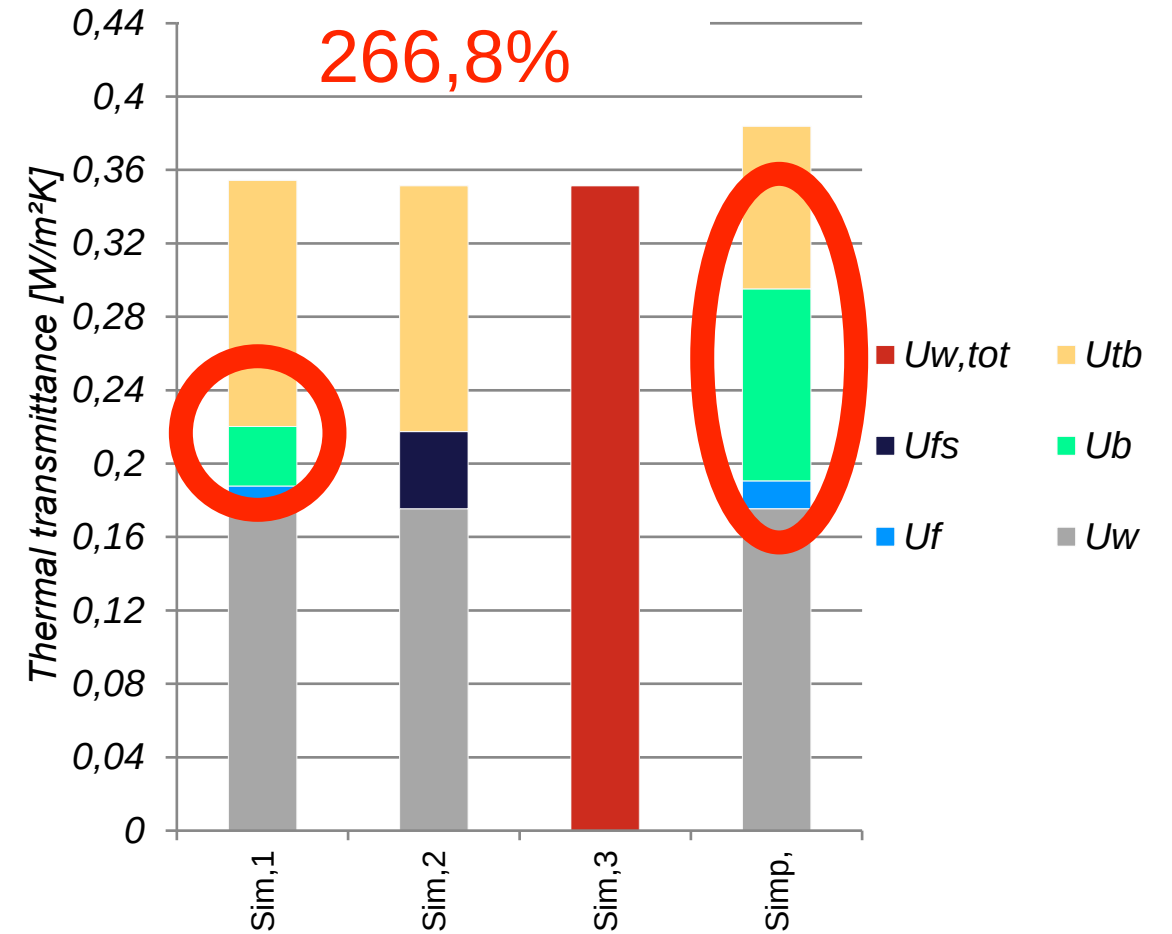
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Conclusions

- In this paper, we presented the BIM-based building physics modelling of a ventilated façade system.
- The results showed that numerical modelling gave lower corrected wall thermal transmittance as well as total thermal transmittance than simplified results, meaning, that the simplified method overall means design safety.
- However, **the effect of the brackets was significantly higher**, while **the effect of linear thermal bridges was significantly lower**, if we compared the numerical modelling results to simplified methods.
- The demonstrated BIM-based numerical thermal performance simulation workflow provides essential and gap-filling information for practical, BIM-based facade design and BIM-based building physics modelling



Thank you for your attention!

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