
TU Delft

A Framework for the On-the-fly Energy Calculation of BIM Models

Mengying Su / 25 January 2023

TU Delft

Thesis Committee

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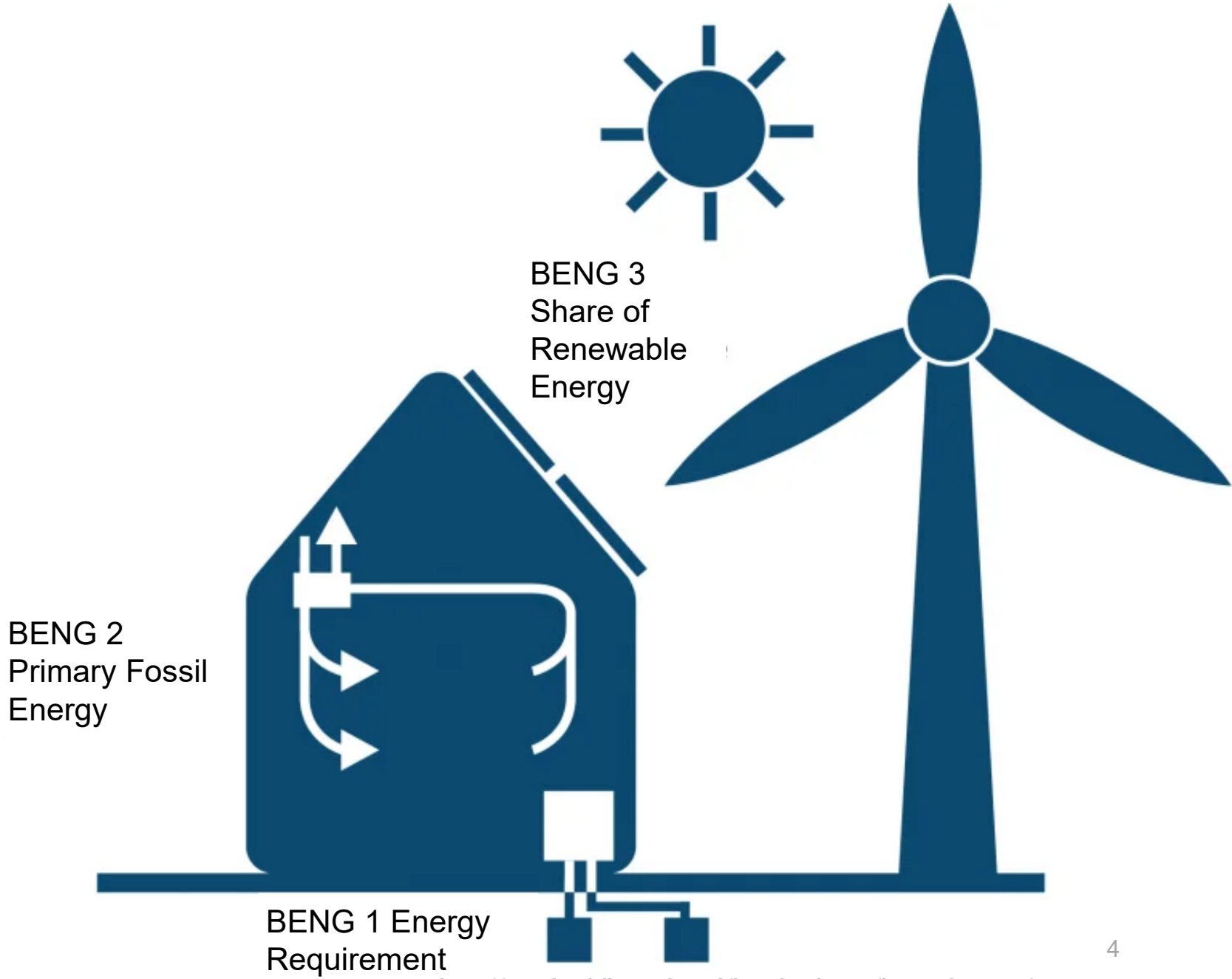
Context

NZEB / BENG

NTA 8800



https://www.handelbouwadvies.nl/beng-berekening/beng-indicatoren/

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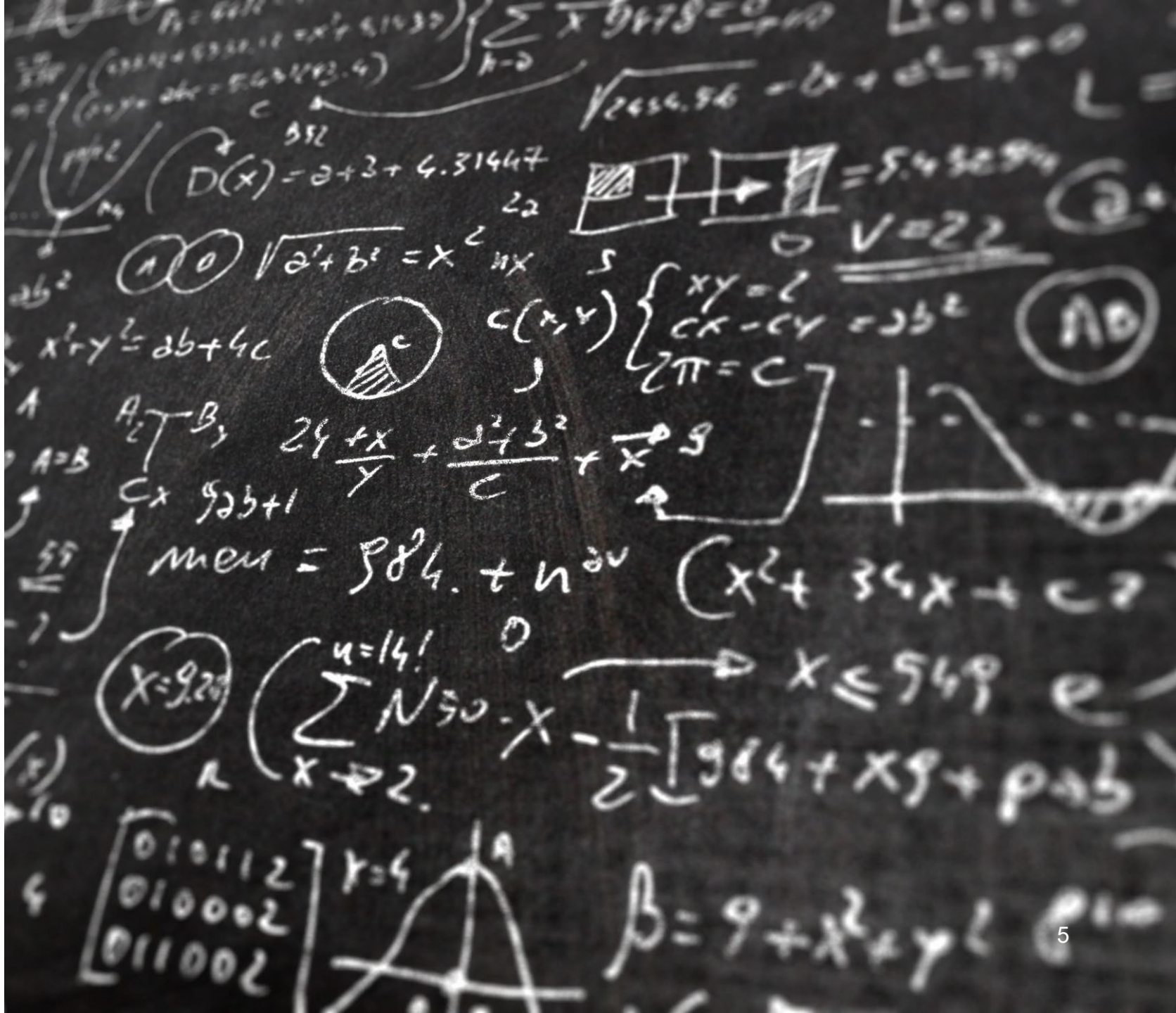

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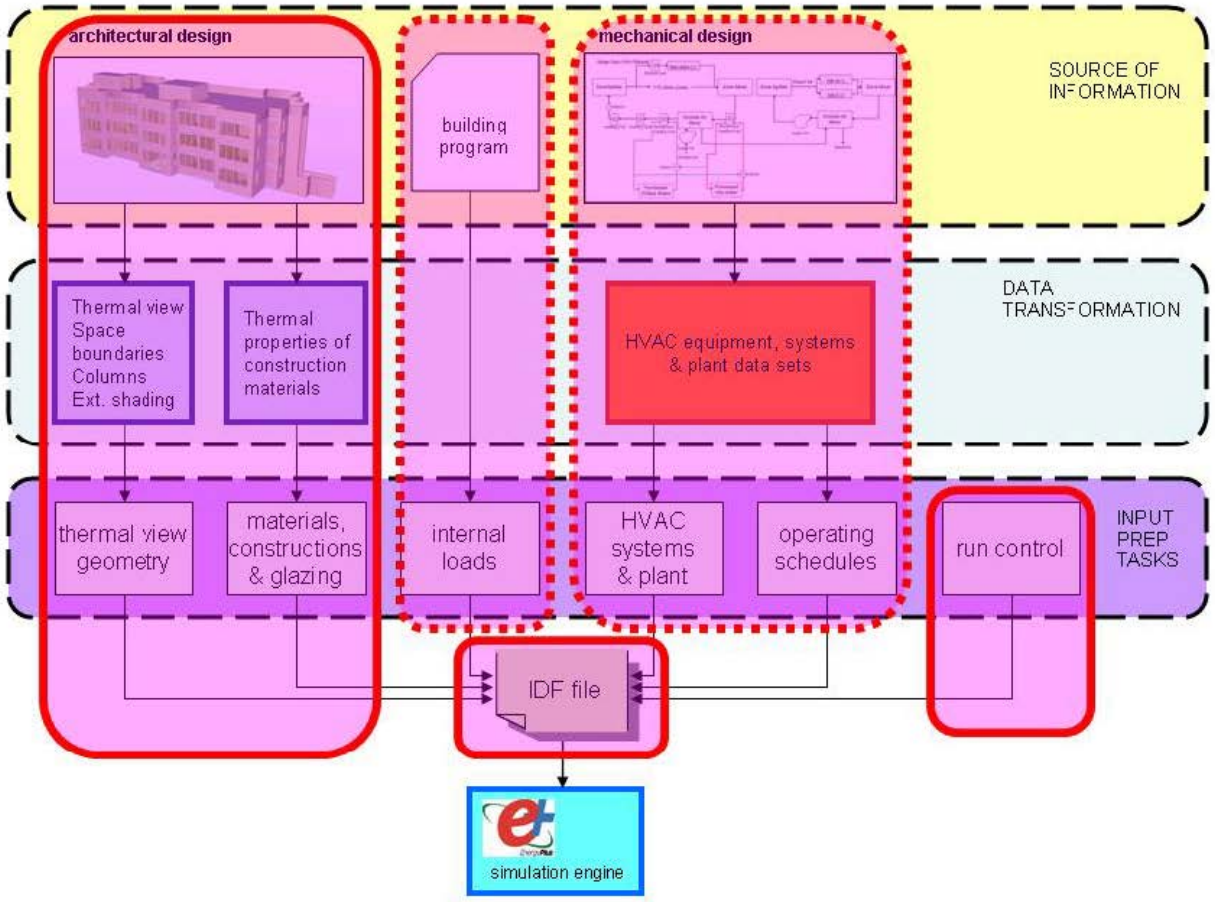
01

Research Background

Research Background

Energy assessment methods

- Detailed energy simulation method
- Simple energy calculation method

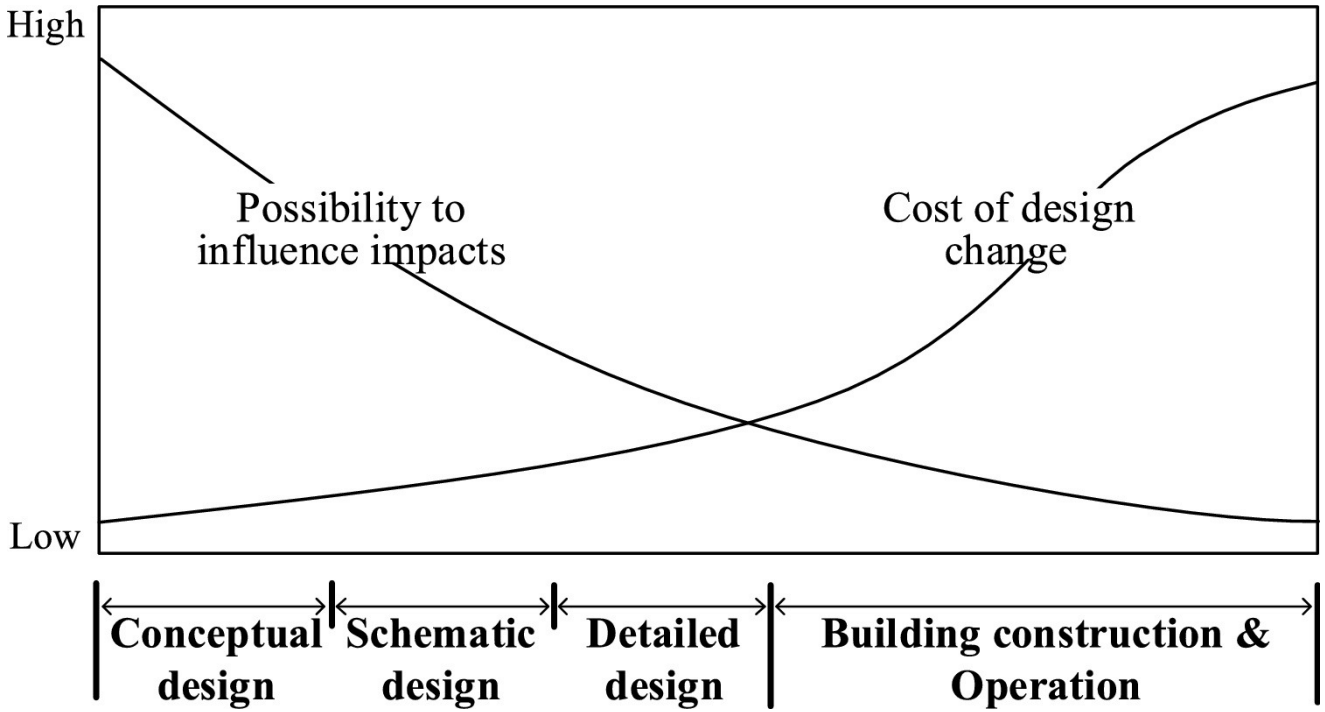


Complete implementation of the methodology for semiautomated BEP simulation (Bazjanac 2009)

Research Background

Early design stage

- High impact
- Low cost of changes



Cost-influence curve (Feng et al. 2019)

Problem Statement

Energy optimizations often take place in the late design stage, when changes to buildings are costly, and the improvements are slight.

- Converting BIM models (automatically) is difficult.
- Manually creating energy models is time-consuming.
- Energy analysis requires special expertise.

Research Question

'How can energy performance be assessed in a very early design stage based on a preliminary BIM model while modifications to the design can be made on-the-fly?'

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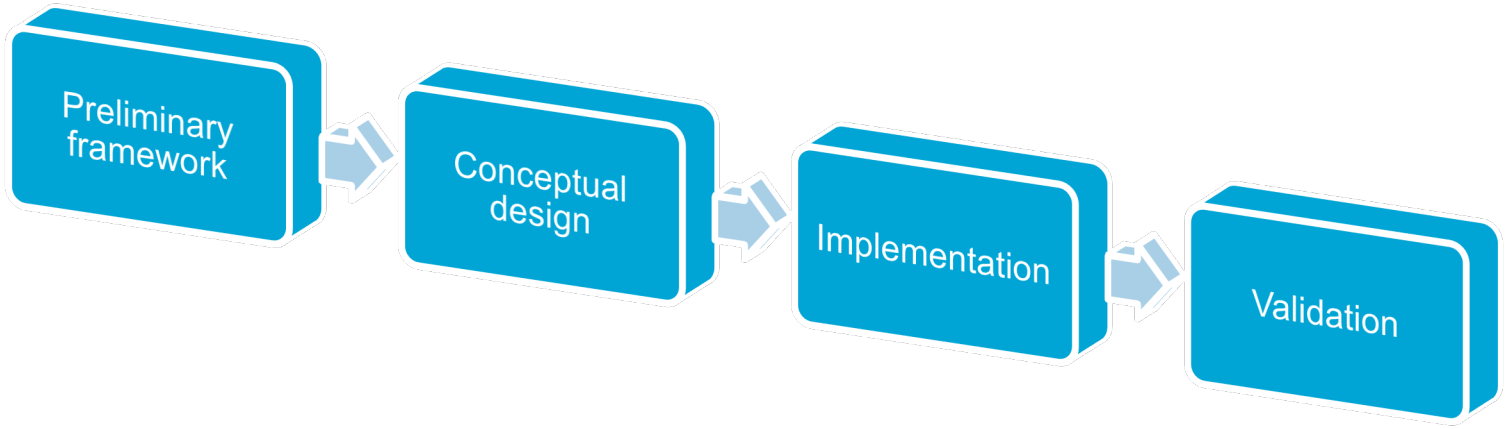
Methodology

- Determine the preliminary framework
- Concetual design of the framework
- Implemention of the framework and demonstration
- Validation of case studies by Uniec 3



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02

Literature Study

Literature Study

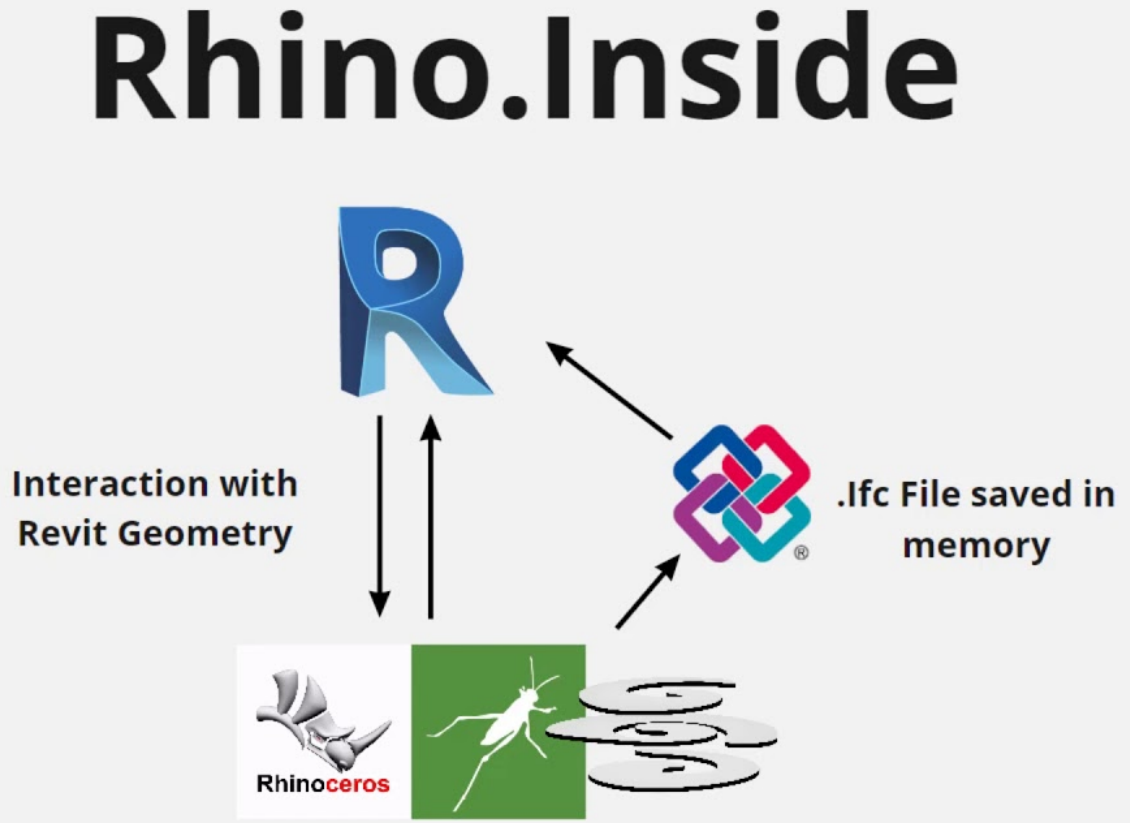
BIM to BEM Model Methods

- IEF-based method
- BIM-API-based method
- Other methods

The workstation's left screen shows the CAD input, while the center shows the translated model, and the right contains BES output. (Pratt et al. 2012)

Literature Study

Revit - Rhino.Inside. - Grasshopper



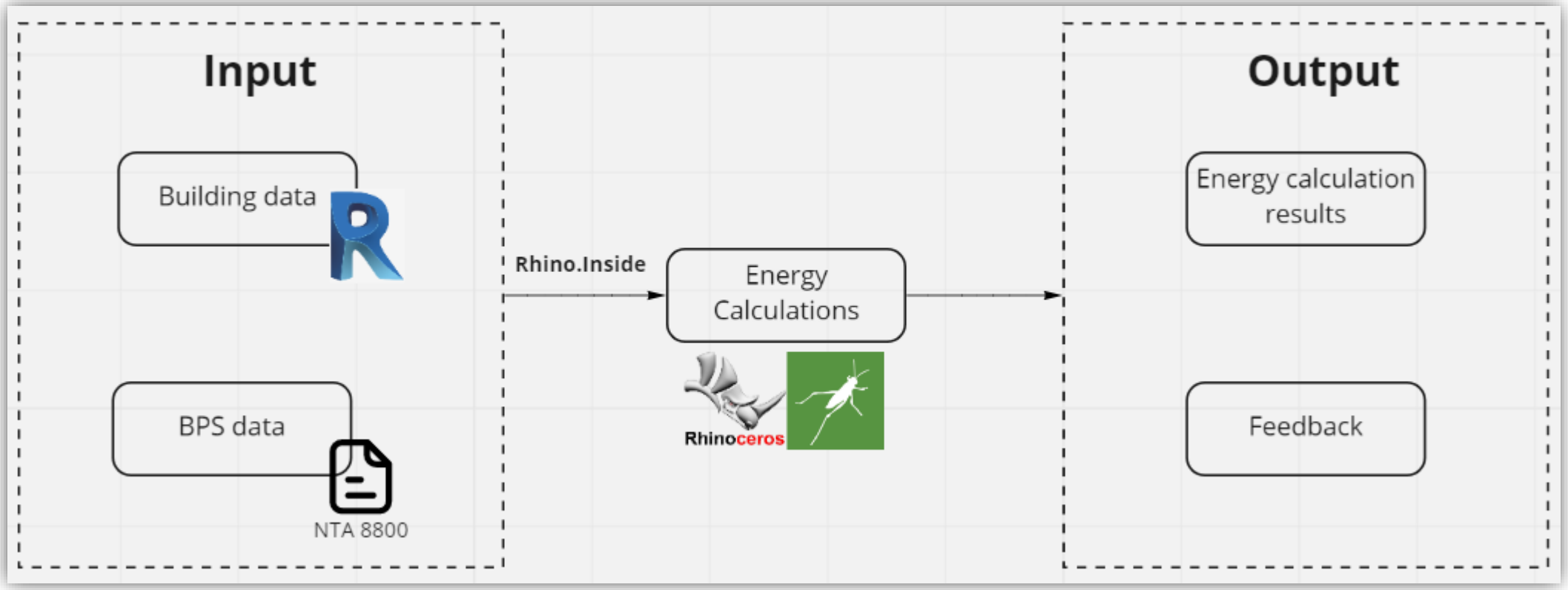
https://www.youtube.com/watch?v=0m1rn6EAI54&ab_channel=GeometryGym

03

Framework Development

Conceptual Design

The structure of the framework



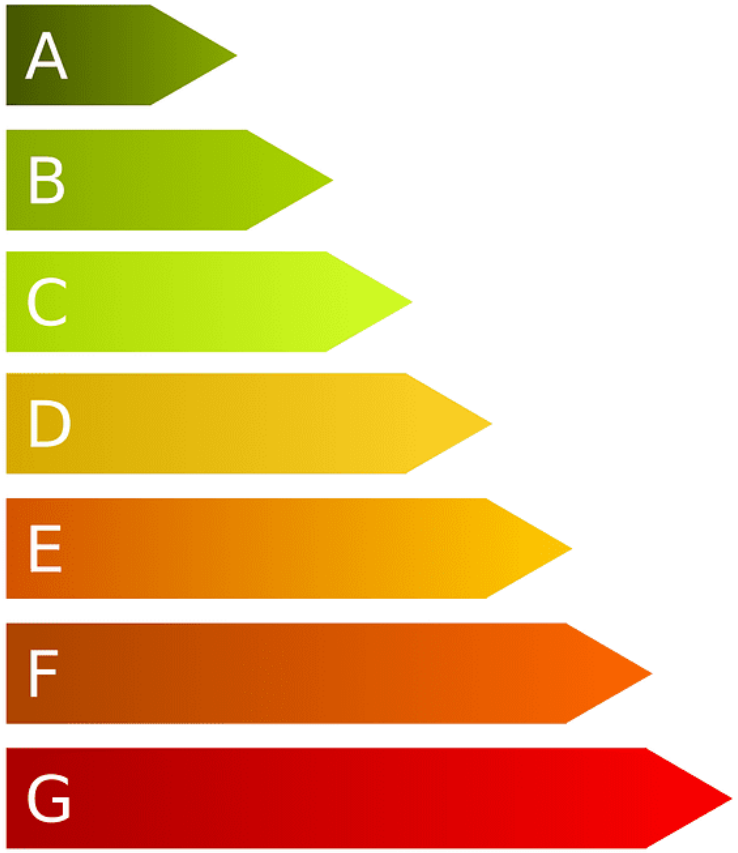
Scope Limitations

NTA 8800 Indicators

- **Energy demand indicator *Ewe*** $_{H+C;nd;ventsys=C1}$;
- Primary fossil energy indicator *Ewe* $_{PTot}$;
- Share of renewable energy RER $_{PrenTot}$.

Application scope of GH script

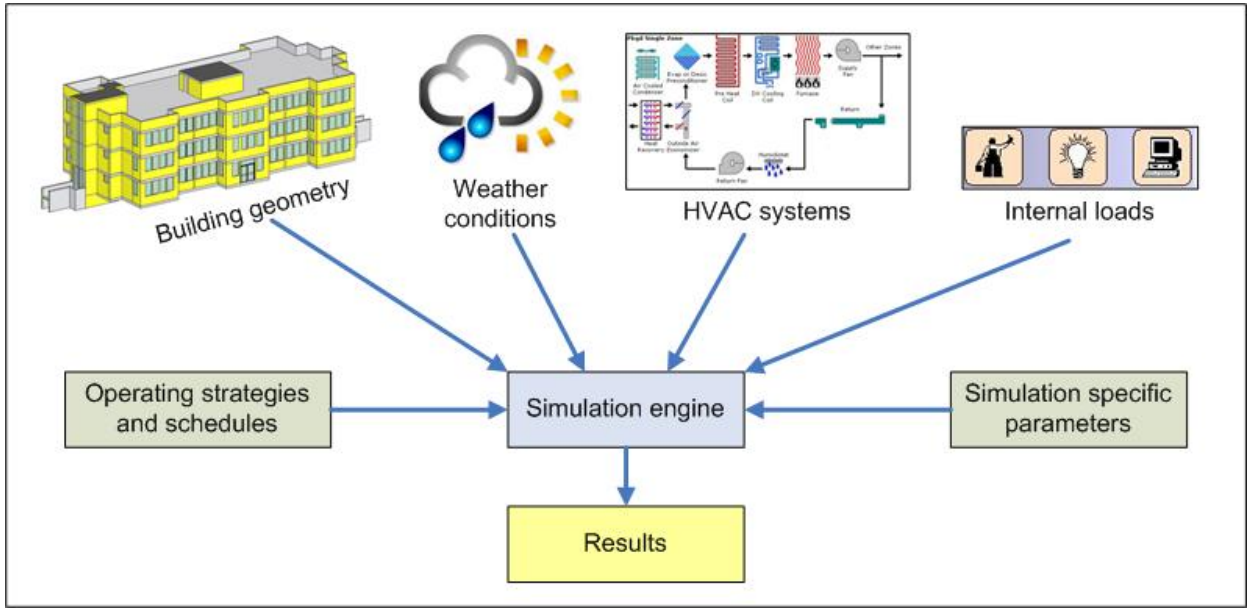
- Residential buildings
- Single calculation zone



https://www.nieman.nl/training/training-beng-en-nta-8800

Data Input

Collecting Building Data



General data flow of simulation engines (Maile et al. 2007)

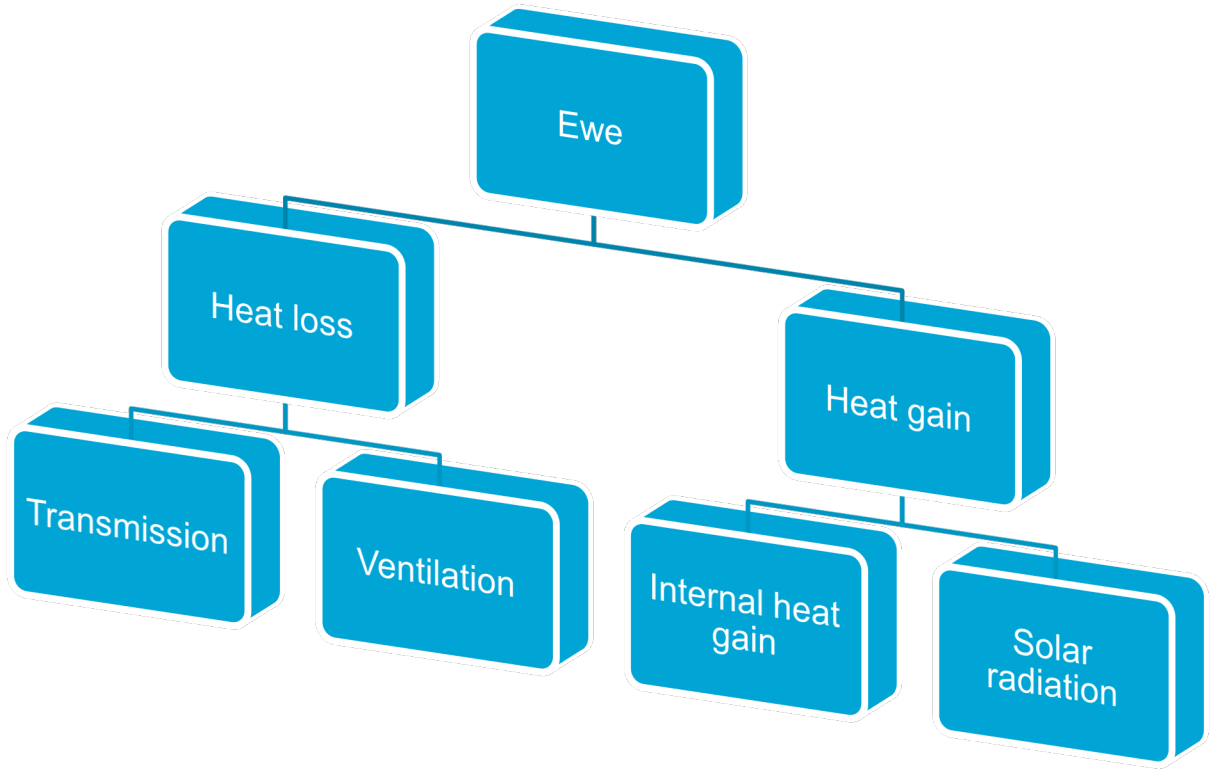
Walls	Roofs	Windows	Doors	Floors	Rooms
Area	Area	Area	Area	Area	Area
Rc value	Rc value	Sill height	Rc value	Rc value	N living
If exterior		Glazing type	If transparent	Perimeter	N people
Orientation		If fixed	Orientation		
		U-value			
		Orientation			
		Shading reduction factor			

Energy Calculation

Energy Requirement NTA 8800:

- Heat loss through transmission
- Heat loss through ventilation

- Internal Heat gain
- Heat gain by solar radiation

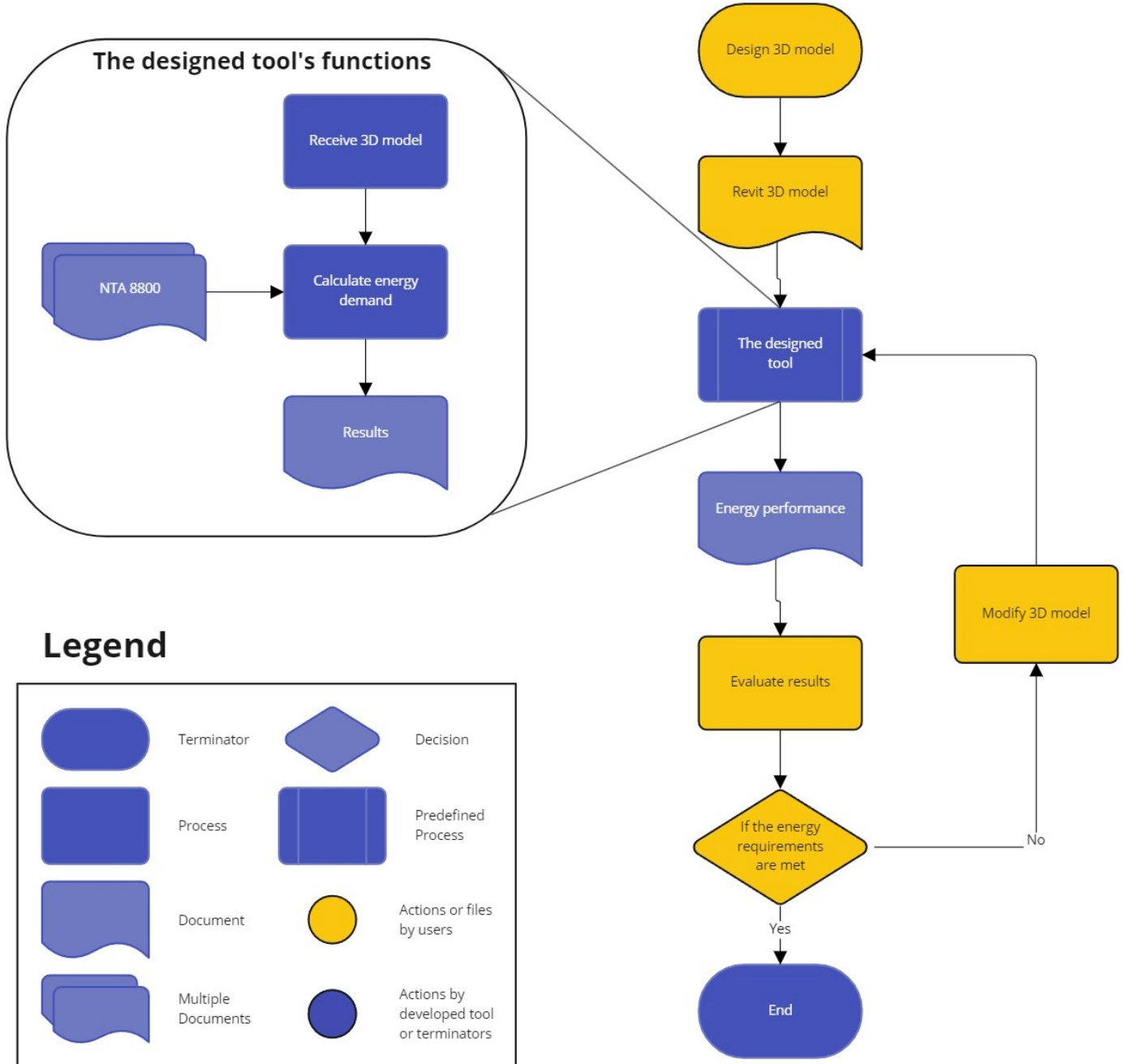


04

Tool Development

Workflow

Tool Procedure



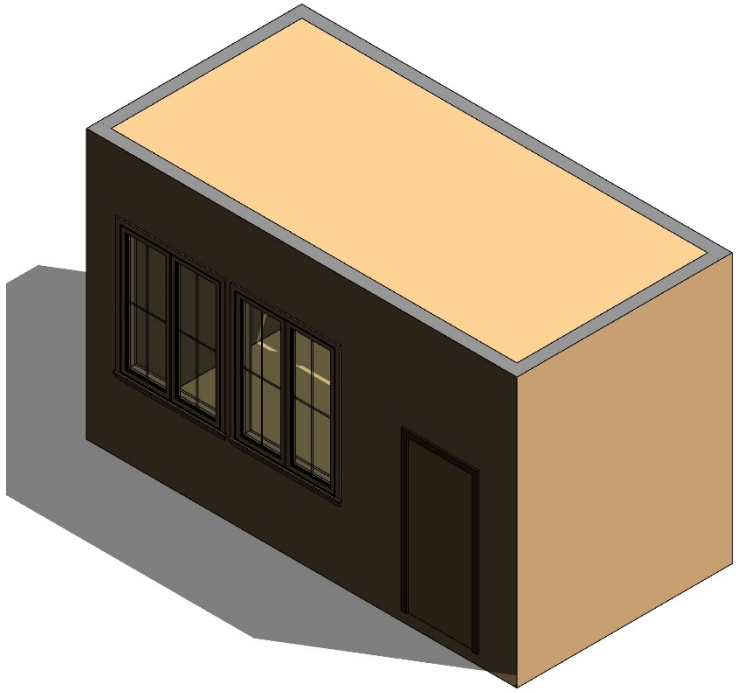
Preliminary Test

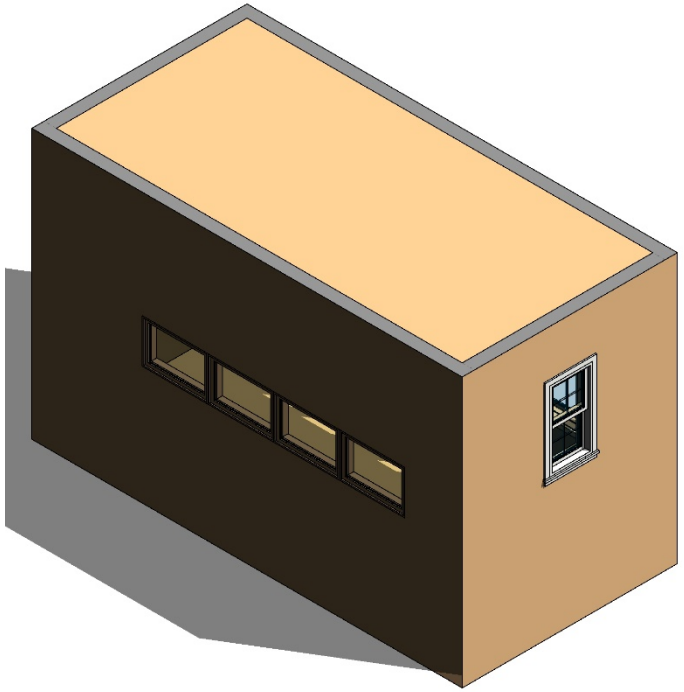
- A residential “Tiny house” for calculation

https://reisleven.nl/ikea-tiny-houses

Preliminary Test

Tiny house





	Als/Ag	6.02	-
	total area	15.04	m²
Floor	area	15.04	m²
	perimeter	16.63	m
	Rc	4.91	m²K/W
	U	0.20	W/m²K
Wall	Rc	4.12	m²K/W
	U	0.24	W/m²K
	north_area	22.50	m²
	south_area	22.50	m²
	east_area	9.97	m²
	west_area	9.97	m²
Door	Rc	0.59 m²K/W	m²K/W
	U	1.70 W/m²K	W/m²K
	ggl	0.00	-
	area	1.95	v
Window A	U	3.69 W/m²K	W/m²K
	Rc	0.27 m²K/W	m²K/W
	ggl	0.75	-
	area	0.56	m²
Window B	U	3.10 W/m²K	W/m²K
	Rc	0.32 m²K/W	m²K/W
	ggl	0.75	-
	area	2.52	v
Window C	U	3.10 W/m²K	W/m²K
	Rc	0.32 m²K/W	m²K/W
	ggl	0.75	-
	area	0.66	m²
Roof	Rc	5.58 m²K/W	m²K/W
	U	0.18	W/m²K
	area	15.04	m²

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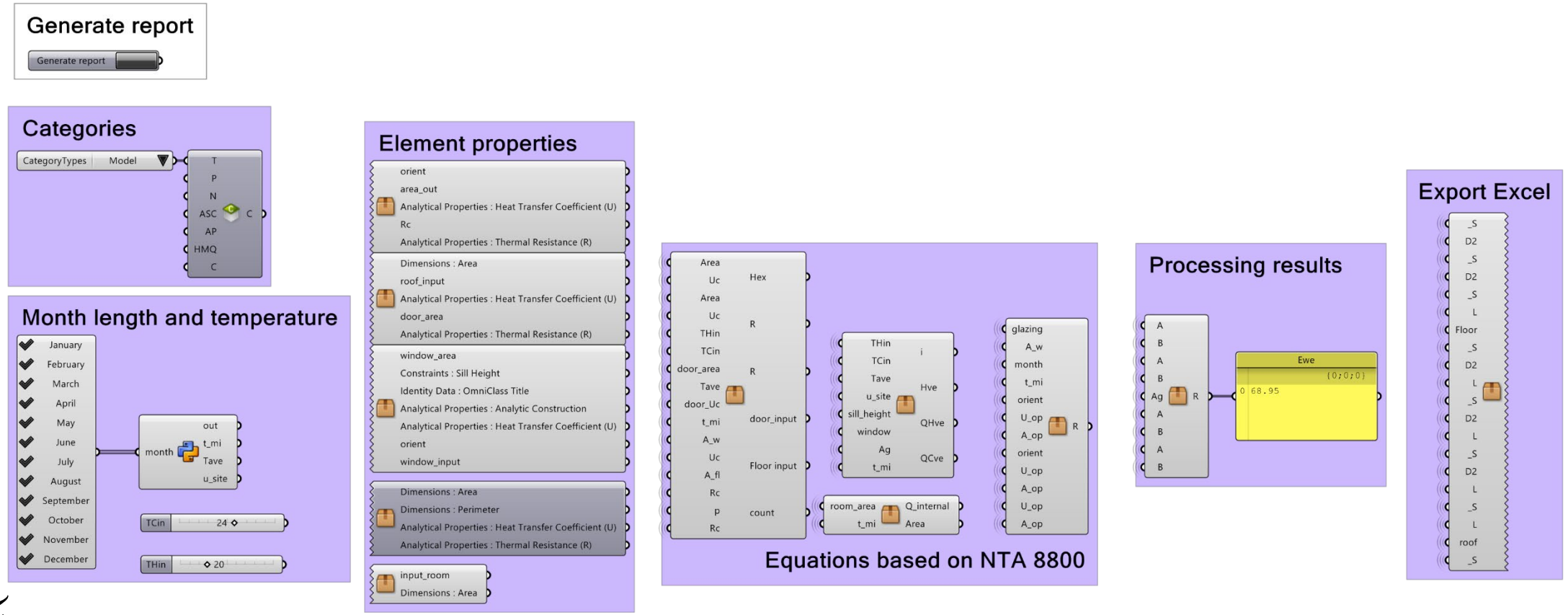
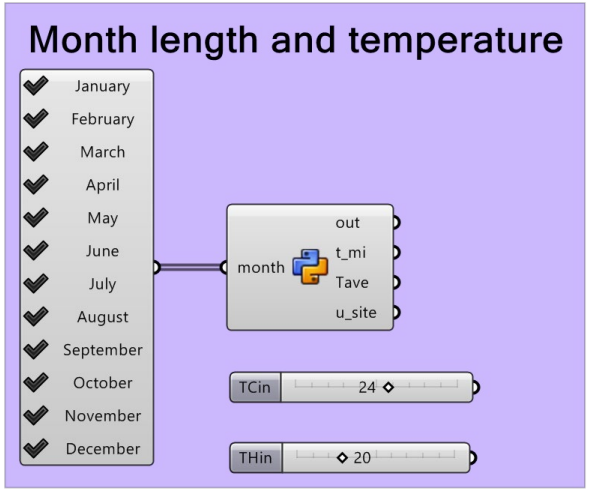
Grasshopper Script

Implementation and script



Grasshopper Script

- Month length and temperature



Tabel 17.1 — Lengte van de maand, t_{mi}, maandgemiddelde buitenluchttemperatuur, $\vartheta_{e;avg;mi}$, maandgemiddelde buitenluchttemperatuur voor zomernachtventilatie, $\vartheta_{e;argII,mi}$, maandgemiddelde windsnelheid, $u_{site;mi}$, en de maandgemiddelde temperatuur van de toevoerlucht vóór de WTW gedurende de periode dat er sprake is van koudeterugwinning via de WTW, $\vartheta_{ODA;preh;WTWC;zi;mi}$

Maand	t_{mi} h	$\vartheta_{e;avg;mi}$ °C	$\vartheta_{e;argII,mi}$ °C	$u_{site;mi}$ m/s	$\vartheta_{ODA;preh;WTWC;zi;mi}$ °C
Januari	744	2,61	-	3,04	0,00
Februari	672	4,82	13,97	4,15	0,00
Maart	744	5,91	13,00	2,99	0,00
April	720	9,32	13,70	3,06	0,00
Mei	744	14,73	14,56	2,97	25,63
Juni	720	16,12	15,62	2,78	27,49
Juli	744	18,05	16,17	2,63	26,34
Augustus	744	18,48	16,90	2,51	27,29
September	720	15,63	15,11	2,71	25,30
Oktober	744	10,40	15,04	2,78	0,00
November	720	7,99	13,43	2,83	0,00
December	744	4,00	-	2,83	0,00

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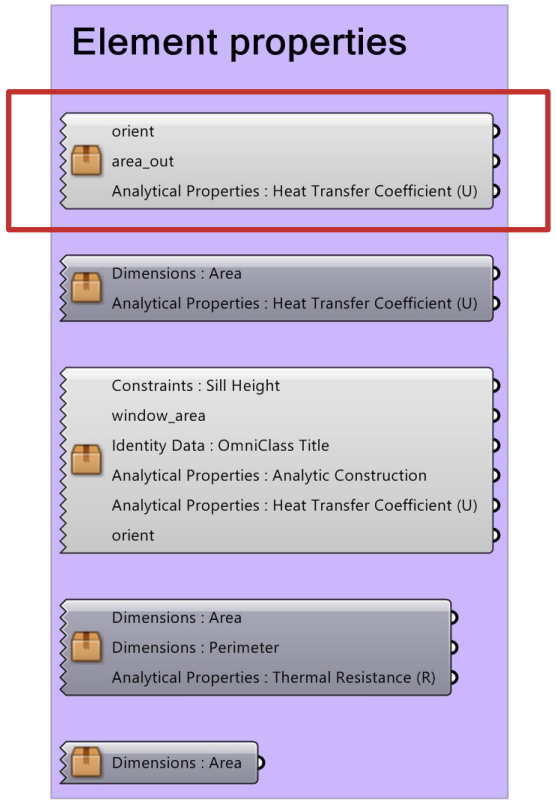
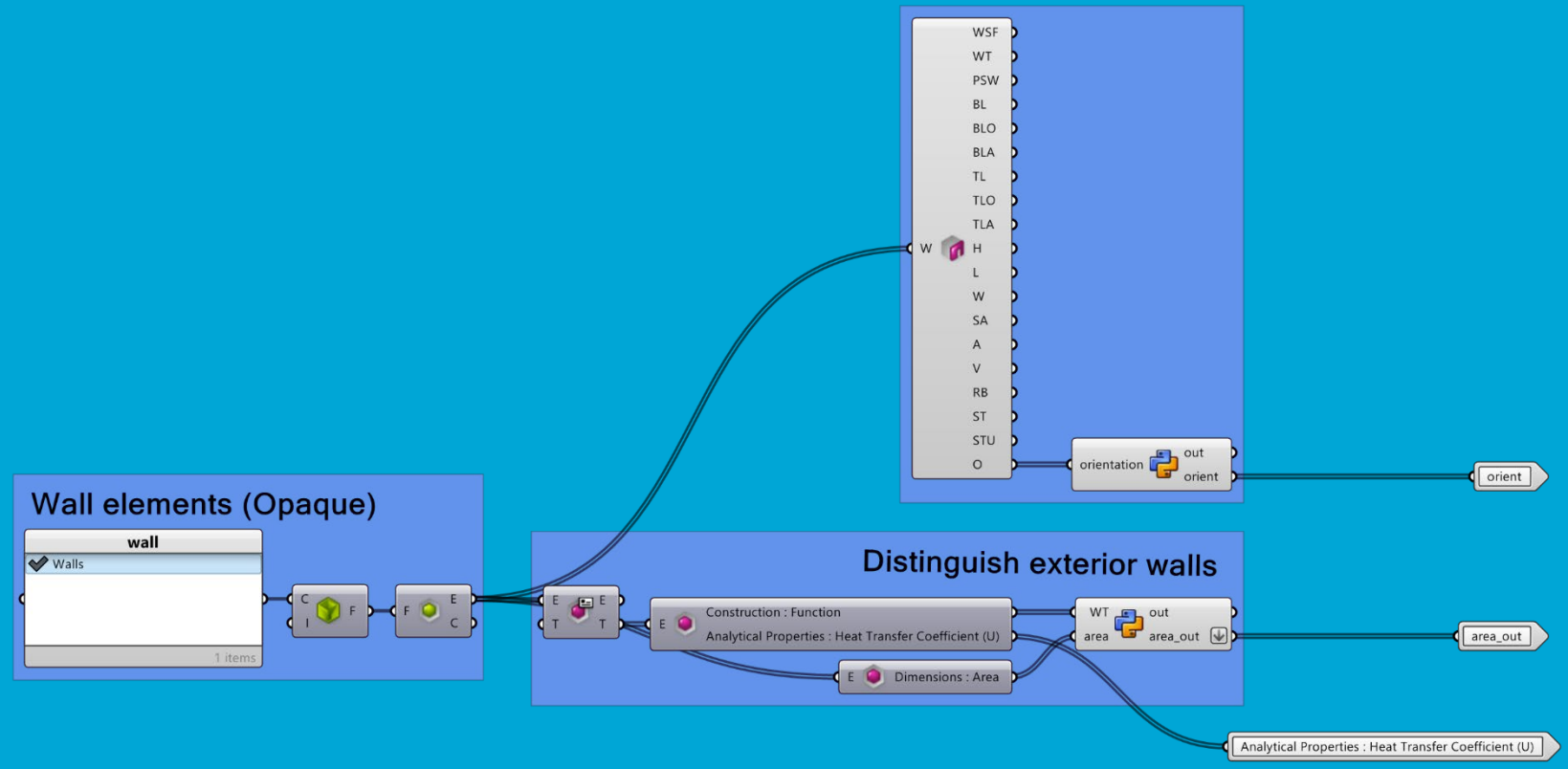
Grasshopper Script

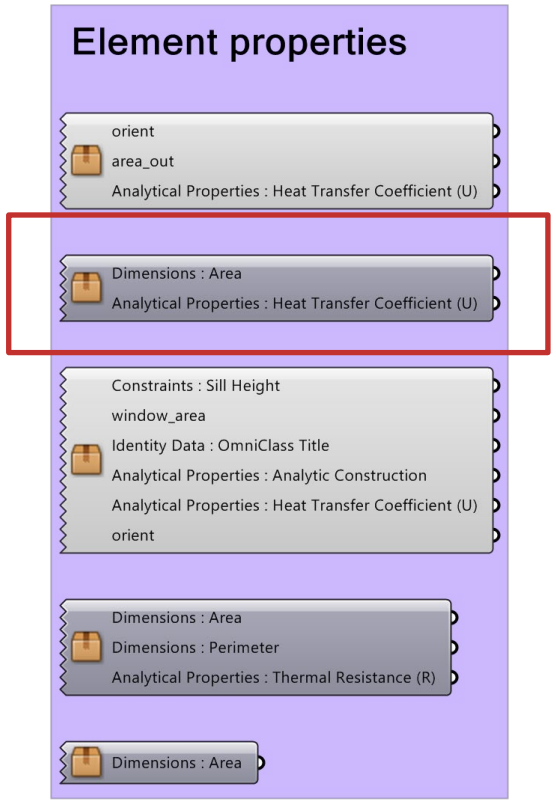
- Geometric and thermal input

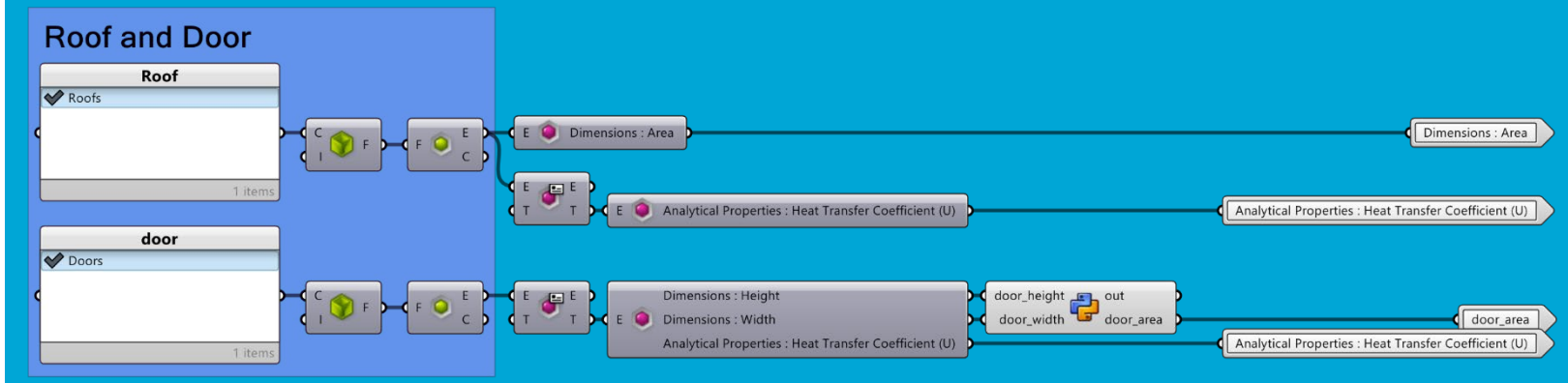




Grasshopper Script

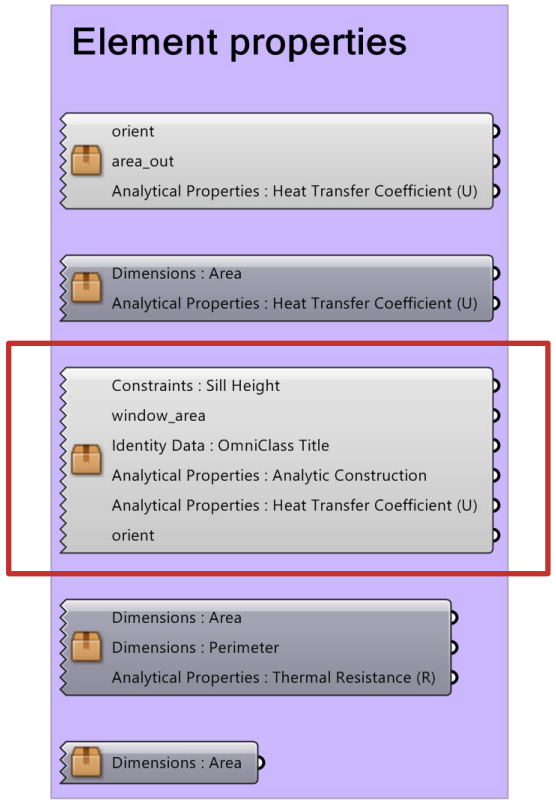
- Geometric and thermal input

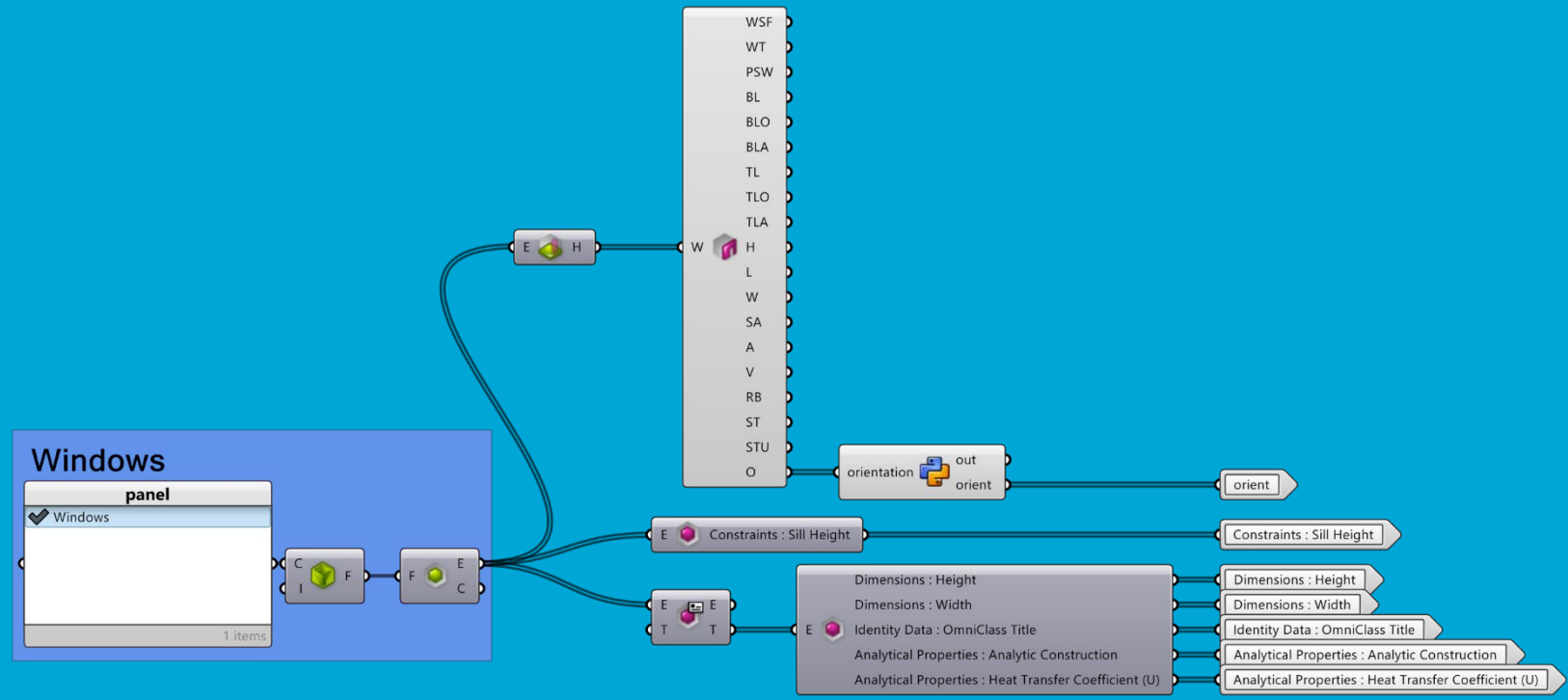


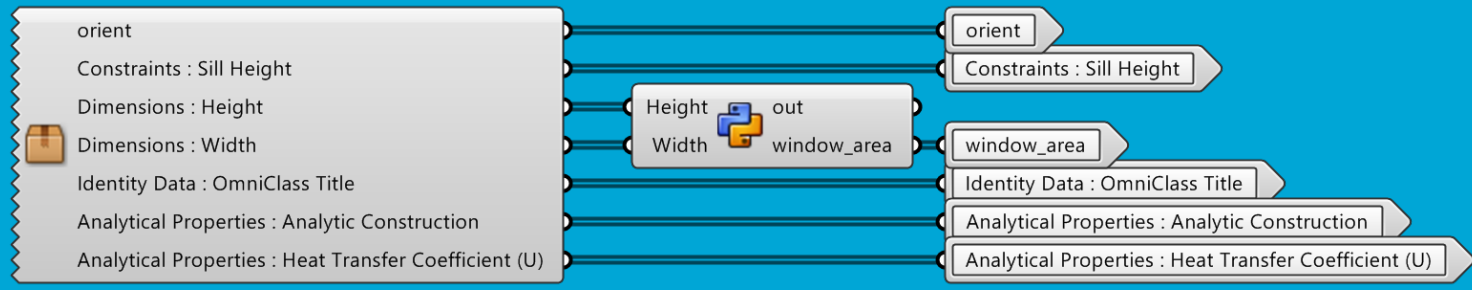


Grasshopper Script

- Geometric and thermal input

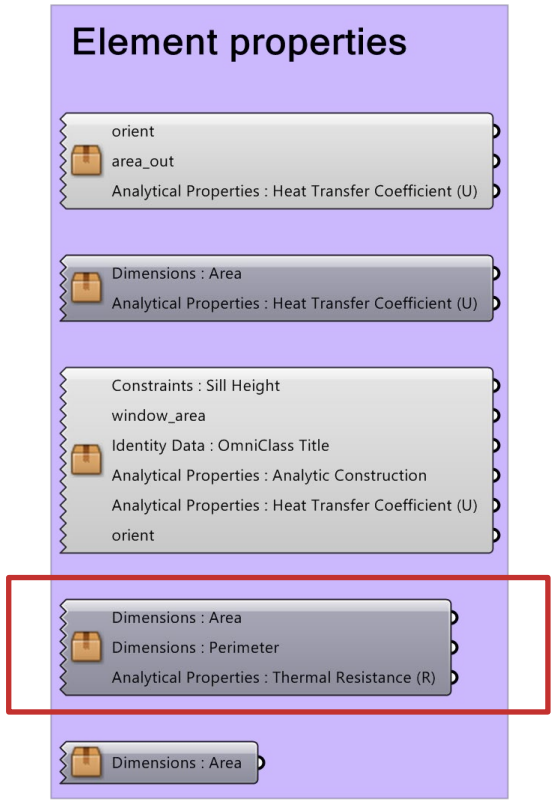


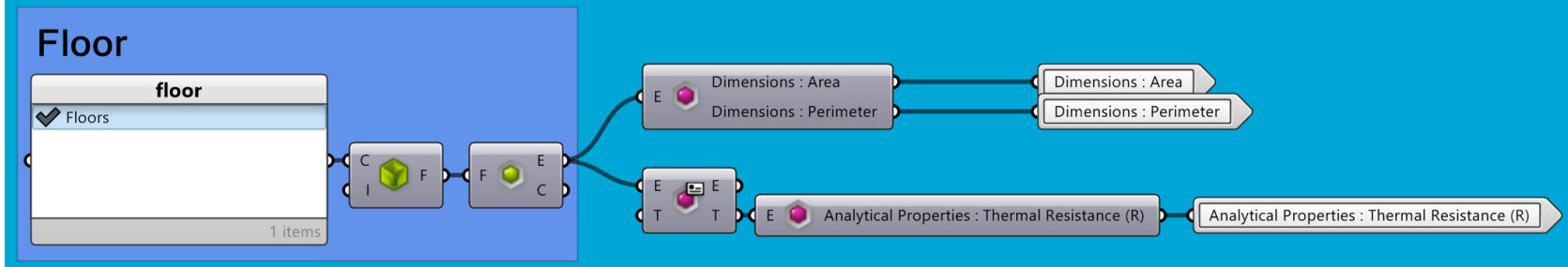




Grasshopper Script

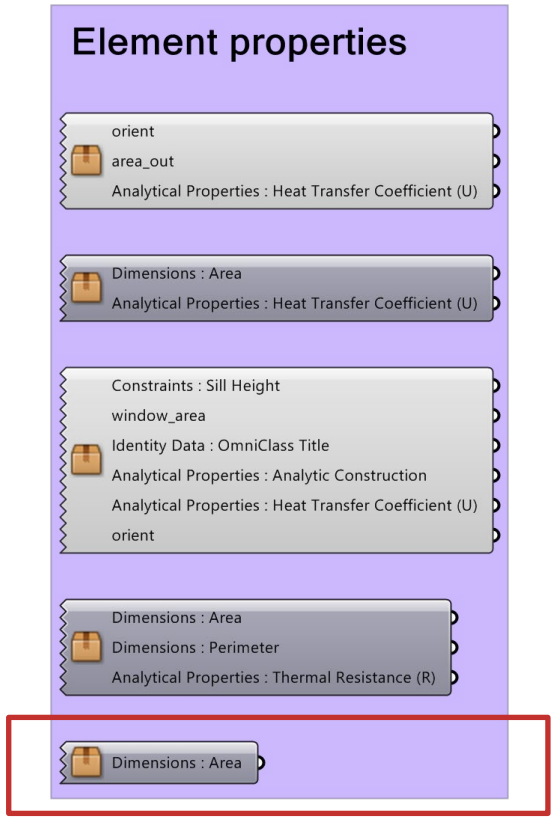
- Geometric and thermal input

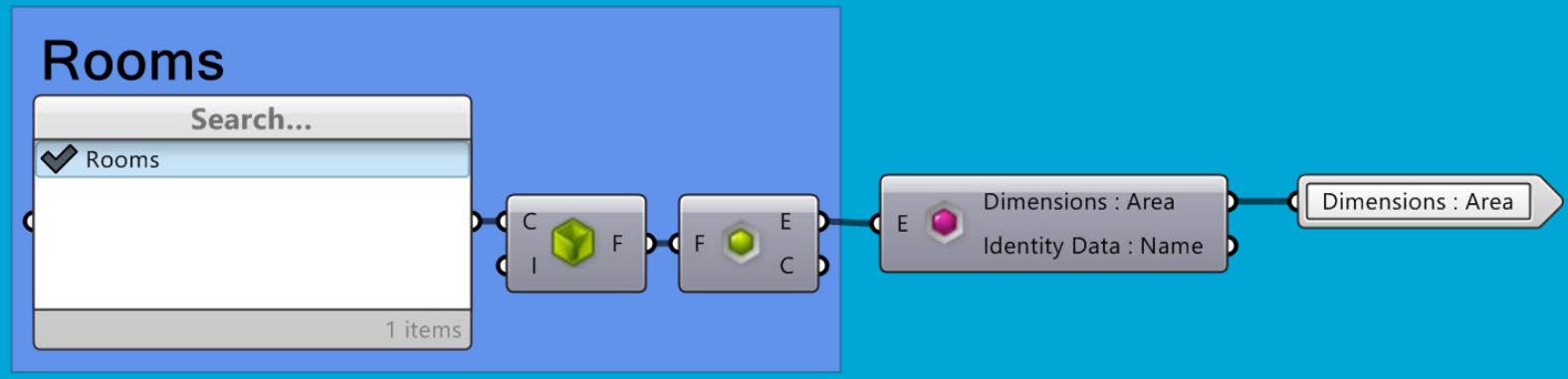




Grasshopper Script

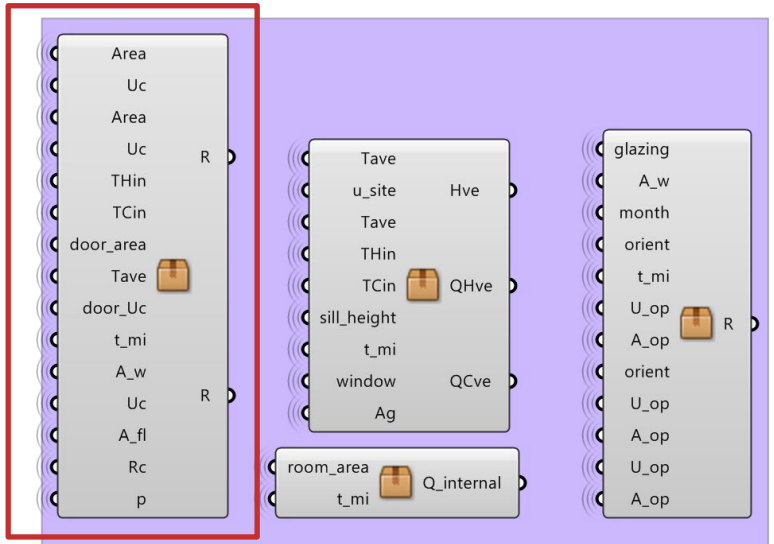
- Geometric and thermal input

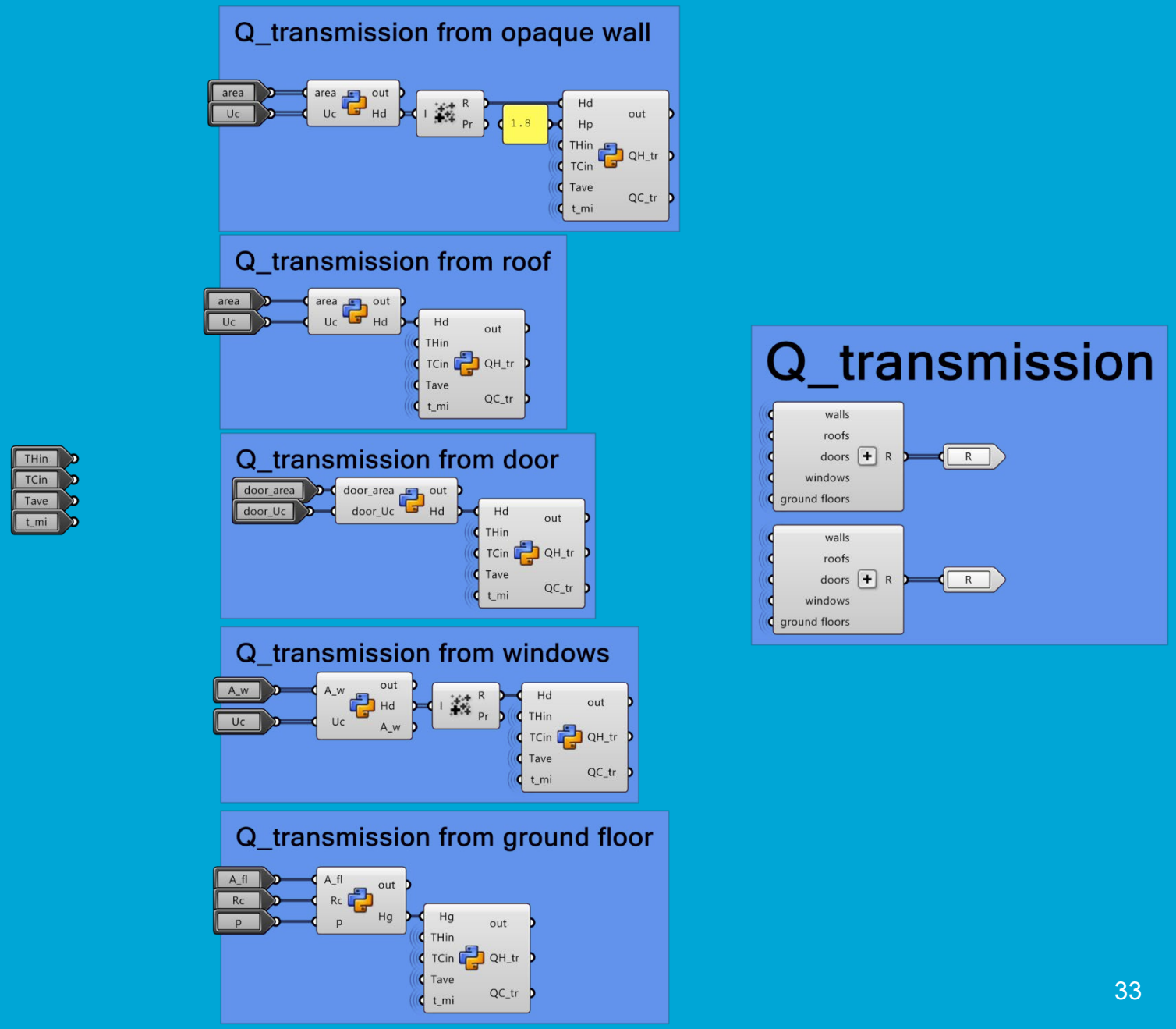




Grasshopper Script

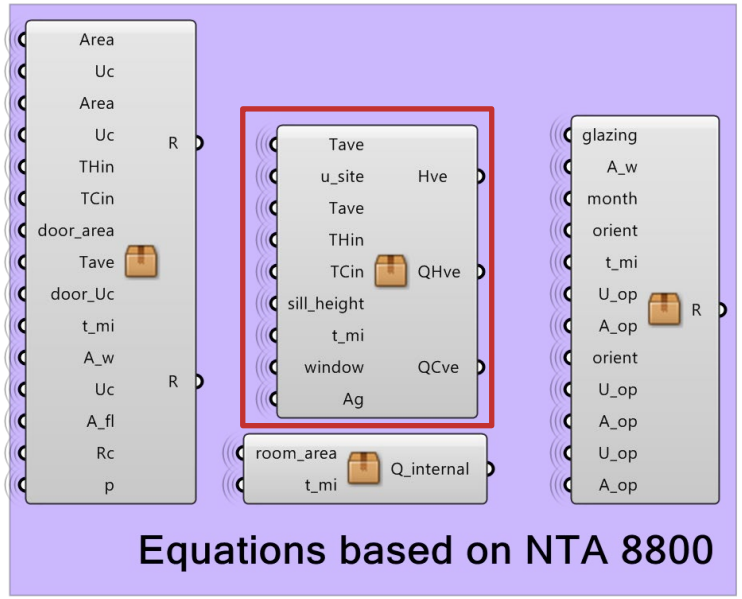
- Energy calculations

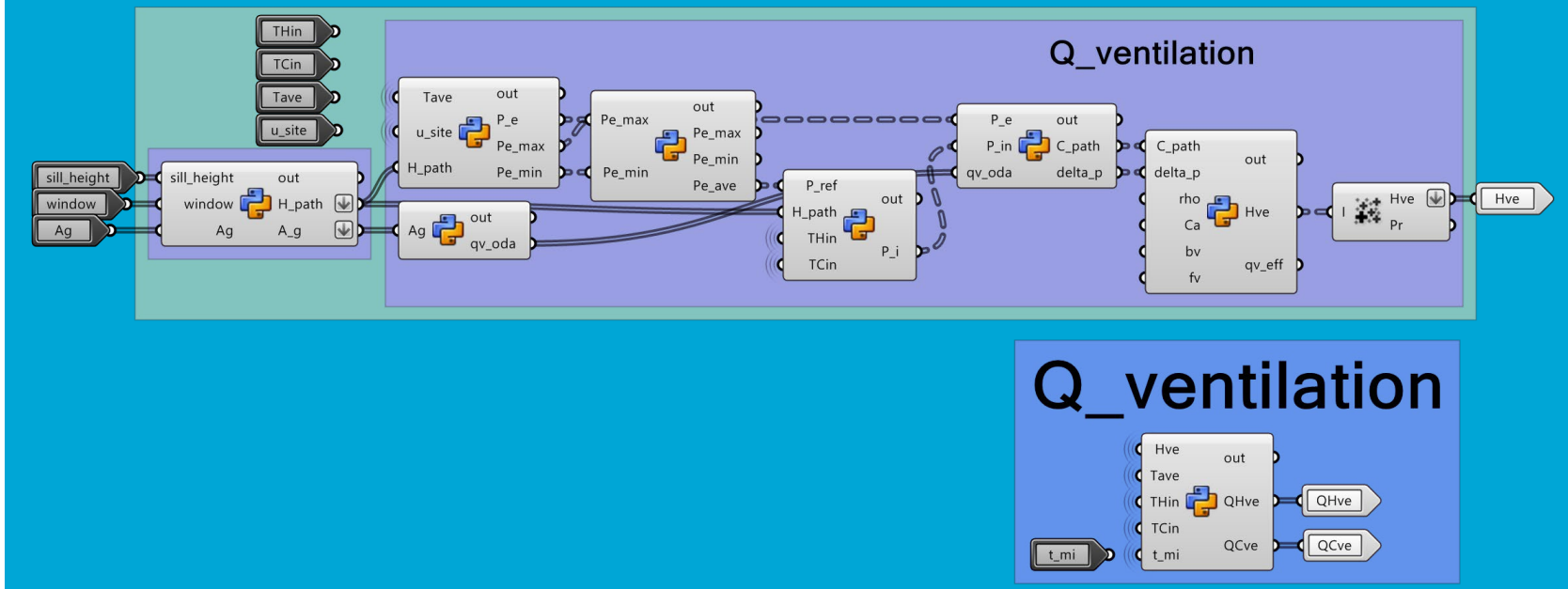




Grasshopper Script

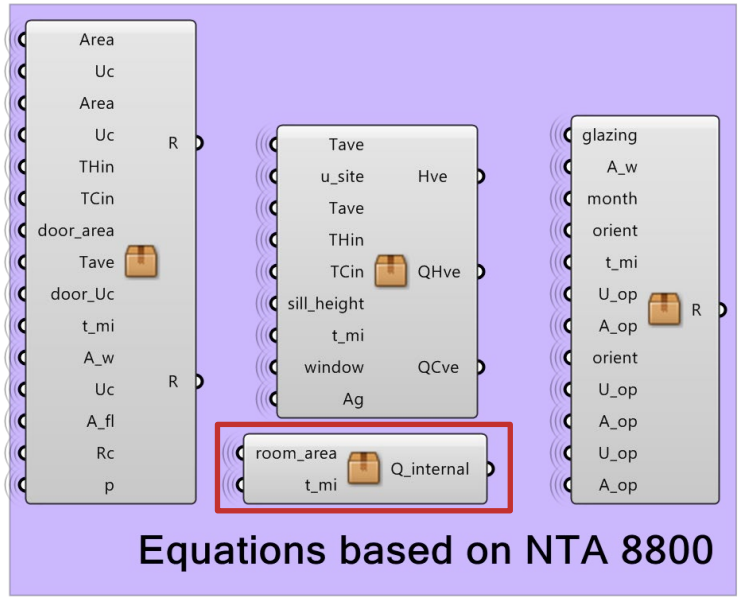
- Energy calculations

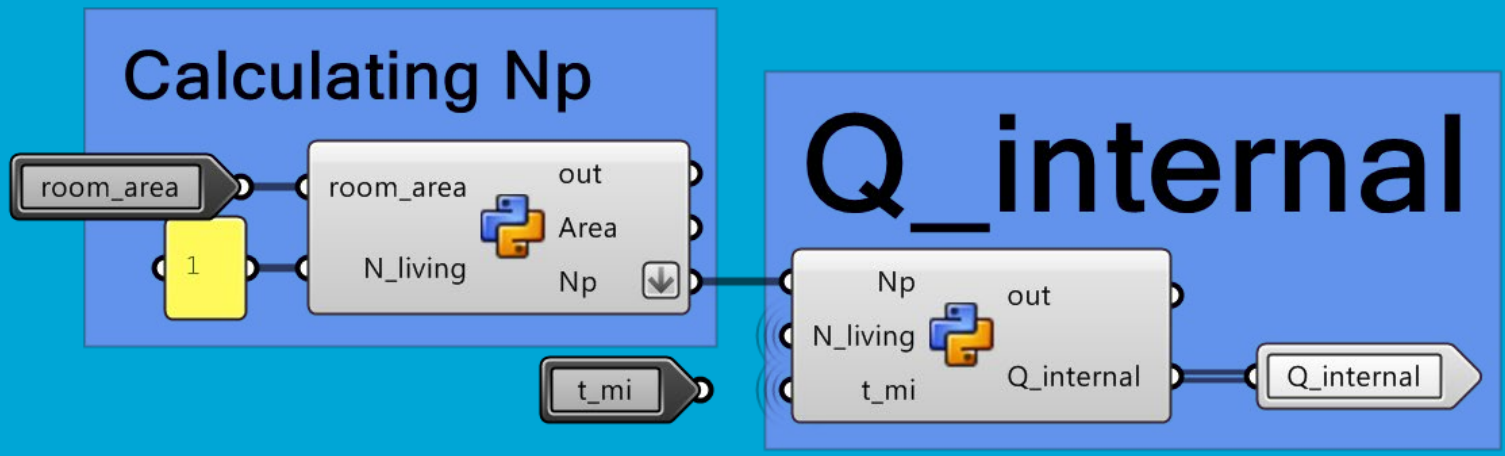




Grasshopper Script

- Energy calculations





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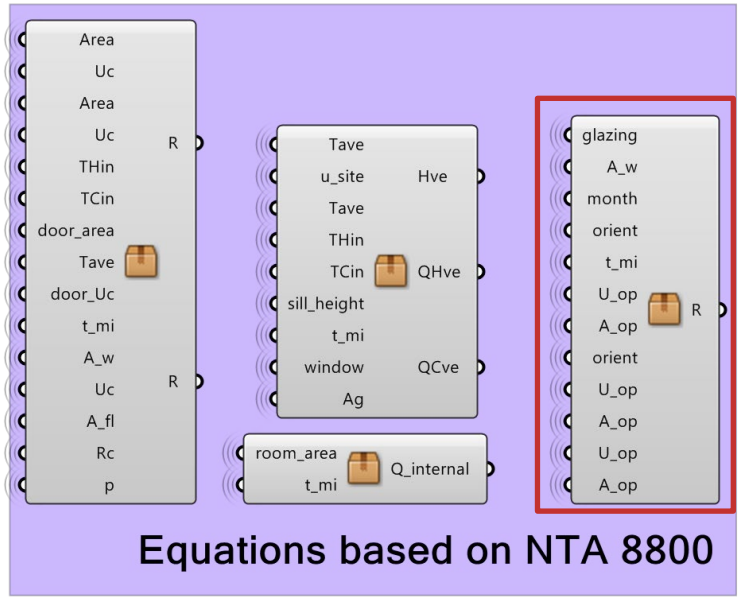
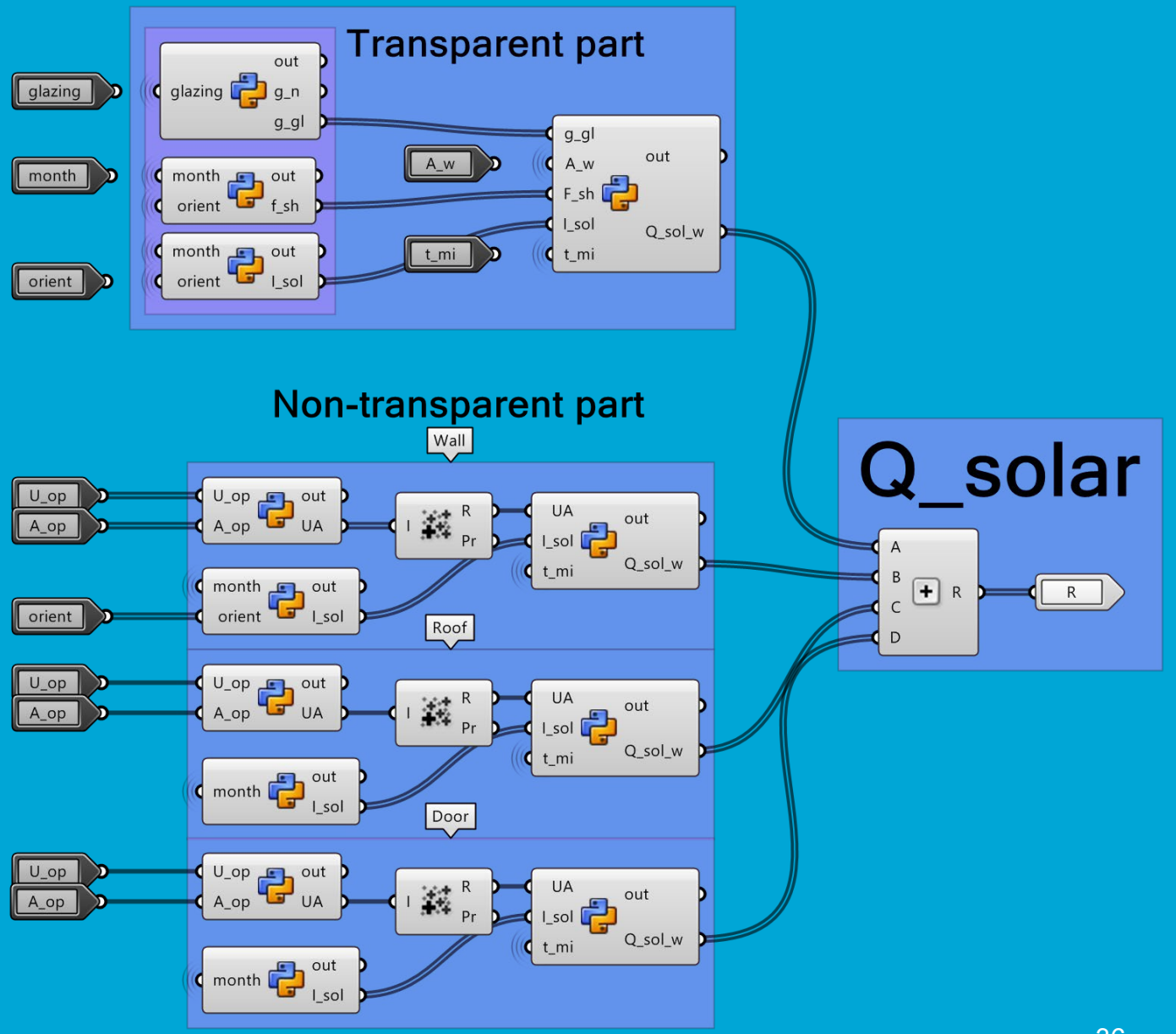
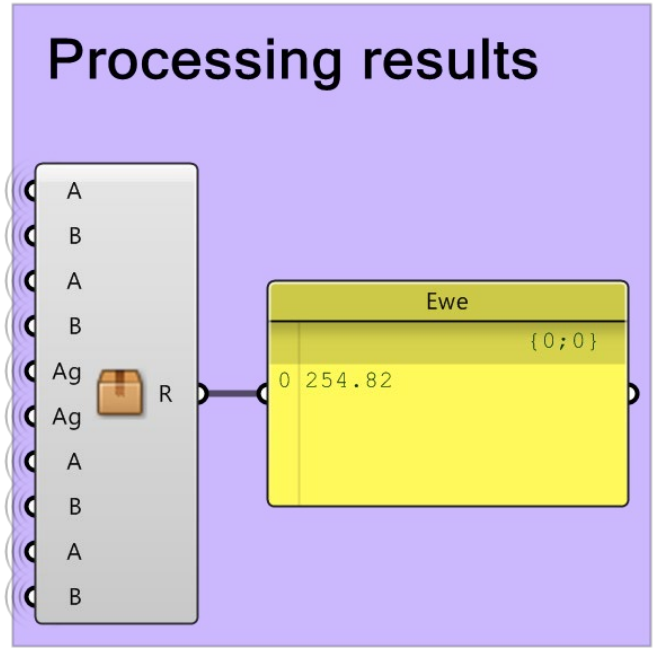
- Energy calculations

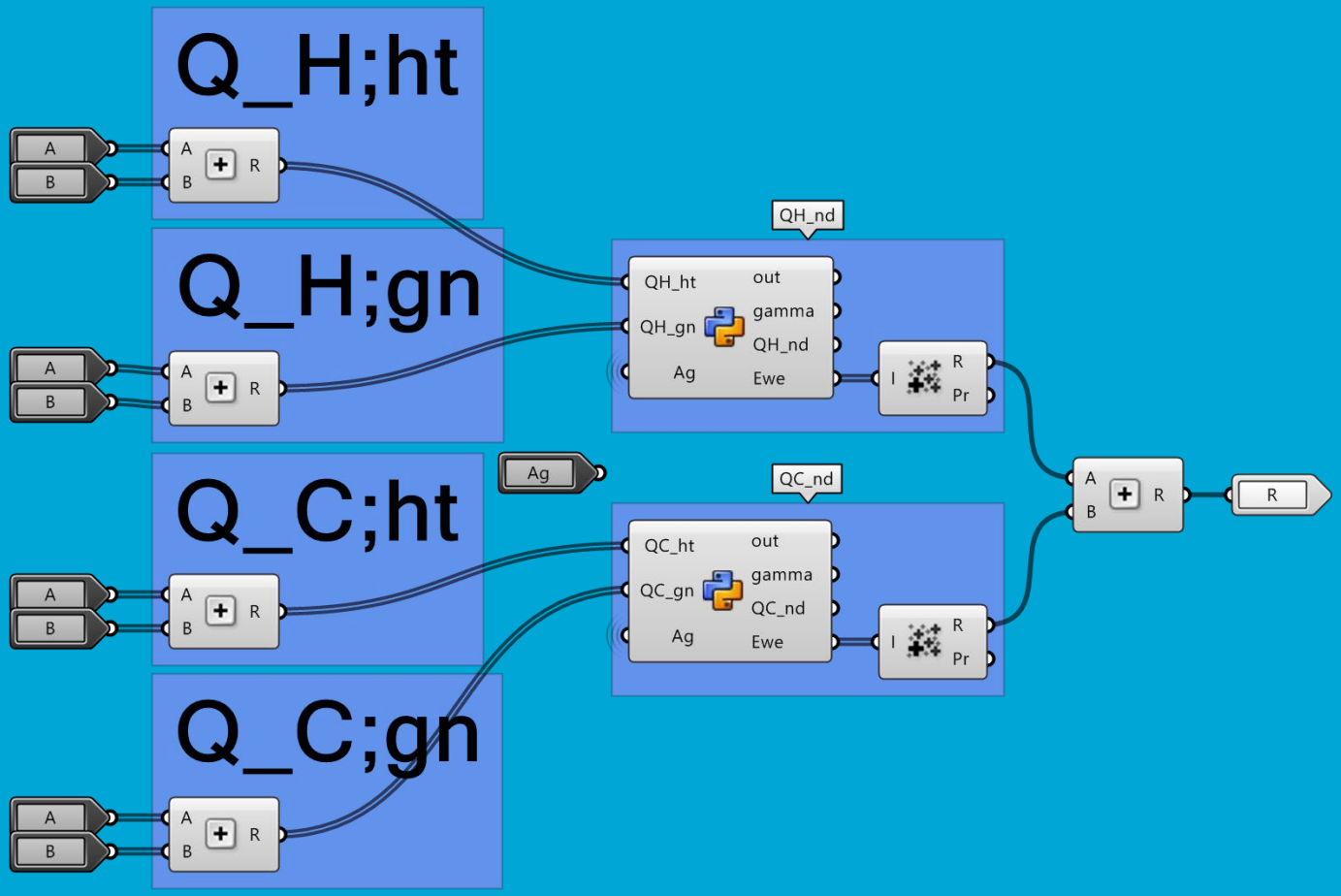




Grasshopper Script

- Processing results





Uniec 3

Ewe from GH script: 171.19 kWh/m²

Energieprestatie		
indicator		resultaat
energiebehoefte	$Ewe_{H+C;nd;ventsys=C1}$	176,53 kWh/m²
primaire fossiele energie	Ewe_{PTot}	220,06 kWh/m²
aandeel hernieuwbare energie	$RER_{PrenTot}$	44,7 %
hernieuwbare energie indicator	$E_{wePRenTot}$	178,46 kWh/m²
temperatuuroverschrijding	$TO_{juli;max}$	2,95
energielabel		C
netto warmtebehoefte (EPV)	$E_{H;nd;net}$	206,46 kWh/m²

Preliminary Test

Results and the report

Energy assessment

Ewe (kWh/m^2)
171.19

Room area (m^2)
15.04

Floor Area (m^2)	Perimeter (m)	Rc (m^2K/W)
15.04	16.63	4.91

Wall area S (m^2)	Wall area W (m^2)	Wall area N (m^2)	Wall area E (m^2)	Rc (m^2K/W)
20.27	9.97	15.51	9.31	4.12

Door area (m^2)	U (W/m^2K)
1.95	1.7

Window orientation	Window type	Area (m^2)	U (W/m^2K)	Sill height (m)	g_nl;n
north	Casement Windows	2.52	3.1	0.9	0.75
north	Casement Windows	2.52	3.1	0.9	0.75
east	Double-Hung Windows	0.66	3.1	1.8	0.75
south	Fixed Windows	0.56	3.69	1.5	0.75
south	Fixed Windows	0.56	3.69	1.5	0.75
south	Fixed Windows	0.56	3.69	1.5	0.75
south	Fixed Windows	0.56	3.69	1.5	0.75

Roof area (m^2)	Rc (m^2K/W)
15.04	5.58

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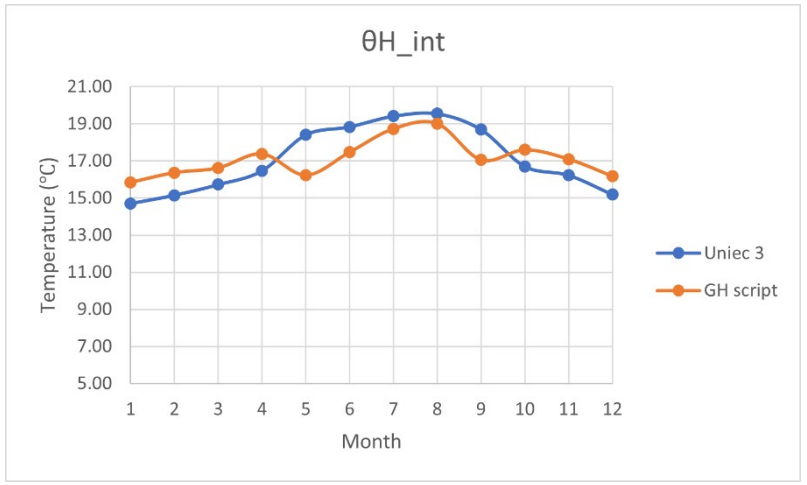
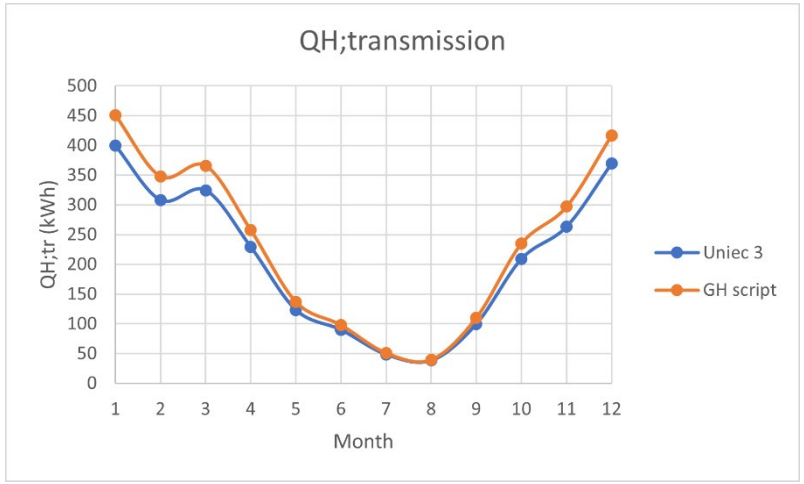
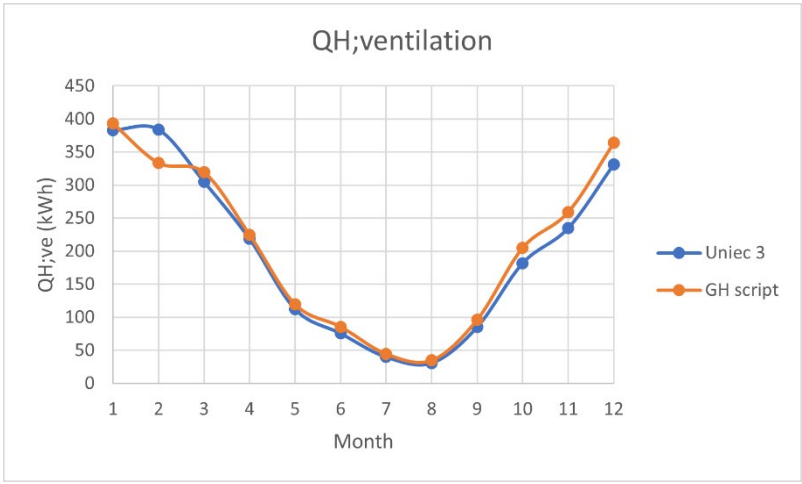
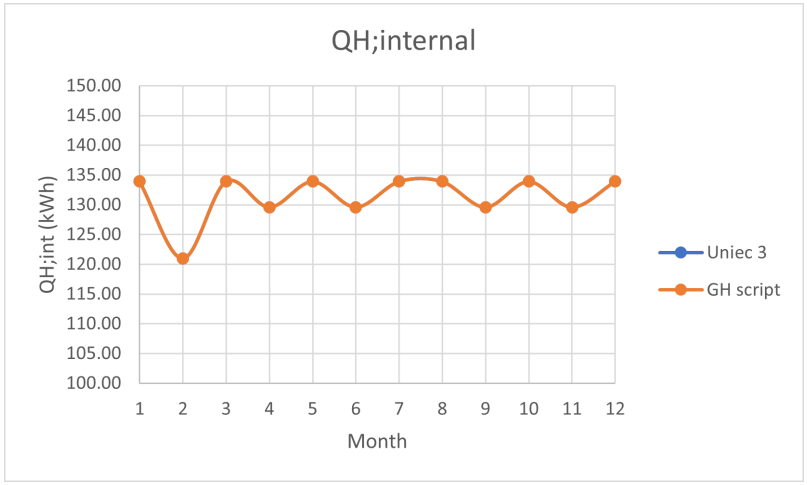
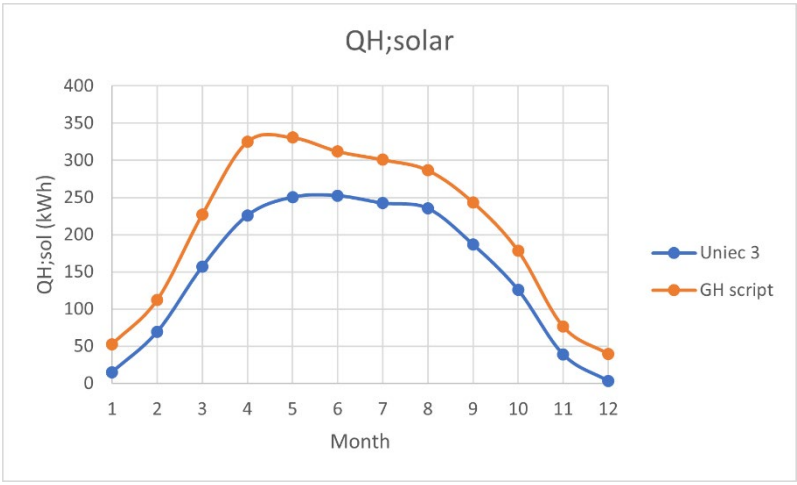
Results Analysis











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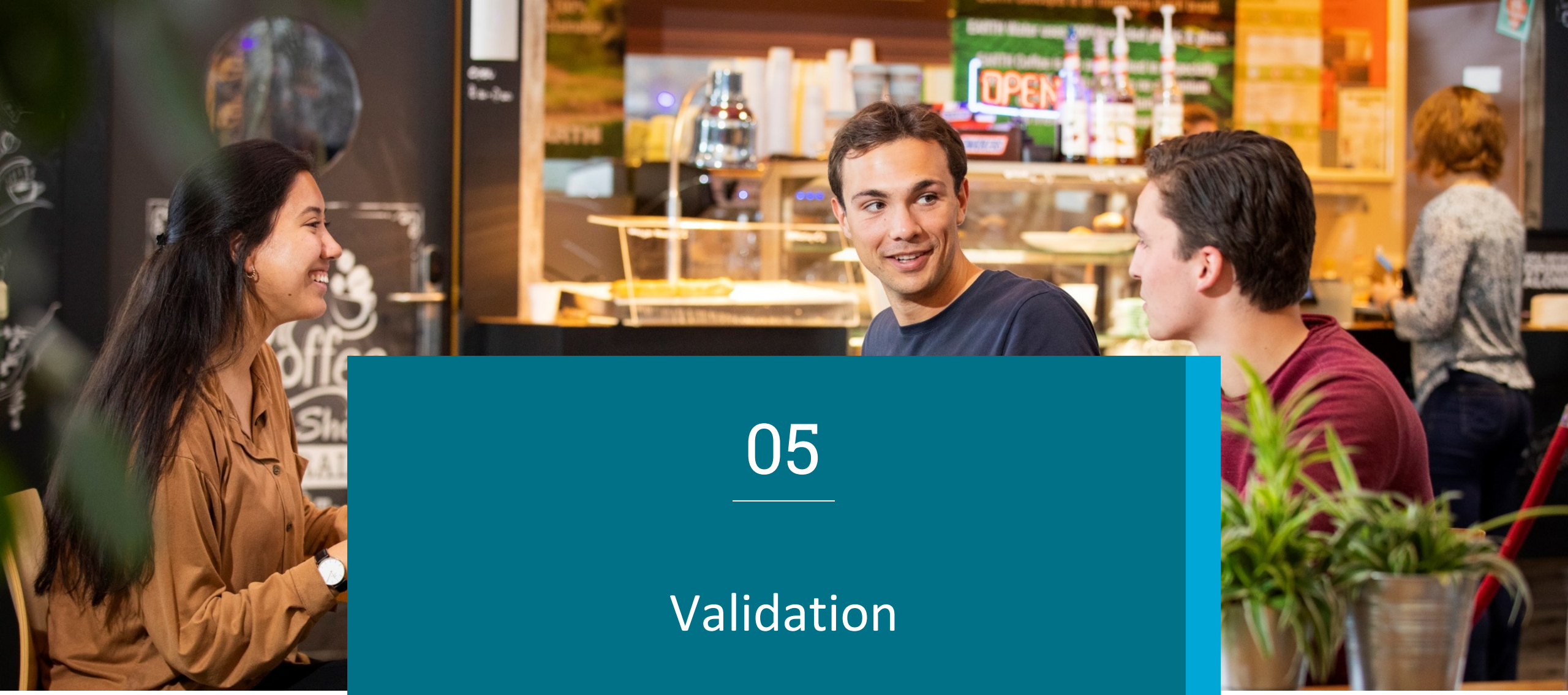


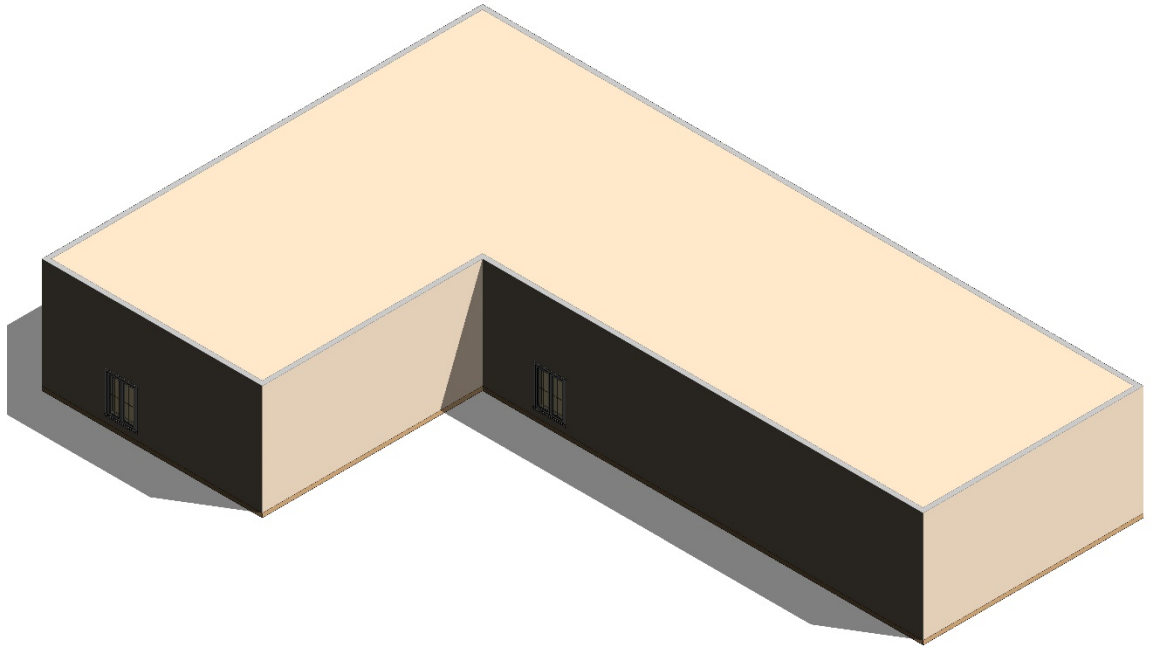
05

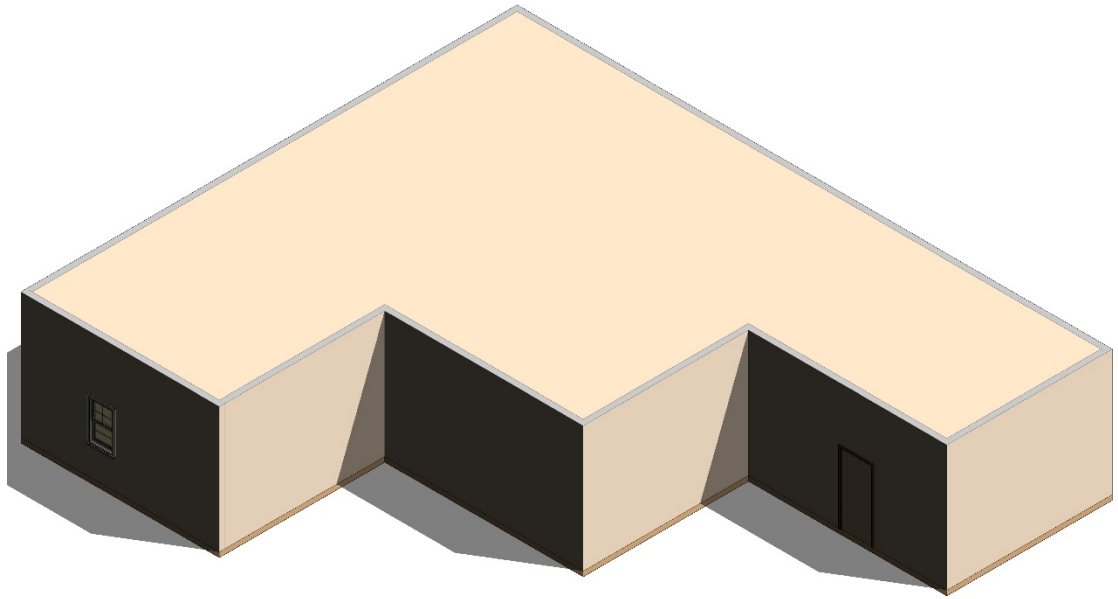
Validation

Case Study 1 - Dimensions

Variants	Ag (m²)	Total wall area (m²)
Tiny house	15.04	75.08
Variant 1	242.44	329.16
Variant 2	168.83	258.01

Variants	GH (kWh/m²)	Uniec 3 (kWh/m²)	Difference
Tiny house	171.19	176.53	-3.02%
Variant 1	68.95	68.17	1.14%
Variant 2	66.27	67.82	-2.29%





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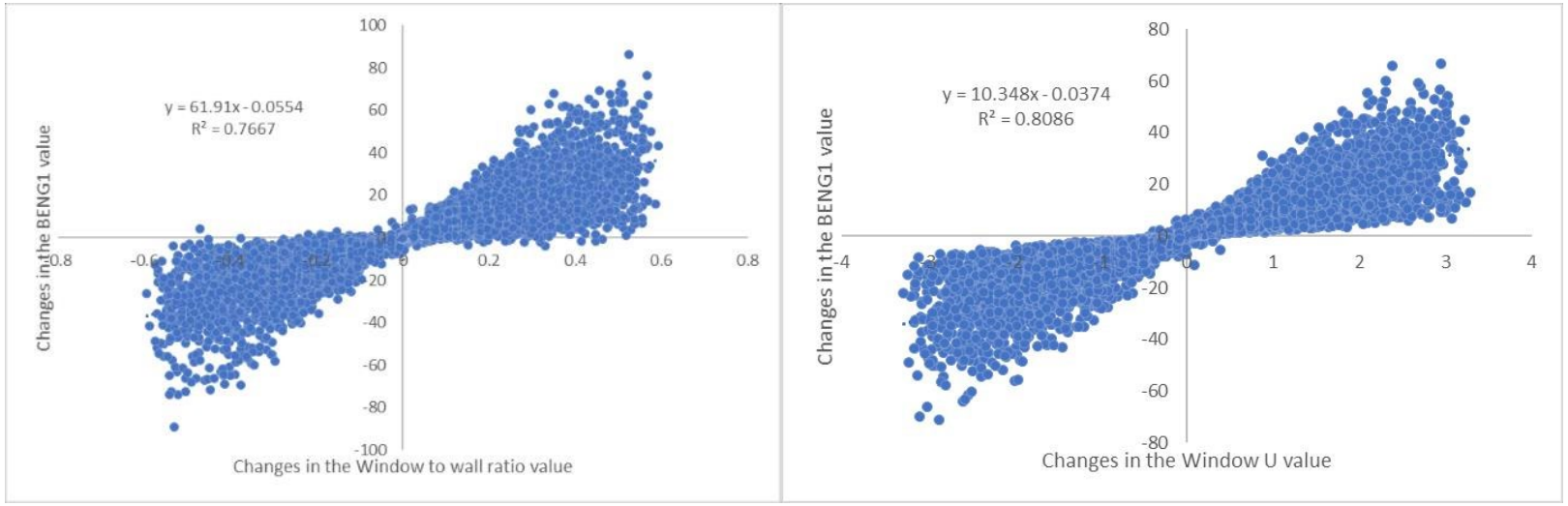
Case Study 2 – Physical Properties



Changes in the BENG1 value from changes in the value of Als/Ag (left) and window to wall ratio (right). (Kafaei 2021)

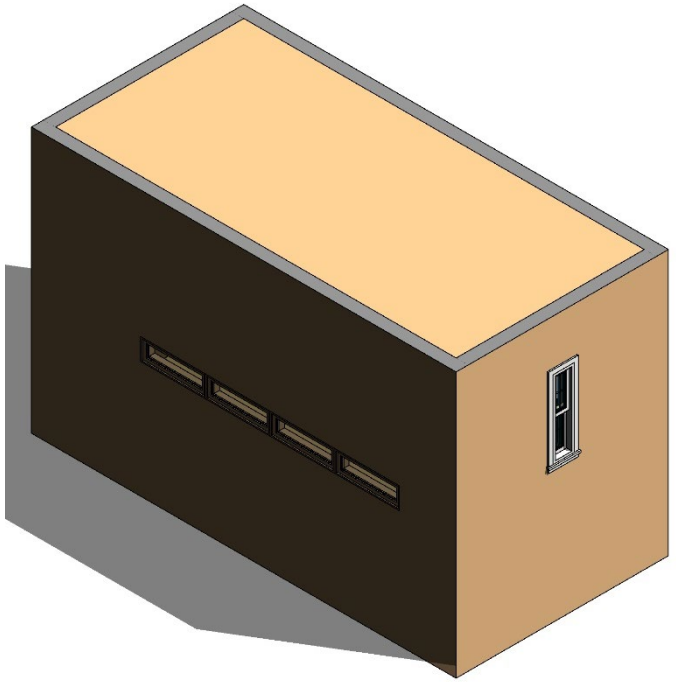
Case Study 2 – Physical Properties

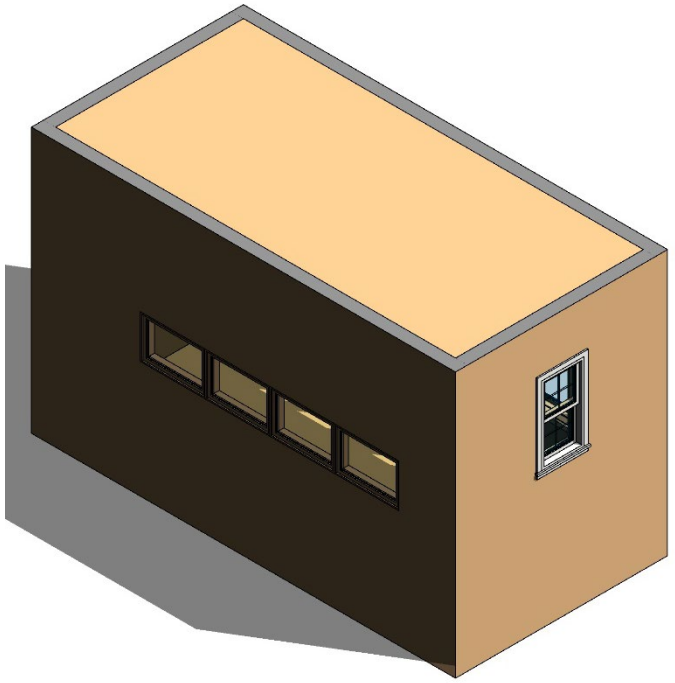
Ewe (kWh/m^2)	Developed tool	Uniec 3	Difference	Notes
Tiny house	171.19	176.53	-3.02%	
Variant 3	134.20	127.20	5.50%	Window size / 2
Variant 4	153.03	159.80	-4.20%	Window U / 2

Als/Ag	BENG 1 Eis [kWh/m²]
≤ 1,83	≤ 65
≤ 3	≤ 55 + 30 * (Als/Ag - 1,5)
> 3	≤ 100 + 30 * (Als/Ag - 3,0)

https://zoek.officielebekendmakingen.nl/stb-2019-501.html

Als/Ag = 6.02
BENG 1 = 100 + 30 * (6.02 – 3) = 190.6





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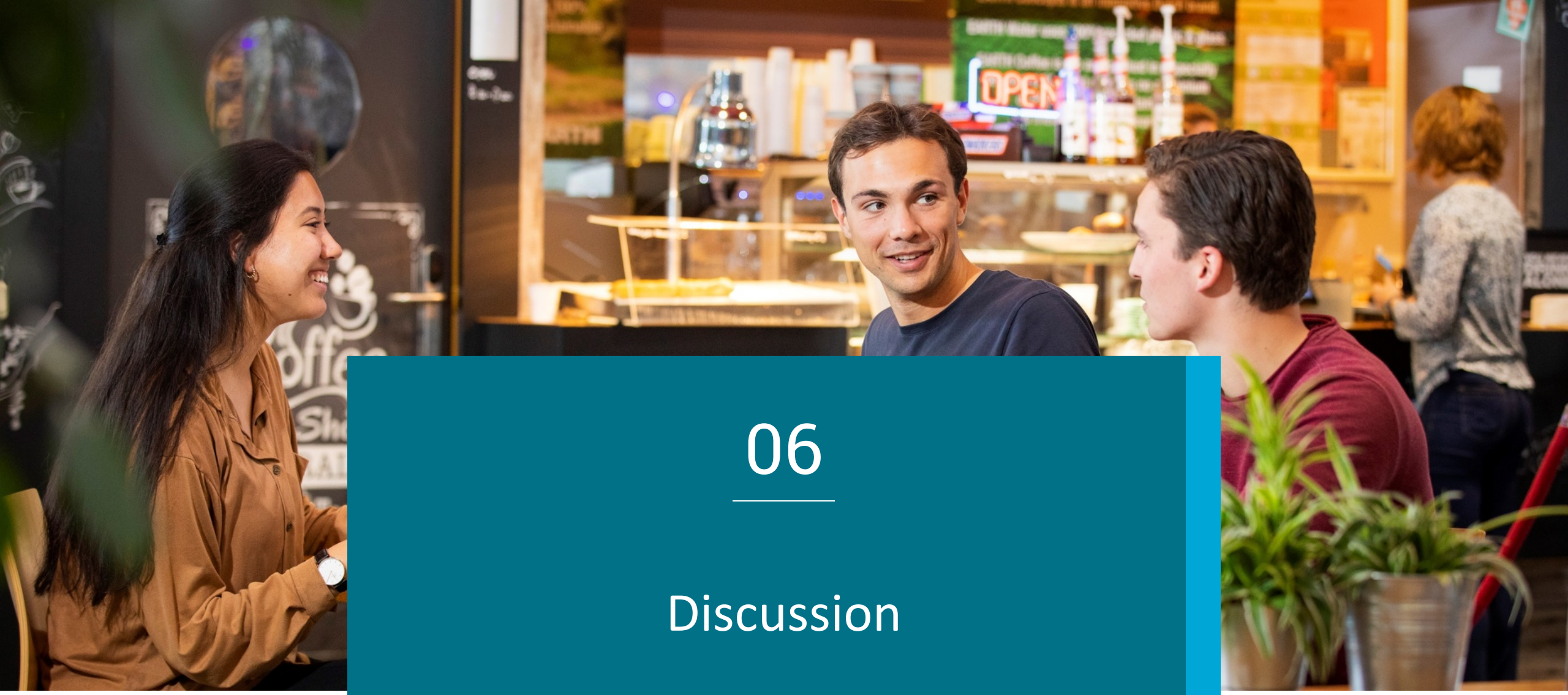


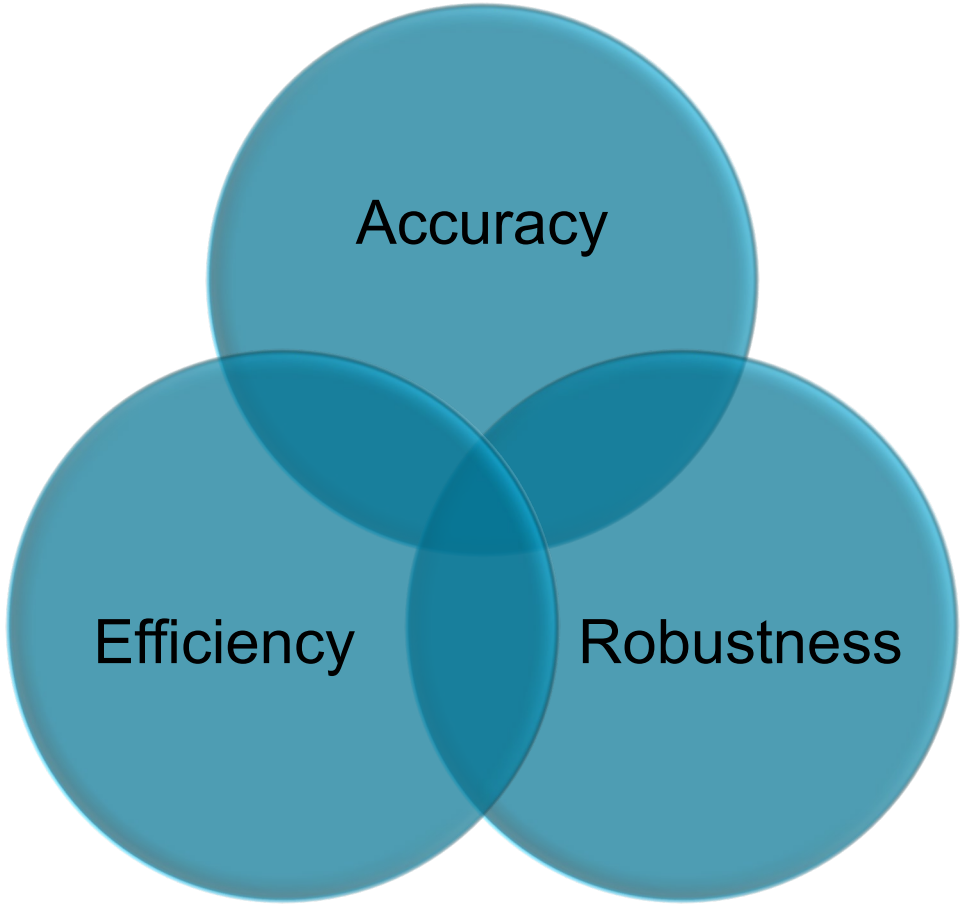
06

Discussion

Discussion

'How can energy performance be assessed in a very early design stage based on a preliminary BIM model while modifications to the design can be made on-the--fly?'

- Results of case studies
- Framework limitations
- Significance



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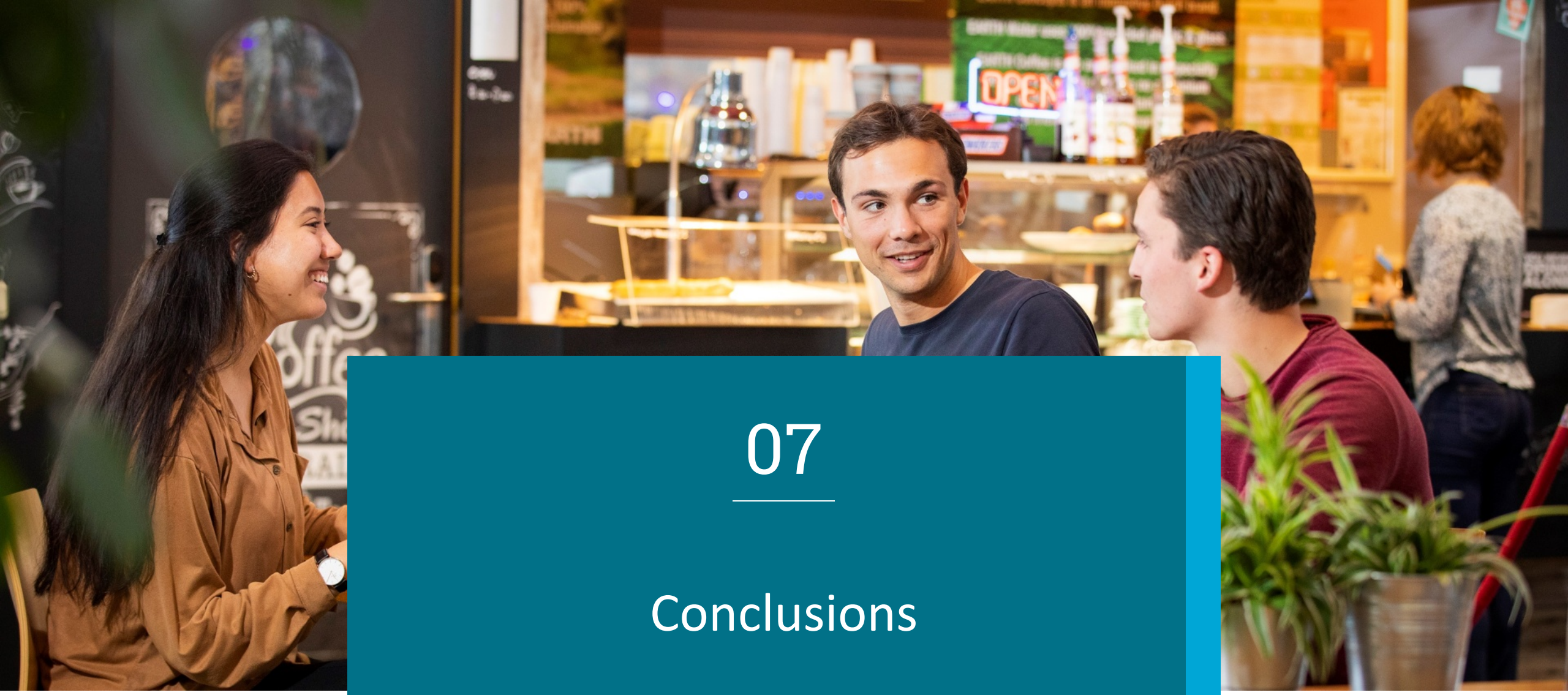

07

Conclusions

Conclusions

BIM-API-Grasshopper framework

The framework improves the efficiency of energy design by making the energy assessment on-the-fly.

Demonstration tool

The developed GH script produces meaningful results for energy assessment in early design stage, despite the slight difference due to simplification.

Practical applications

The framework may be applied to assist architects in the early design stage for energy efficiency optimization.

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Recommendations

Recommendations

- Research on the development of the automation of energy optimization in the late stage.
- Comparison research on different energy calculation norms and methods using on-the-fly assessment tool.
- Research on developing interoperable software in different specializations, e.g., structural, lighting.

Thank you for your attention

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