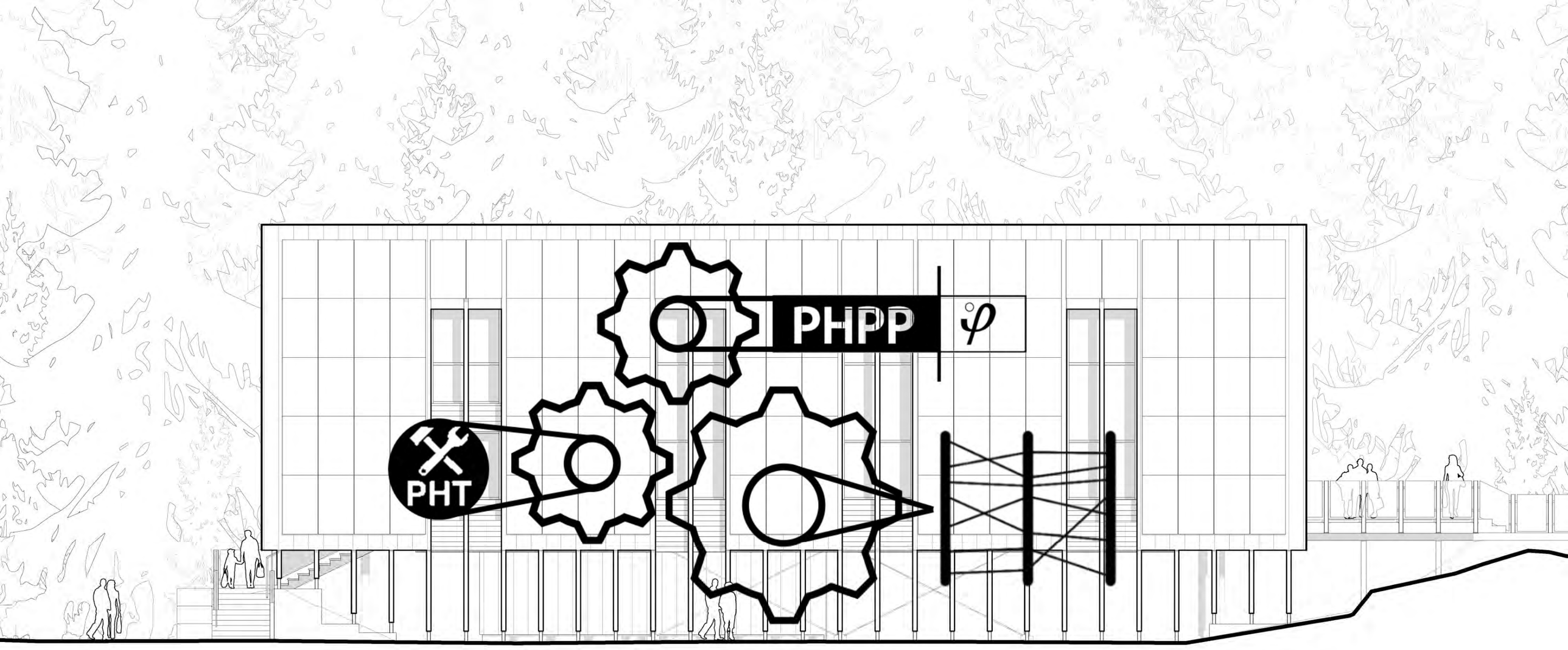



# COMPUTATIONAL DESIGN FOR PASSIVE HOUSE PROJECTS

Cheney Chen & Cillian Collins

**Perkins&Will**

# SUMMARY

This research aims to integrate the Passive House Planning Package (PHPP), a sophisticated tool used for Passive House certification into Perkins & Will's framework of Design Space Construction (DSC). This harnesses the benefits of both approaches, the deep energy efficiency measures embedded in the Passive House methodology and the power of the optimization processes within the computational design framework with the new analysis engine, whilst also streamlining the process by keeping the workflow with our typical Revit/Rhino environment.


*Integrating PHPP engine into the framework of Design Space Construction*

# RELEVANCE

## Our Commitment:

The building sector is responsible for 39% of process-related greenhouse gas emissions globally, making net- or nearly-zero energy buildings pivotal for reaching climate neutrality.

Perkins&Will is committed to reducing its carbon footprint, both through the company's operations[1] and the buildings and developments we design and build[2].

# RELEVANCE

## Our Projects:

The Vancouver studio has a number of Passive House projects underway. These projects all require energy modelling via the Passive House Planning Package (PHPP) as part of their pathway to certification.

PRESS RELEASES 03.10.2021

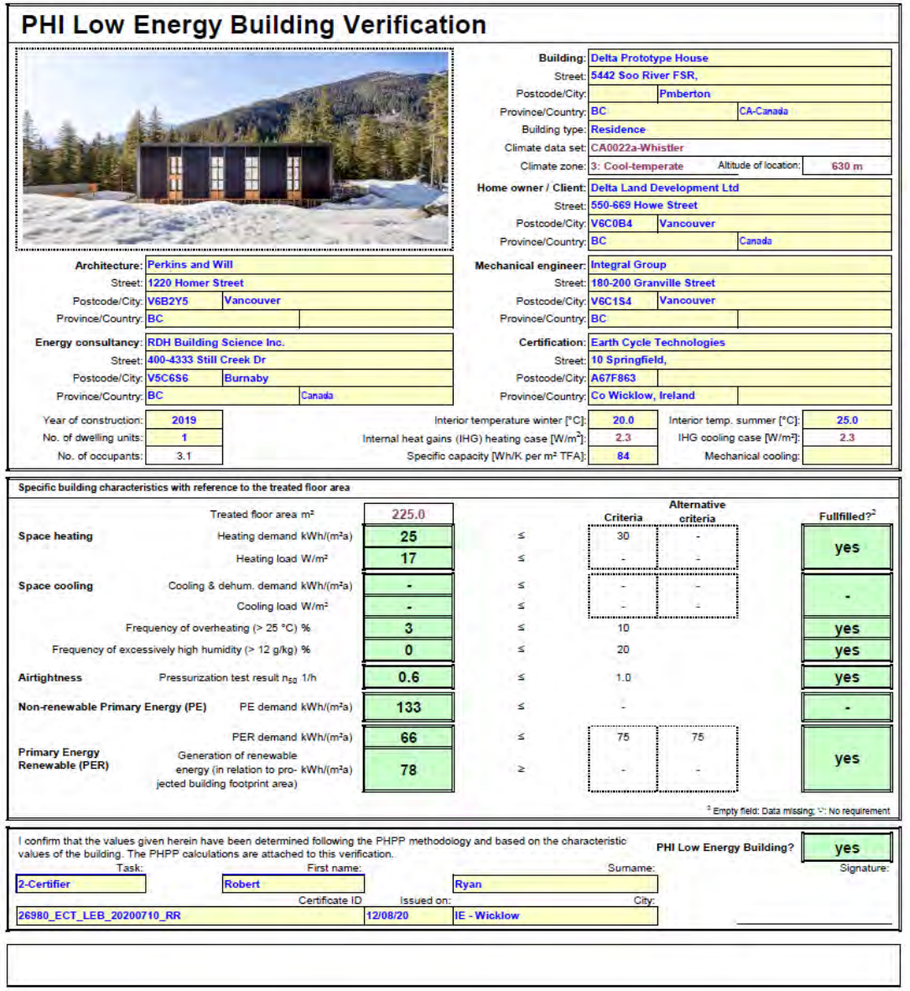
**University of Victoria's New Student Housing and Dining Buildings Set Passive House Precedent**

Designed by Perkins&Will, the university mixed-use complex raises the bar for high performance

# PASSIVE HOUSE PLANNING PACKAGE

The Passive House Planning Package (PHPP) is a design, verification and certification tool developed by the Passive House Institute. It is a is a series of interlinked worksheets in Excel built up to create a complete building model to determine the energy performance of both the whole building and its individual elements.

Careful yet tedious data input is necessary to ensure accurate results. As a static energy model, it is an excel spreadsheet requiring manual input. It makes PHPP modeling a cumbersome process in real design practice, especially for larger buildings. But being excel based there is opportunity for optimization.



**PHI Low Energy Building Verification**



| | | | | | |
|---|---|---|---|---|---|
| Building: | Delta Prototype House | | | | |
| Street: | 5442 Soo River FSR, | | | | |
| Postcode/City: | | Pmberton | | | |
| Province/Country: | BC | | CA-Canada | | |
| Building type: | Residence | | | | |
| Climate data set: | CA0022a-Whistler | | | | |
| Climate zone: | 3: Cool-temperate | | Altitude of location: | 630 m | |
| Home owner / Client: | Delta Land Development Ltd | | | | |
| Street: | 550-669 Howe Street | | | | |
| Postcode/City: | V6C0B4 | Vancouver | | | |
| Province/Country: | BC | | Canada | | |
| Architecture: | Perkins and Will | | | | |
| Street: | 1220 Homer Street | | | | |
| Postcode/City: | V6B2Y5 | Vancouver | | | |
| Province/Country: | BC | | | | |
| Mechanical engineer: | Integral Group | | | | |
| Street: | 180-200 Granville Street | | | | |
| Postcode/City: | V6C1S4 | Vancouver | | | |
| Province/Country: | BC | | | | |
| Energy consultancy: | RDH Building Science Inc. | | | | |
| Street: | 400-4333 Still Creek Dr | | | | |
| Postcode/City: | V5C6S6 | Burnaby | | | |
| Province/Country: | BC | | Canada | | |
| Certification: | Earth Cycle Technologies | | | | |
| Street: | 10 Springfield, | | | | |
| Postcode/City: | A67F863 | | | | |
| Province/Country: | Co Wicklow, Ireland | | | | |
| Year of construction: | 2019 | | Interior temperature winter [°C]: | 20.0 | Interior temp. summer [°C]: 25.0 |
| No. of dwelling units: | 1 | | Internal heat gains (IHG) heating case [W/m²]: | 2.3 | IHG cooling case [W/m²]: 2.3 |
| No. of occupants: | 3.1 | | Specific capacity [Wh/K per m² TFA]: | 84 | Mechanical cooling: |

Specific building characteristics with reference to the treated floor area

| | | | | Criteria | Alternative criteria | Fullfilled?[2] |
|---|---|---|---|---|---|---|
| | Treated floor area m² | 225.0 | | | | |
| Space heating | Heating demand kWh/(m²a) | 25 | ≤ | 30 | - | yes |
| | Heating load W/m² | 17 | ≤ | - | - | |
| Space cooling | Cooling & dehum. demand kWh/(m²a) | - | ≤ | - | - | - |
| | Cooling load W/m² | - | ≤ | - | - | |
| | Frequency of overheating (> 25 °C) % | 3 | ≤ | 10 | | yes |
| | Frequency of excessively high humidity (> 12 g/kg) % | 0 | ≤ | 20 | | yes |
| Airtightness | Pressurization test result $n_{50}$ 1/h | 0.6 | ≤ | 1.0 | | yes |
| Non-renewable Primary Energy (PE) | PE demand kWh/(m²a) | 133 | ≤ | - | | - |
| Primary Energy Renewable (PER) | PER demand kWh/(m²a) | 66 | ≤ | 75 | 75 | yes |
| | Generation of renewable energy (in relation to projected building footprint area) kWh/(m²a) | 78 | ≥ | - | - | |

[2] Empty field: Data missing; "-": No requirement

I confirm that the values given herein have been determined following the PHPP methodology and based on the characteristic values of the building. The PHPP calculations are attached to this verification.

PHI Low Energy Building? yes

| Task: | First name: | Surname: | Signature: |
|---|---|---|---|
| 2-Certifier | Robert | Ryan | |

| Certificate ID | Issued on: | City: |
|---|---|---|
| 26980_ECT_LEB_20200710_RR | 12/08/20 | IE - Wicklow |

# RELEVANCE

## Our Process:

In our active PH projects, there are two alternative processes

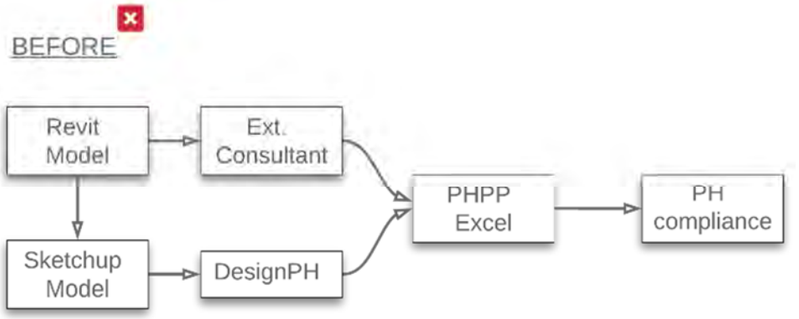
A. In House via direct input to PHPP or through a SketchUp plugin called designPH. This happens outside the Revit/Rhino environment therefore does not offer spontaneous integration of design and performance decision making.

example: SoLo, Bellevue

B. Outsourcing PHPP modeling to an External consultant. This entails not only additional consulting fee but a substantial coordination/translation effort between the Revit design (architect) and PHPP model (energy modeler/consultant

example: University of Victoria Student Housing

2204 Bellevue Ave



# RELEVANCE

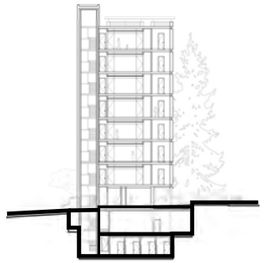
## Our Projects:

As projects grow in size and complexity the need arises for a flexible framework to:

- Facilitate Information transfer from Revit/Rhino to PHPP
- Allow optimization of design parameters

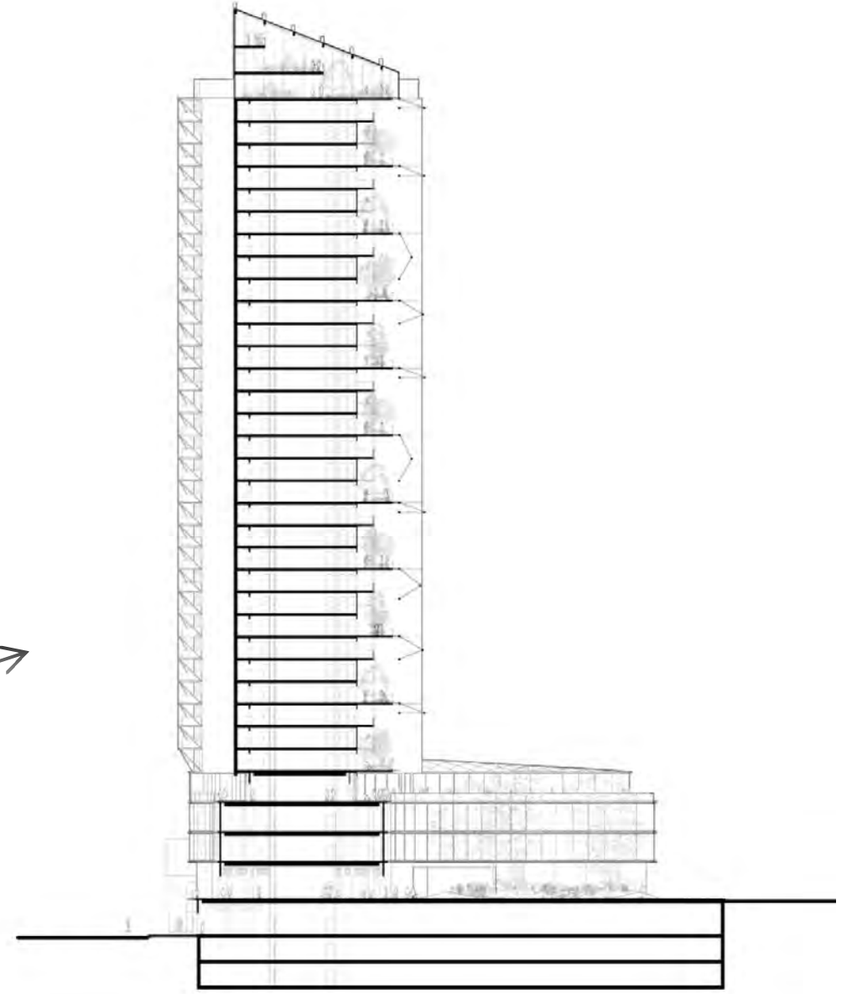
S

**SoLo**
**2 storey Single Family Home**
**Completed**



M

**2204 Bellevue**
**8 storey Multifamily**
**Development Permit**



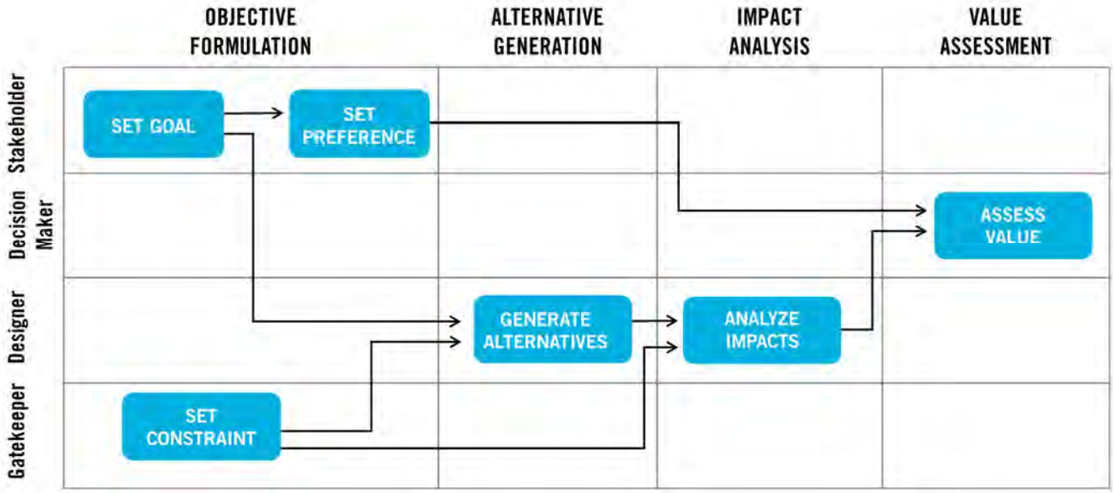
L

**Canada's Earth Tower**
**30-35 storey Mixed-used Development**
**Schematic Design**

# RELEVANCE

## Our Research Framework:

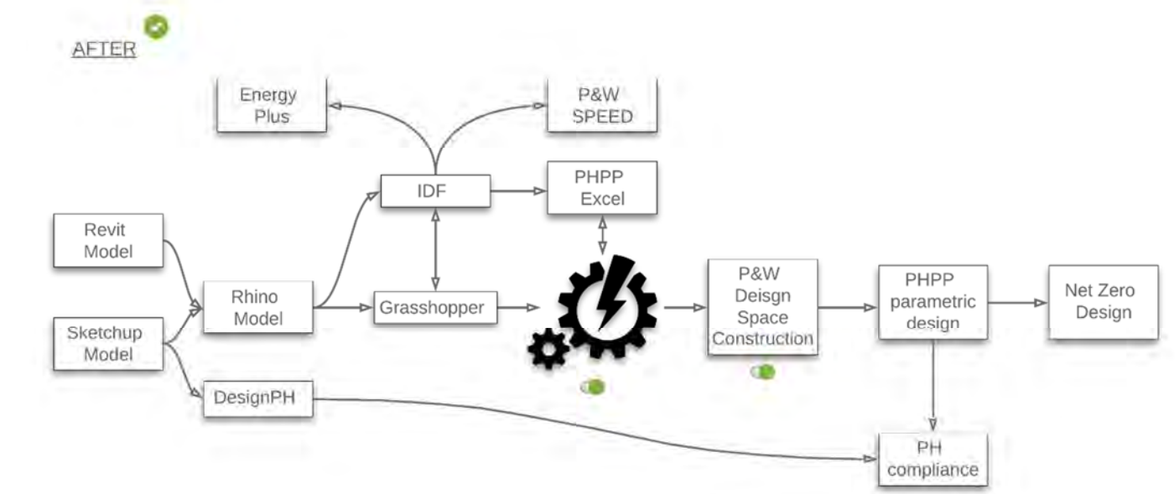
Perkins&Will research team has developed a framework to assist design teams known as Design Space Construction. This leverages the power of computational design to allow designers to review and weigh up the impact of interlocking design parameters on (often competing) performance metrics e.g. energy, daylighting, cost, views etc.

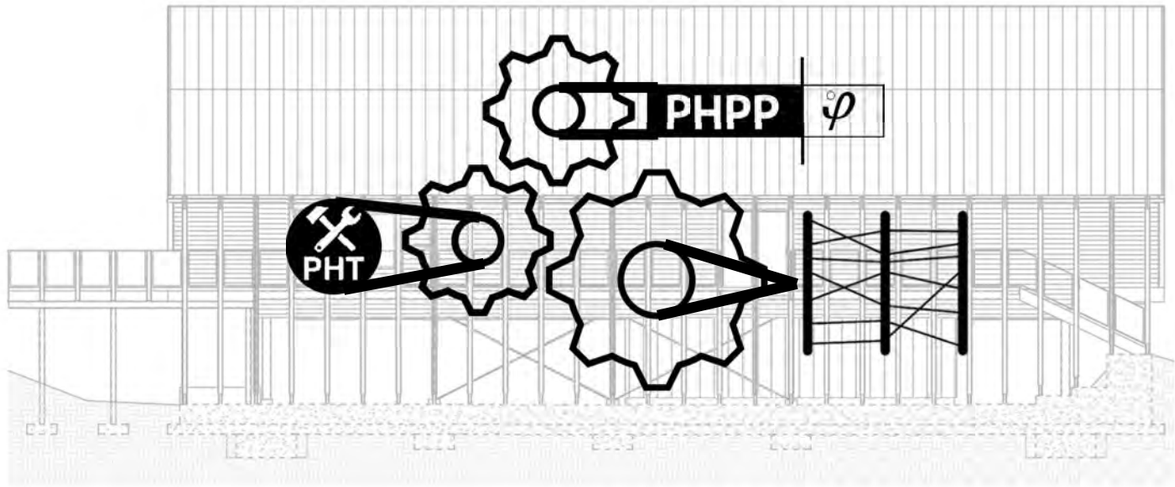



# RESEARCH GOAL

This research aims to fully integrate PHPP as a calculation engine in a computational design framework. The aim is to generate rapid feedback, validate design decisions, highlight problem areas, identify most significant design parameters, and undertake sensitivity analysis throughout the design process.

We use SoLo as a Case Study



# RESEARCH GOAL

It's Fast

It's Early

It's Comprehensive

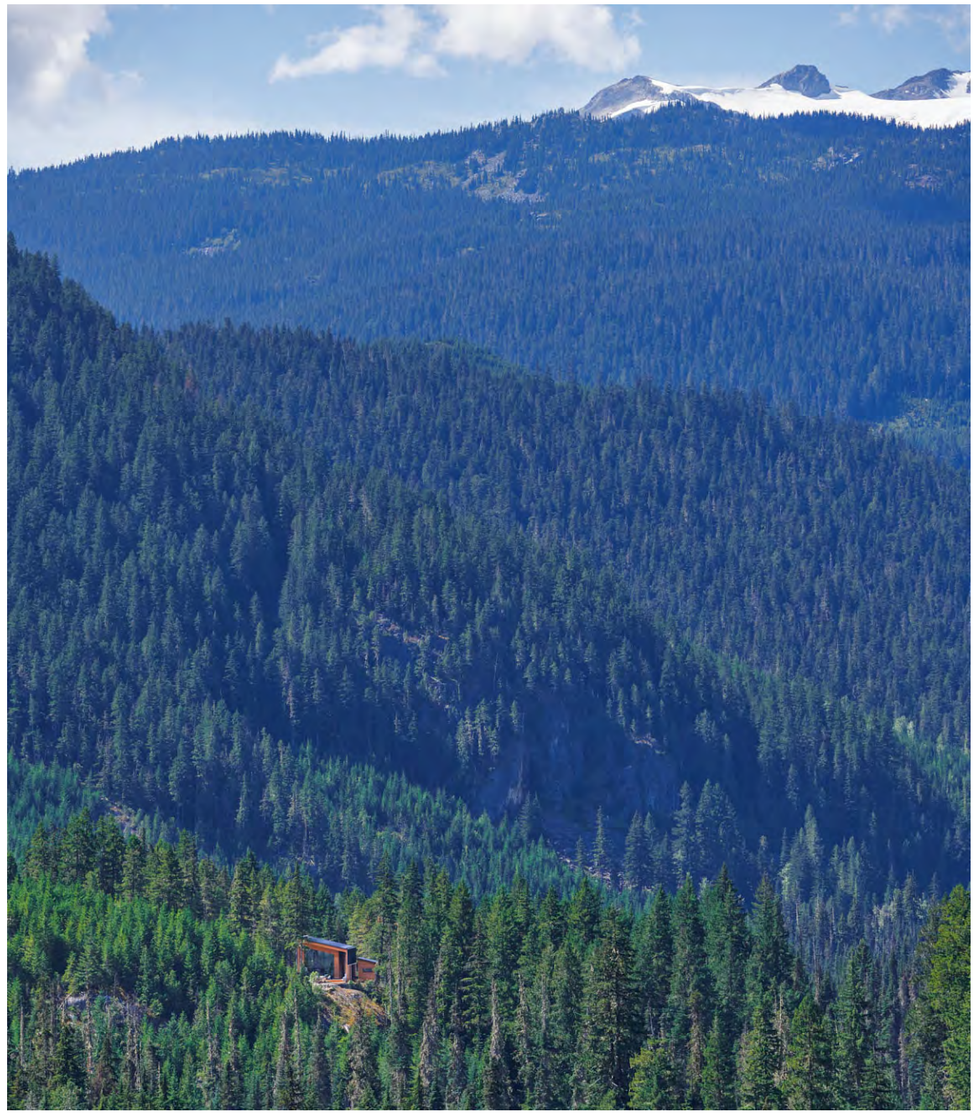
It's Passive House

# SoLo – Our Case Study

# PASSIVE HOUSE CERTIFICATION

SoLo is an off-grid mass timber house in a remote area of British Columbia's Coast Mountains. It earned Passive House certification, becoming the first Passive House certified building designed by Perkins&Will[3].

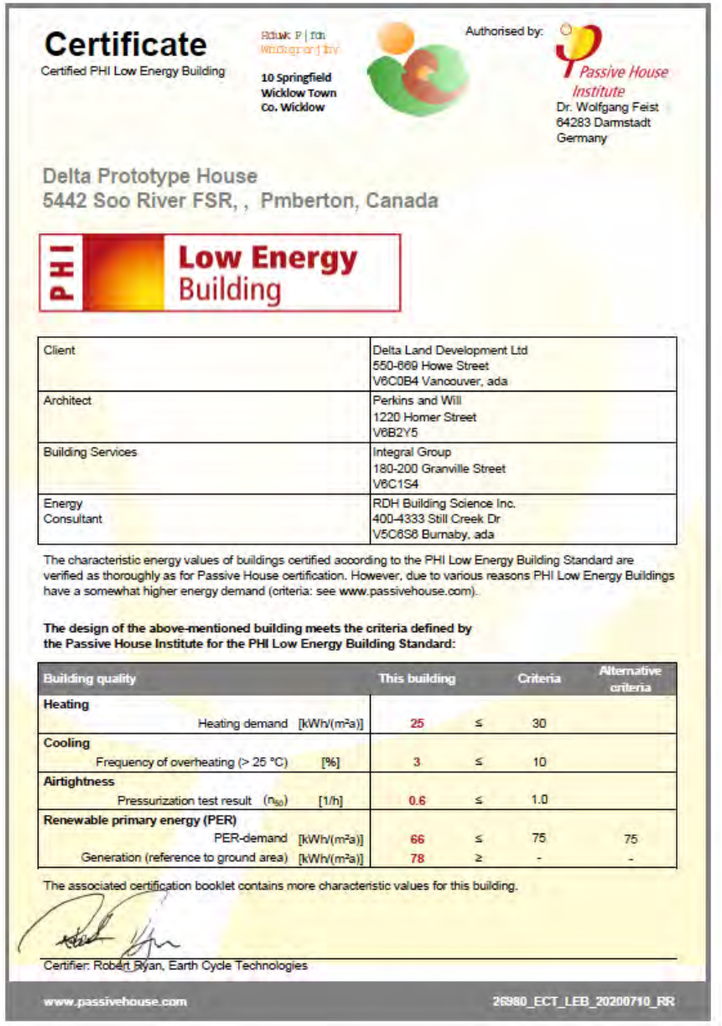
The Certified Passive House Designer scope and associated PHPP energy modelling was kept in-house



# PASSIVE HOUSE CERTIFICATION

The project fell short of achieving the 15kWh/m²a Space Heating Demand target for full Passive House Certification, instead achieving PHI Low Energy Building certification (heating demand less than 30kWh/m²a ), still exceeding the highest level of the BC Energy Step Code.

Whilst the project were deemed a success questions remained on if it was possible to achieve the full certification performance levels. Had the lower space heating demand been met, Passive House Plus certification could have been achieved due to the amount of PV generation.



**Certificate**
Certified PHI Low Energy Building

10 Springfield
Wicklow Town
Co. Wicklow

Authorised by:
Passive House Institute
Dr. Wolfgang Feist
64283 Darmstadt
Germany

Delta Prototype House
5442 Soo River FSR, , Pmberton, Canada

PHI Low Energy Building

| | |
|---|---|
| Client | Delta Land Development Ltd<br>550-669 Howe Street<br>V6C0B4 Vancouver, ada |
| Architect | Perkins and Will<br>1220 Homer Street<br>V6B2Y5 |
| Building Services | Integral Group<br>180-200 Granville Street<br>V6C1S4 |
| Energy Consultant | RDH Building Science Inc.<br>400-4333 Still Creek Dr<br>V5C6S6 Burnaby, ada |

The characteristic energy values of buildings certified according to the PHI Low Energy Building Standard are verified as thoroughly as for Passive House certification. However, due to various reasons PHI Low Energy Buildings have a somewhat higher energy demand (criteria: see www.passivehouse.com).

**The design of the above-mentioned building meets the criteria defined by the Passive House Institute for the PHI Low Energy Building Standard:**

| Building quality | | This building | | Criteria | Alternative criteria |
|---|---|---|---|---|---|
| **Heating** | | | | | |
| Heating demand | [kWh/(m²a)] | 25 | ≤ | 30 | |
| **Cooling** | | | | | |
| Frequency of overheating (> 25 °C) | [%] | 3 | ≤ | 10 | |
| **Airtightness** | | | | | |
| Pressurization test result ($n_{50}$) | [1/h] | 0.6 | ≤ | 1.0 | |
| **Renewable primary energy (PER)** | | | | | |
| PER-demand | [kWh/(m²a)] | 66 | ≤ | 75 | 75 |
| Generation (reference to ground area) | [kWh/(m²a)] | 78 | ≥ | - | - |

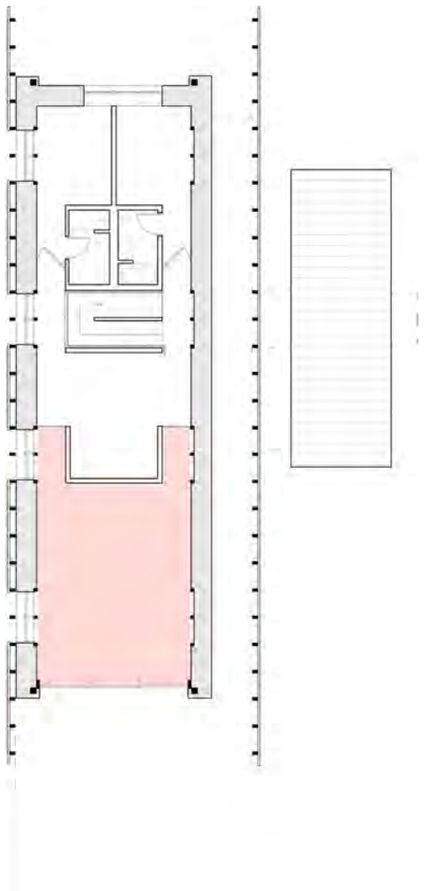
The associated certification booklet contains more characteristic values for this building.

Certifier: Robert Ryan, Earth Cycle Technologies

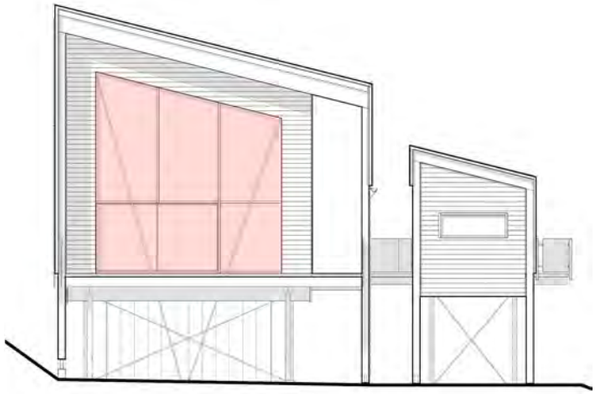
www.passivehouse.com 26980_ECT_LEB_20200710_RR

# PASSIVE HOUSE CERTIFICATION

A harsh climate (-30deg C in winter), site constraints (a mountain to the south blocking winter solar gains) and design decisions (double height space, north east glazing) made achieving 15kWh/m²a heating demand difficult.



**DOUBLE HEIGHT SPACE (50m²) – FORM FACTOR (4.3): ~3-4kWh/m²a**



**GLAZING (NE) – HEAT LOSS: ~2-3kWh/m²a**

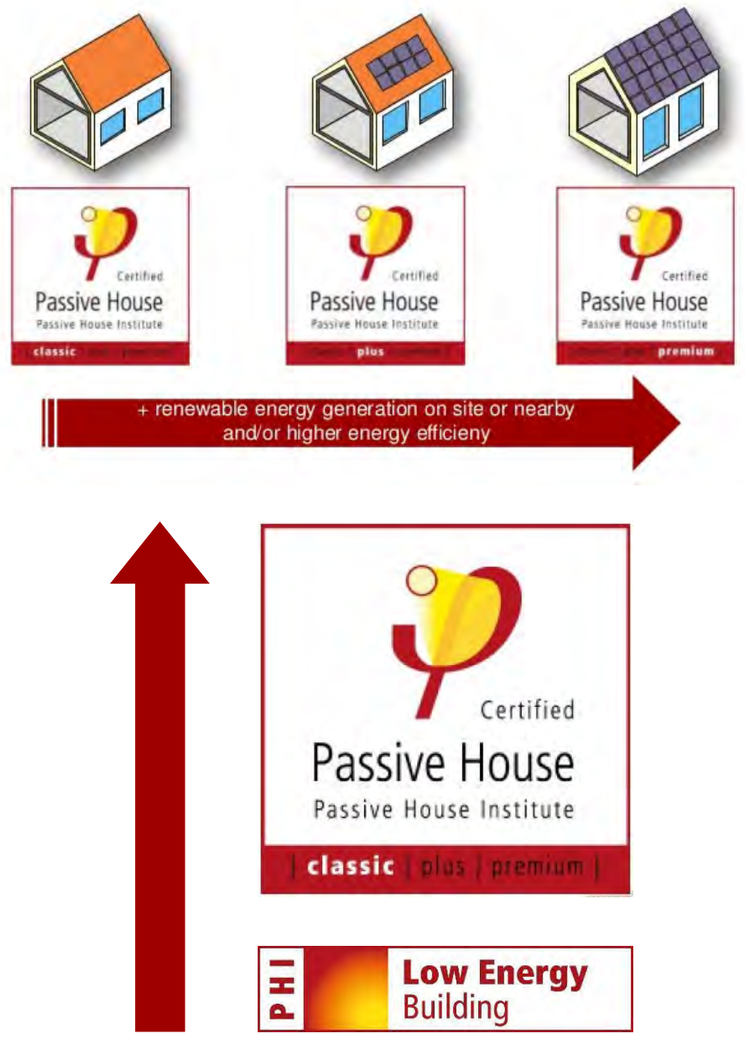
**MOUNTAIN - SOLAR GAINS: ~5-8kWh/m²a**

# PUSHING FOR CERTIFICATON (INTUITIVE)

The design team reviewed options intuitively to achieve the lower space heating demand number

- Fill in double height space
- Reduce/remove northeast glazing
- ‘wind protection coefficient’ (‘e’) - more sheltered
- Improved Glazing Specs (vacuum / g-values vs U-value)
- Lower Airtightness targets (0.3)
- Better window install detailing
- Aerogel wrap at pipework
- Allow for Intermittent occupancy – thermal shutter

This led to a number of questions that could be tested in a parametric design framework.



# QUESTION ONE

How big of a double height space can we have?

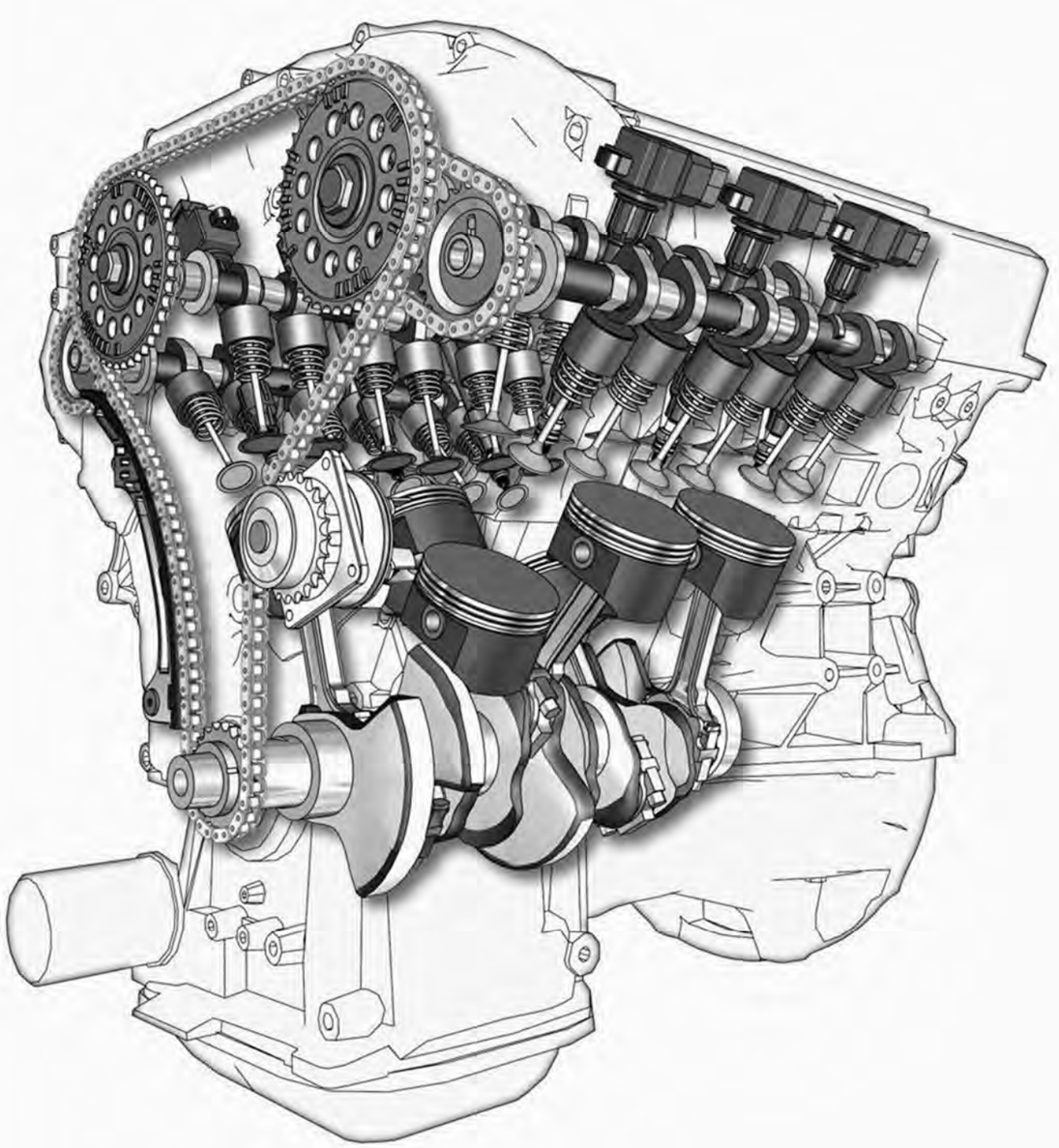
# QUESTION TWO

How much north-east glazing without impacting performance, views and daylighting?

# QUESTION THREE

What is the optimum amount of south facing glazing? Juggling heat loss, solar gain, PV sizing etc.

# SoLo – Computational Analysis



# COLLABRATION JOURNEY



**Oct 2019 International conference**
Brainstorm

**May 2020**
Prototype - IDF2PH

**Feb 2021**
Invitation for collaboration

**22 Feb 2021**
First collaboration meeting
- initial workflow discussion, challenges and opportunities
- tool bugs
- next step

**2 Mar 2021**
Release of LBT2PH beta

**9 Mar 2021**
Second collaboration meeting
- change the vehicle and new workflow development discussion
- tool bugs
- ready for testing in a real project

**25 Mar 2021**
Third collaboration meeting
- model calibration details
- cross platform comparisons
- limitations and future development opportunities

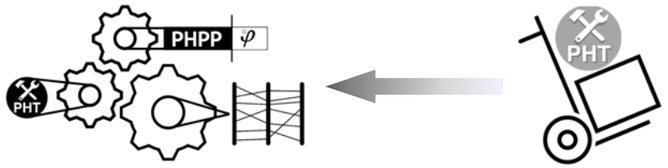
# LBT2PH TOOLKIT

The **LBT2PH** [4] toolkit is a collection of Rhino and Grasshopper items which allow user to control the Passive House Planning Package (PHPP) energy model from within Rhino.

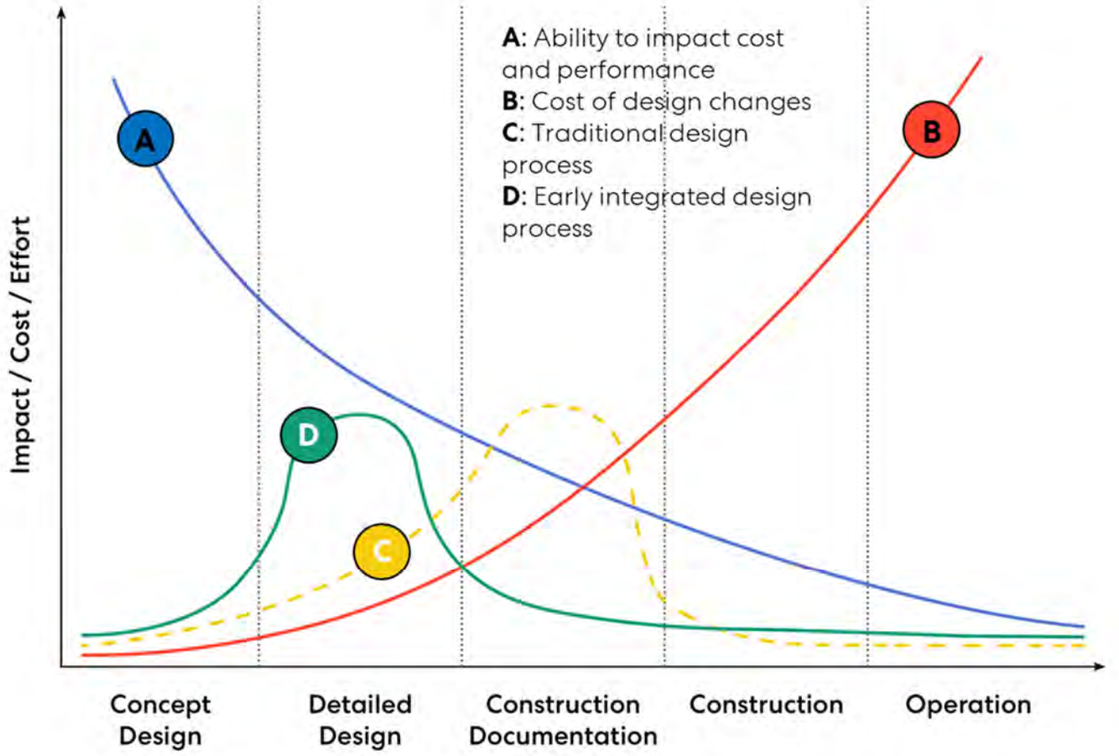
The toolkit fulfils our research objectives and requirements with the following limitations:

- It is not designed as an optimization tool
- Its application is dedicated for PHPP compliance at later design stage when most design variables have to be fixed
- It is an energy only calculation tool

# BEYOND LBT2PH



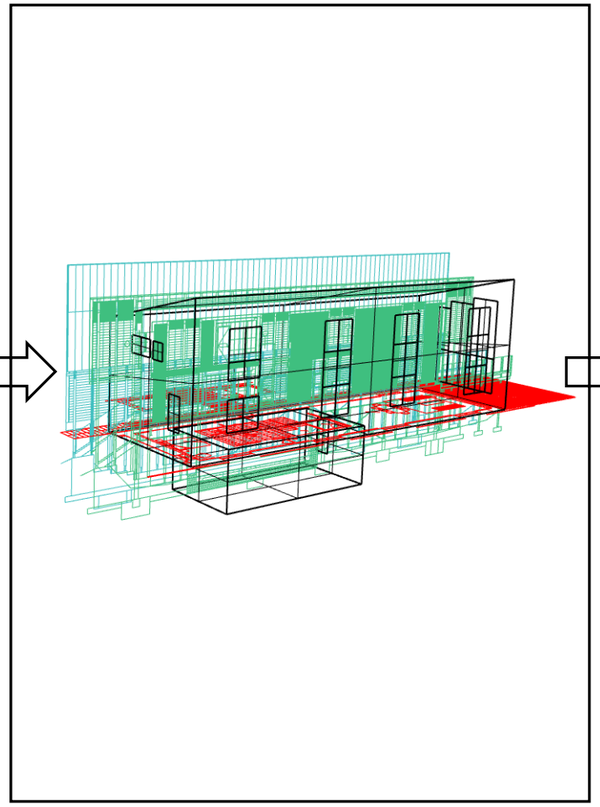

Although LBT2PH is core of the calculation engine, our research development does not simply stay within LBT2PH's original application scope. Instead, we integrate LBT2PH with other tools, convert it as fully parametric script in grasshopper and make early multi-task optimization possible.



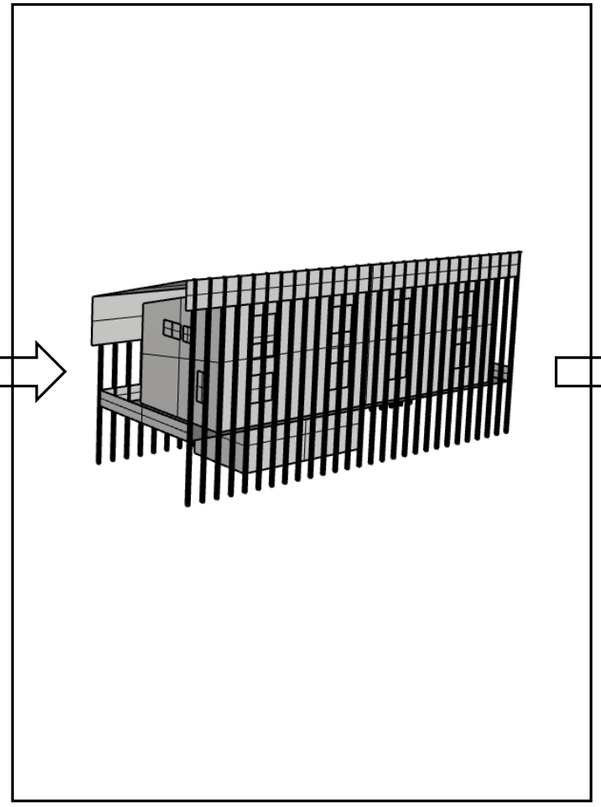
# DEGREES OF GRANULARITY

2D

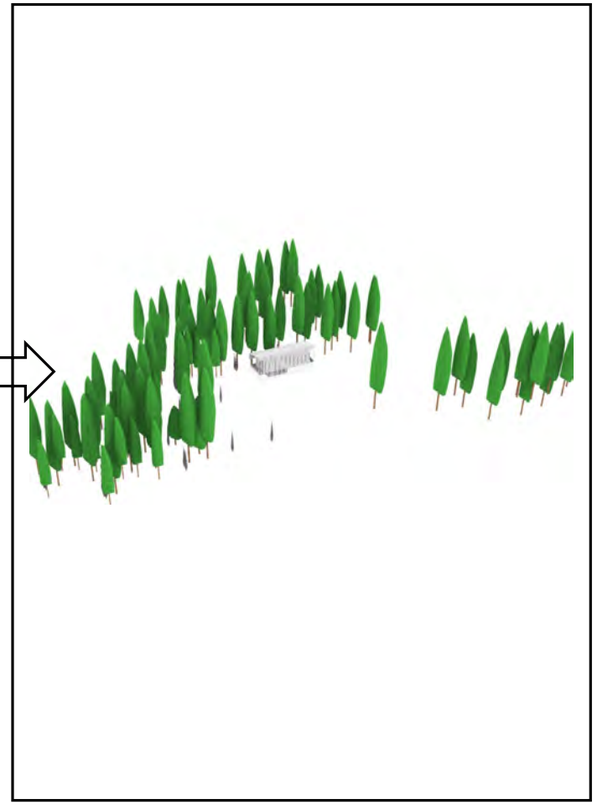
2D to 3D



3D + local shades

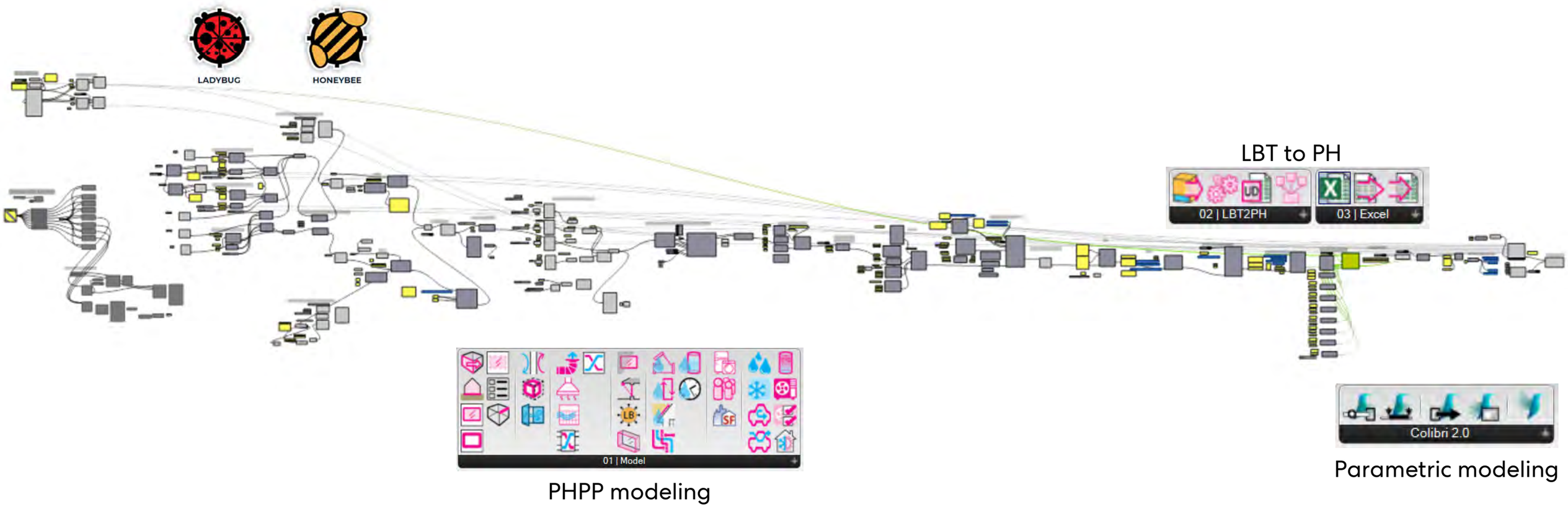


3D + local shades + context



# WORKFLOW

LBT modeling




PHPP modeling

Parametric modeling

# CALIBRATION

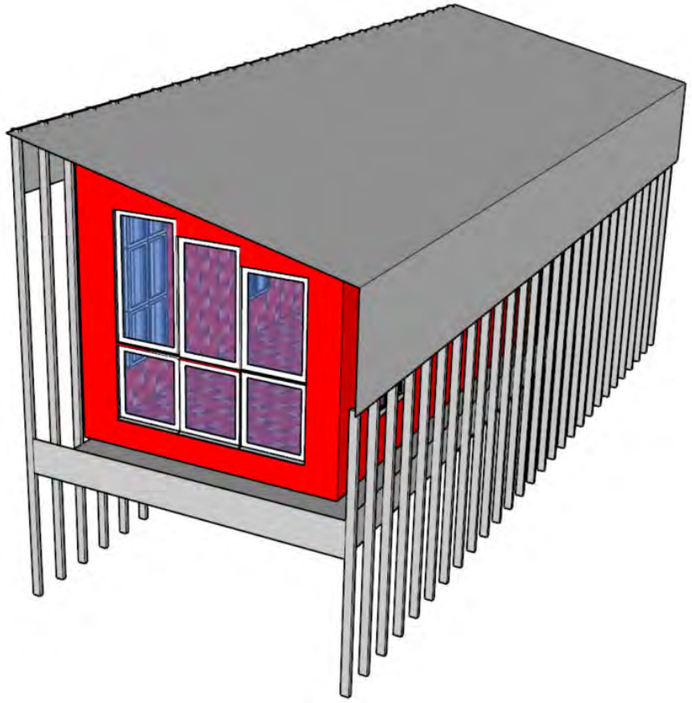
| Specific building characteristics with reference to the treated floor area | | | |
|---|---|---|---|
| | Treated floor area | m² | 225.0 |
| **Space heating** | Heating demand | kWh/(m²a) | 24 |
| | Heating load | W/m² | 16 |
| **Space cooling** | Cooling & dehum. demand | kWh/(m²a) | - |
| | Cooling load | W/m² | - |
| | Frequency of overheating (> 25 °C) | % | 3 |
| | Frequency of excessively high humidity (> 12 g/kg) | % | 0 |
| **Airtightness** | Pressurization test result $n_{50}$ | 1/h | 0.6 |
| **Non-renewable Primary Energy (PE)** | PE demand | kWh/(m²a) | 131 |
| **Primary Energy Renewable (PER)** | PER demand | kWh/(m²a) | 64 |
| | Generation of renewable energy (in relation to projected building footprint area) | kWh/(m²a) | 78 |

PHPP compliance model

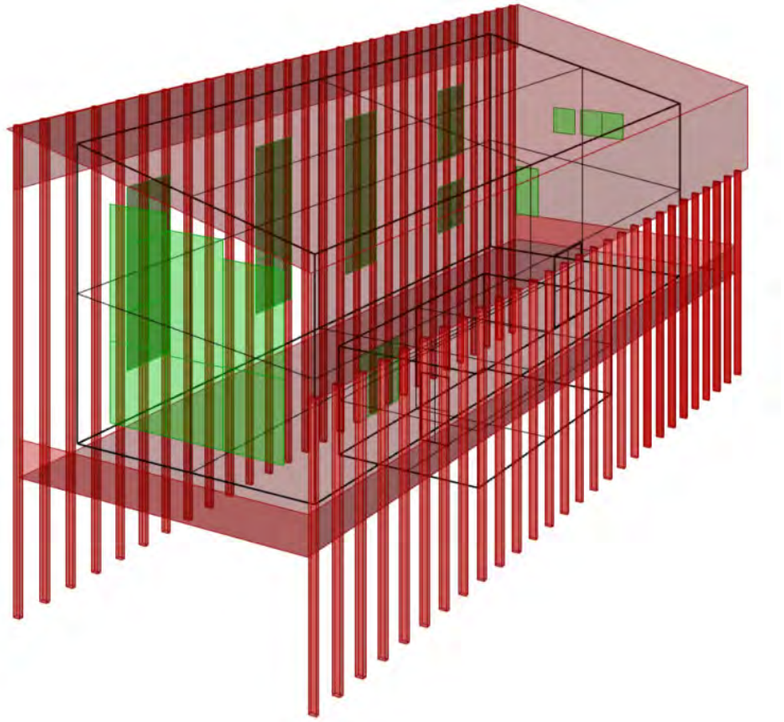
| Specific building characteristics with reference to the treated floor area | | | |
|---|---|---|---|
| | Treated floor area | m² | 225.0 |
| **Space heating** | Heating demand | kWh/(m²a) | 25 |
| | Heating load | W/m² | 17 |
| **Space cooling** | Cooling & dehum. demand | kWh/(m²a) | - |
| | Cooling load | W/m² | - |
| | Frequency of overheating (> 25 °C) | % | 11 |
| | Frequency of excessively high humidity (> 12 g/kg) | % | 0 |
| **Airtightness** | Pressurization test result $n_{50}$ | 1/h | 0.6 |
| **Non-renewable Primary Energy (PE)** | PE demand | kWh/(m²a) | 130 |
| **Primary Energy Renewable (PER)** | PER demand | kWh/(m²a) | 64 |
| | Generation of renewable energy (in relation to projected building footprint area) | kWh/(m²a) | 0 |

New engine model

# CALIBRATION

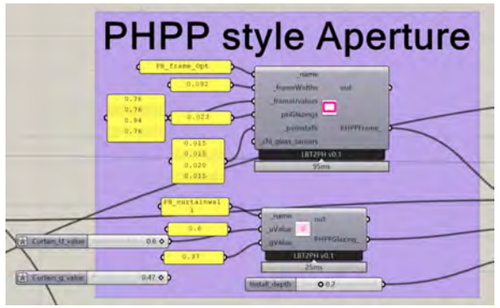


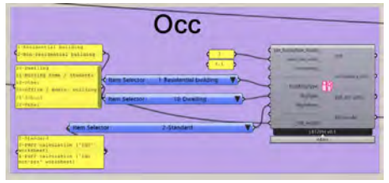
Design PH model

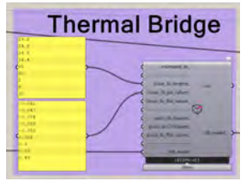


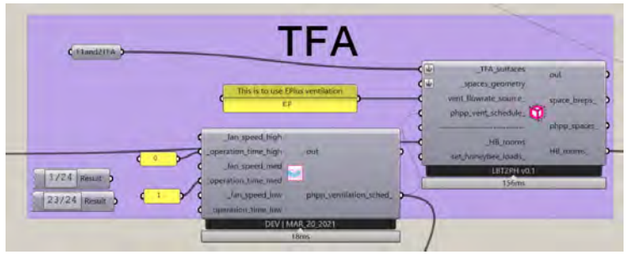
New engine model

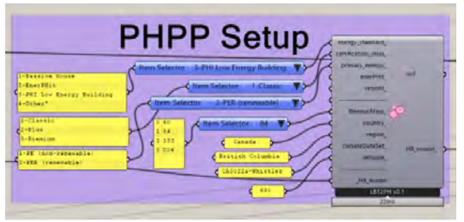
# CALIBRATION

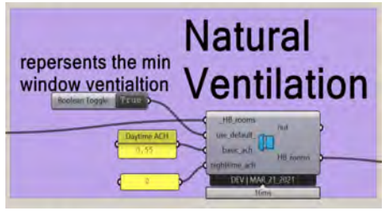


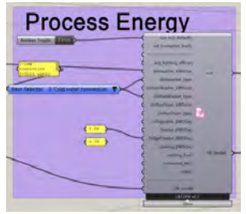



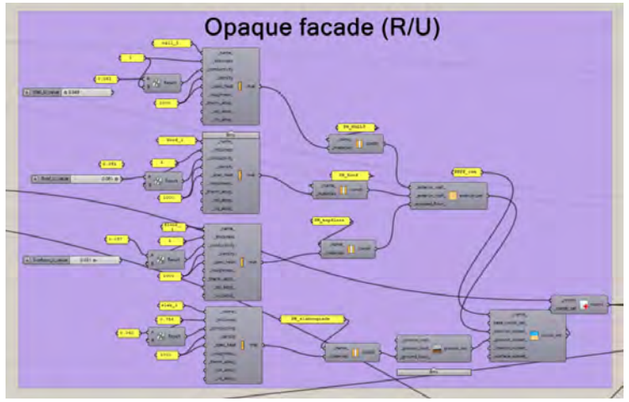



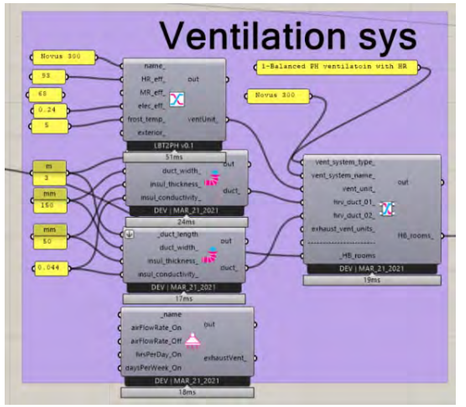



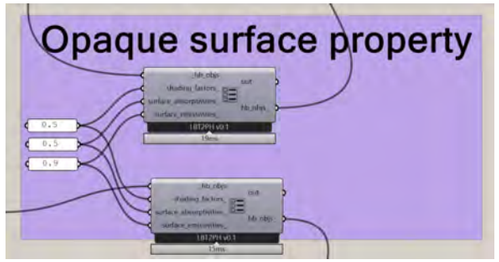



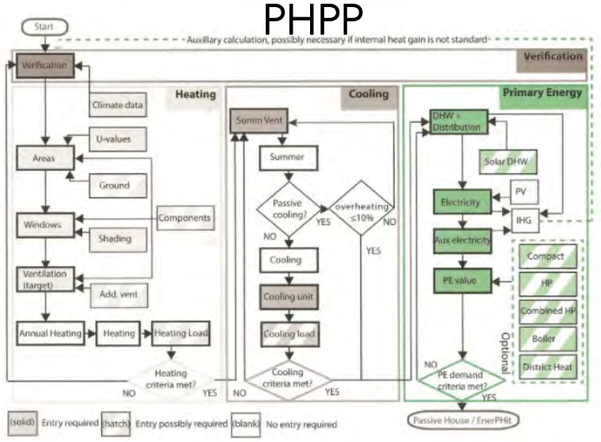



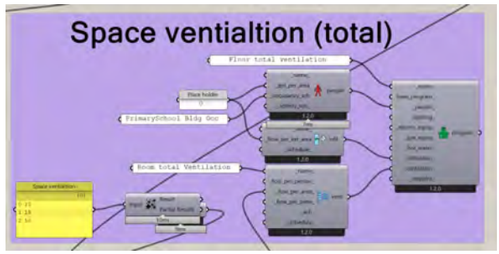



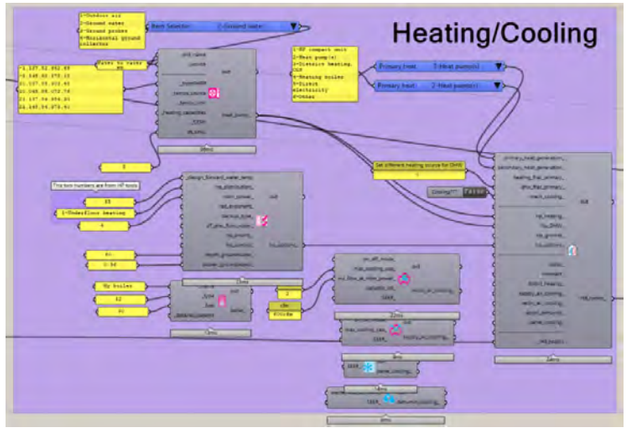



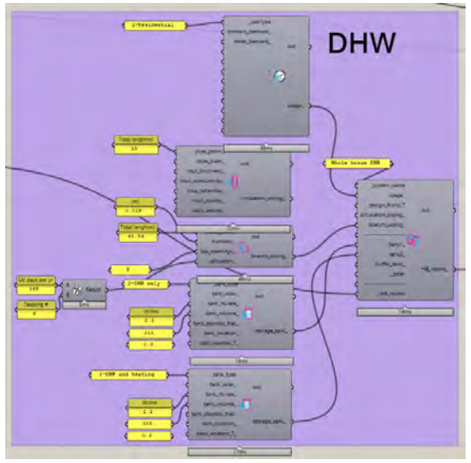




PHPP

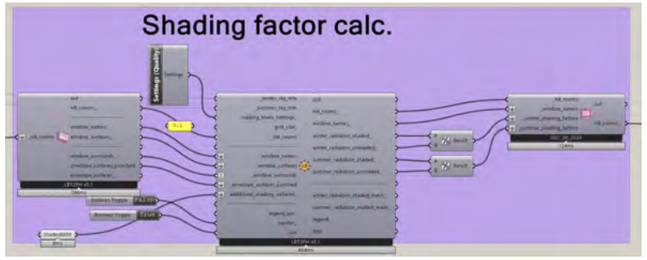






# OPTIMIZATION VARIABLES

Although the new engine is fast in speed, it is still important to reduce the size of total iterations. Originally, we thought 12 variables proposed to improve the design were able be executed together but it turns out to be a humongous size at 131 billions, which makes computational calculation impossible.

| Variables | Range | Iterations |
|---|---|---|
| South WWR | 20%/30%/40%/50%/60% | 5 |
| East WWR | 25%/35%/45%/55% | 4 |
| Uframe | 0%/5%/10%/15%/20% | 5 |
| Uglass | 0%/5%/10%/15%/20% | 5 |
| g value | 15%-/10%-/5%-/0%/5%/10%/15% | 7 |
| U wall | 0%/5%/10%/15%/20% | 5 |
| U roof | 0%/5%/10%/15%/20% | 5 |
| U exposed | 0%/5%/10%/15%/20% | 5 |
| U slab | 0%/5%/10%/15%/20% | 5 |
| Airtightness | 0.6/0.5/0.4/0.3 | 4 |
| Thermal bridging | 0%/5%/10%/15%/20% | 5 |
| TFA | 225/250/275 | 3 |
| | Total = | 131,250,000 |

# OPTIMIZATION VARIABLES

Multi – step optimization:

- It starts from building envelope assembly related variables first. Sensitivity study decides which variables would be retained to the next cycle;

- More building system related variables are added in the 2nd optimization;

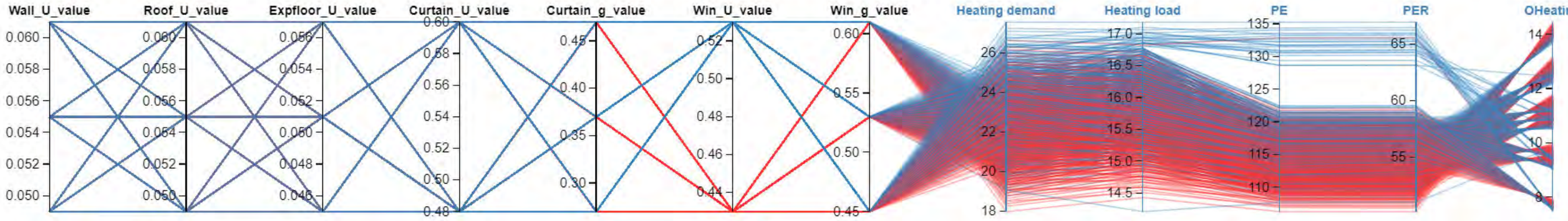
- Eventually building geometry related variables, such as window to wall ratio change, are added to complete the final optimization.

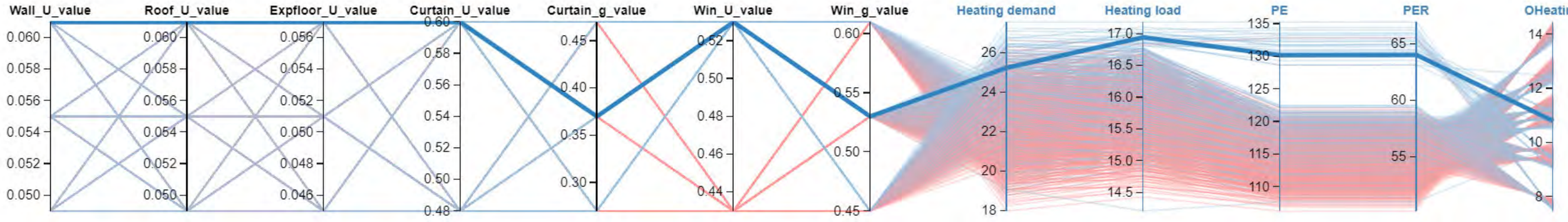
| Variables | Range | Iterations |
|---|---|---|
| U curtainglass | 0%/10%/20% | 2 |
| g curtainvalue | "-15%/0%/15%" | 3 |
| U win | 0%/10%/20% | 2 |
| g win | "-15%/0%/15%" | 3 |
| U wall | 0%/10%/20% | 3 |
| U roof | 0%/10%/20% | 3 |
| U exposed | 0%/10%/20% | 3 |
| | Total = | 972 |

| Variables | Range | Iterations |
|---|---|---|
| U curtainglass | 0%/10%/20% | 2 |
| g win | "-15%/0%/15%" | 3 |
| U roof | 0%/10%/20% | 3 |
| Airtightness | 0.6/0.3 | 2 |
| Thermal bridging | 0%/10%/20% | 3 |
| TFA | 225/275 | 2 |
| | Total = | 216 |

| Variables | Range | Iterations |
|---|---|---|
| South WWR | 20%/40%/60% | 3 |
| East WWR | 25%/40%/55% | 3 |
| U curtainglass | 0%/10%/20% | 2 |
| g win | "-15%/0%/15%" | 3 |
| U roof | 0%/10%/20% | 3 |
| Airtightness | 0.6/0.3 | 2 |
| TFA | 225/275 | 2 |
| | Total = | 648 |

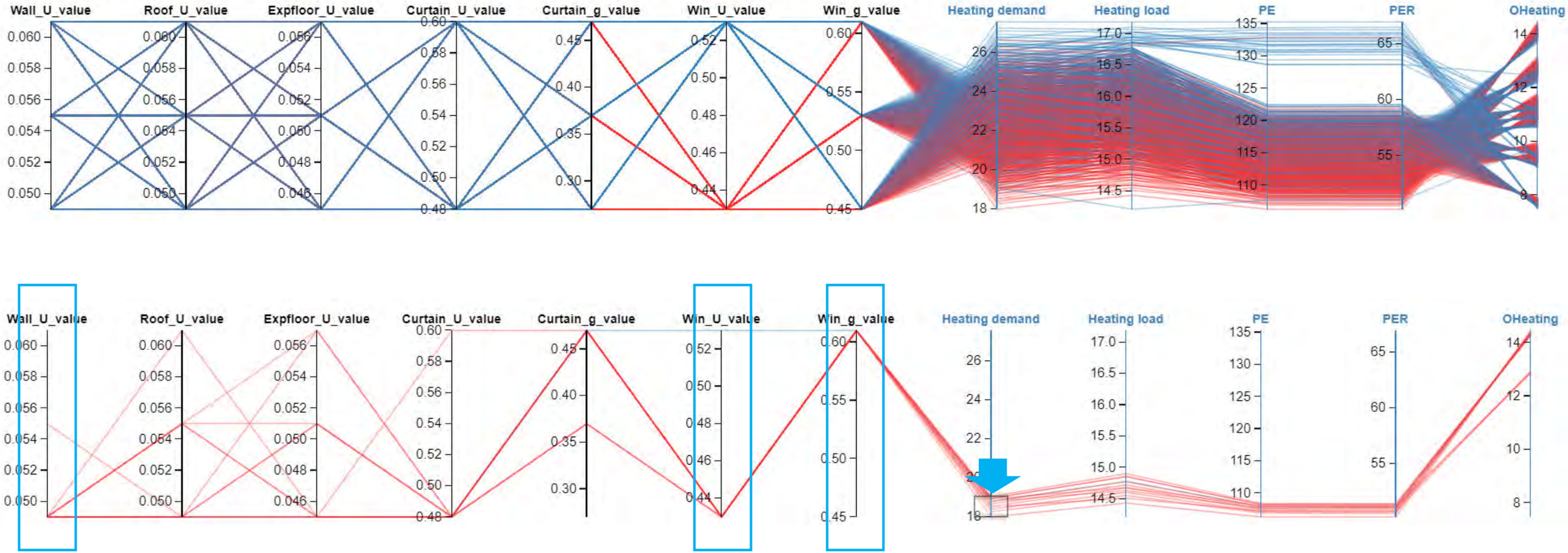
# OPTIMIZATION ONE



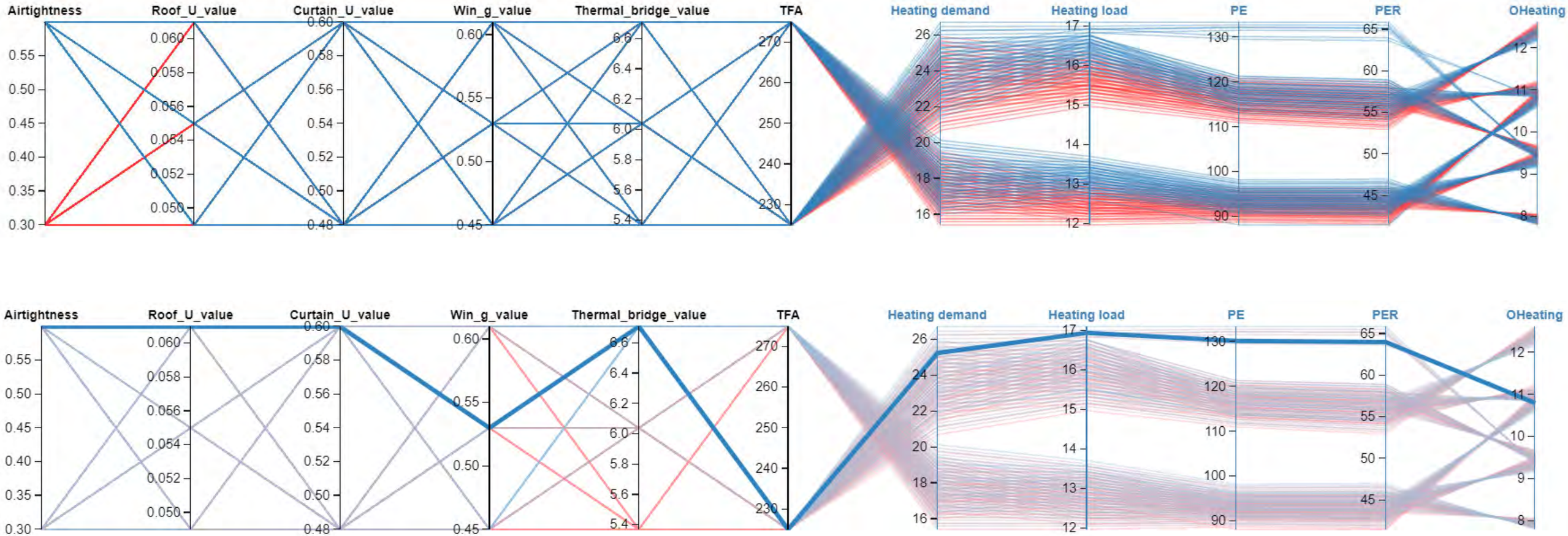

Baseline

# OPTIMIZATION ONE



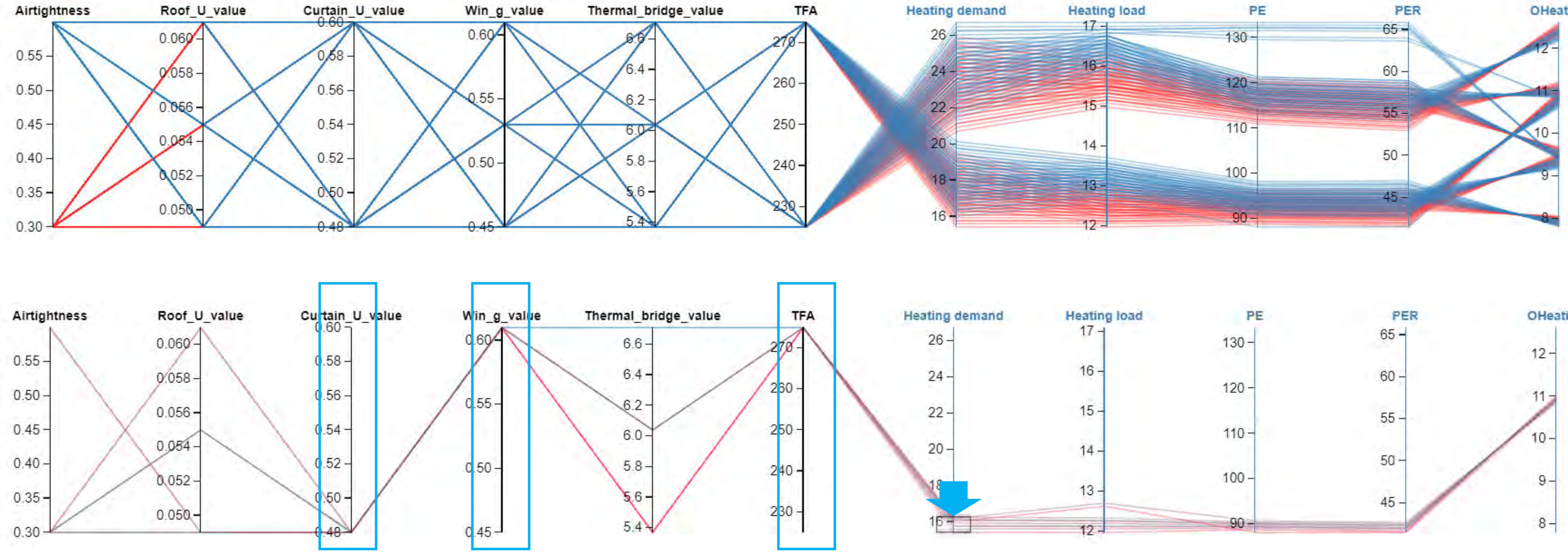

Sensitivity

# OPTIMIZATION TWO



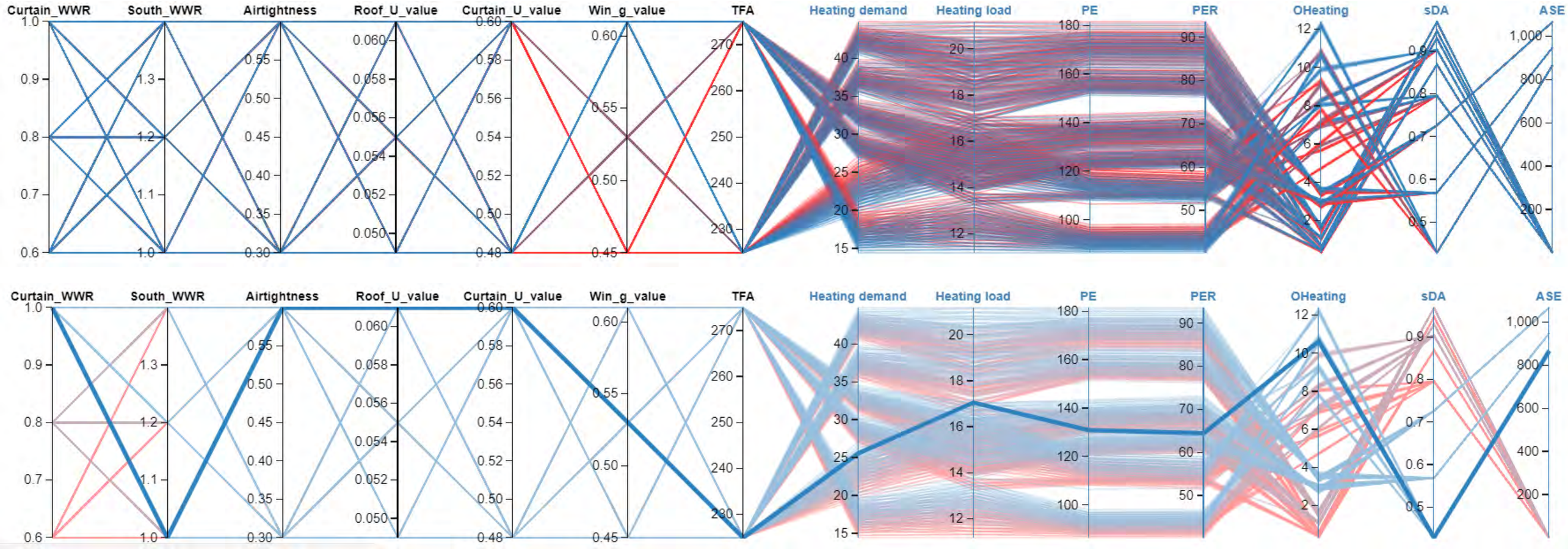

Baseline

# OPTIMIZATION TWO



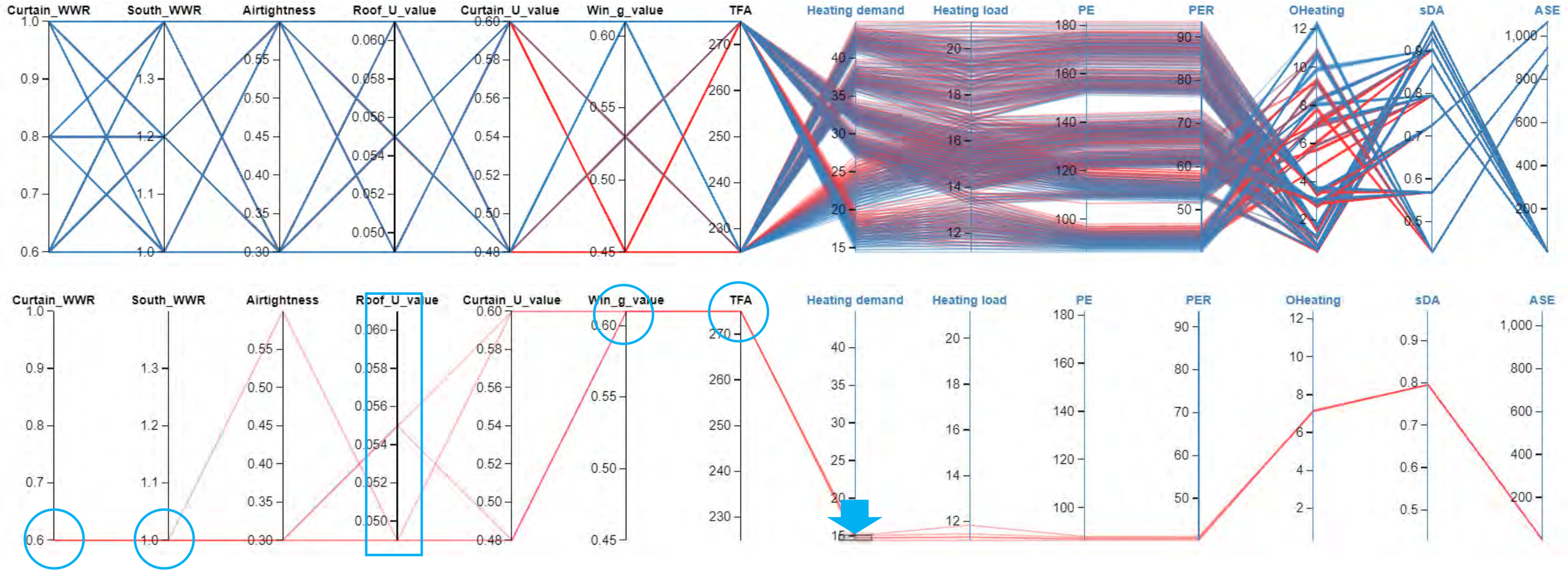

Sensitivity

# OPTIMIZATION THREE



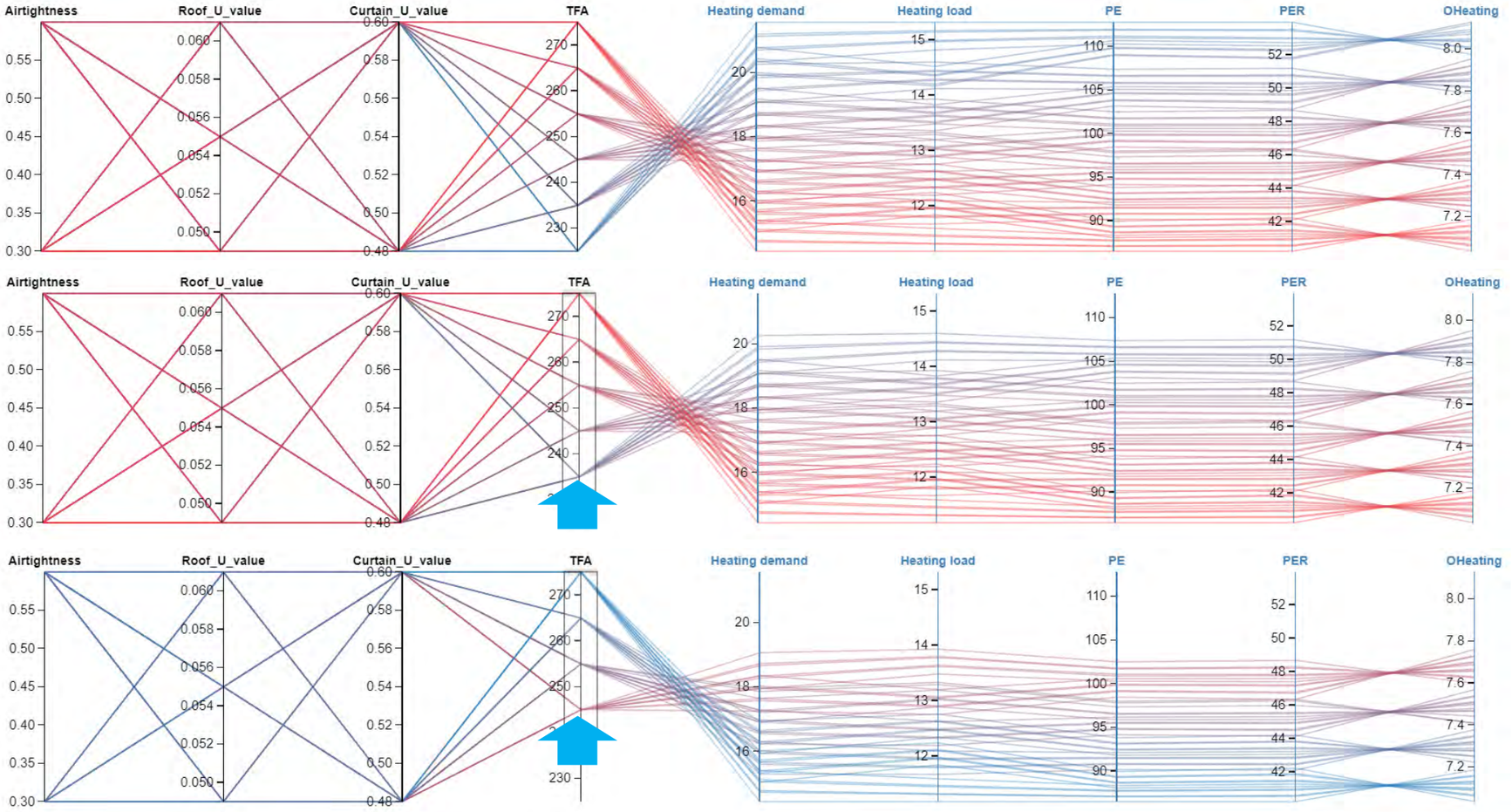

Baseline

# OPTIMIZATION THREE

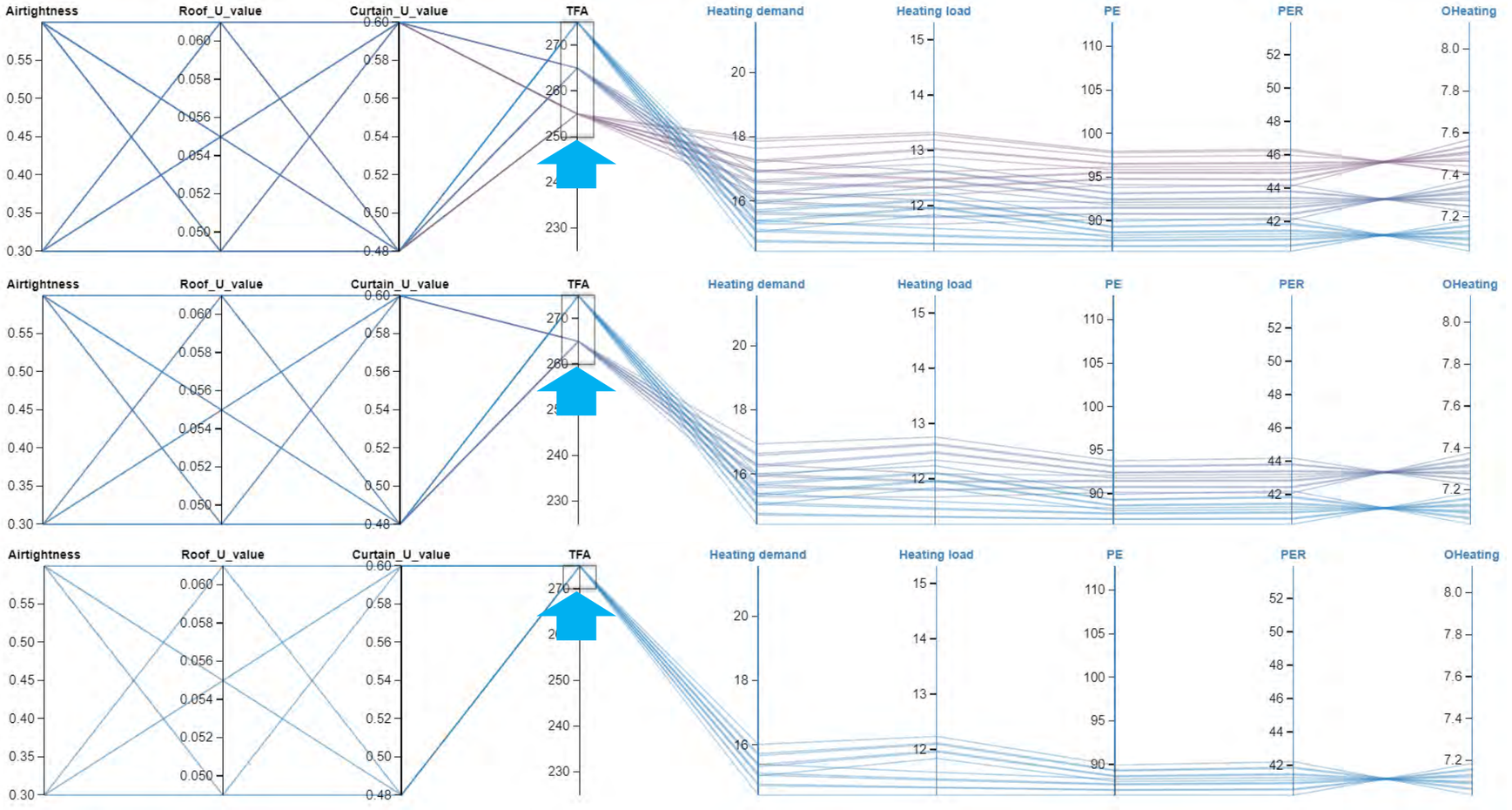



Yes! we could get Solo Passive House certified, if...

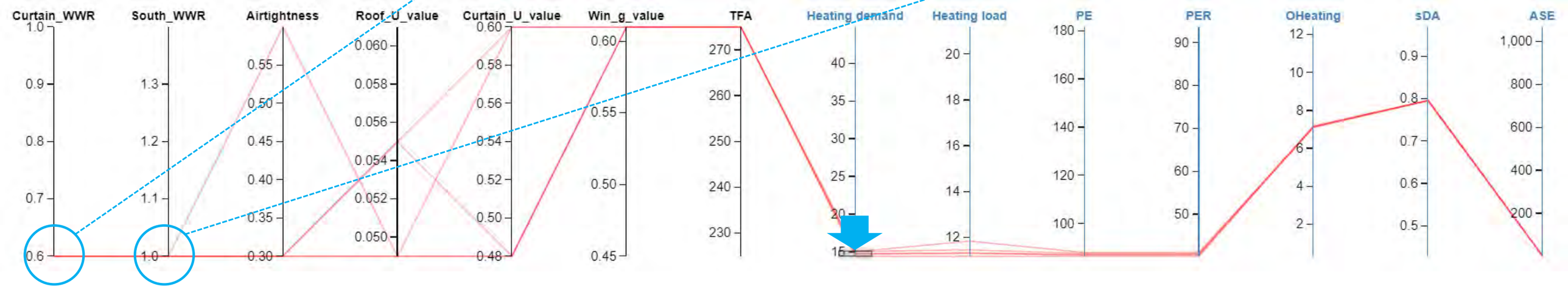
# QUESTION ONE



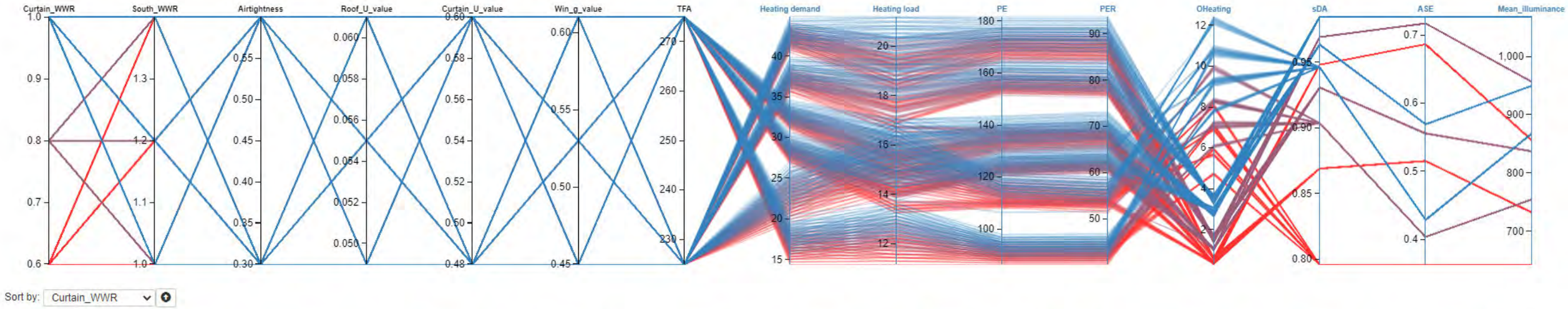
# QUESTION ONE



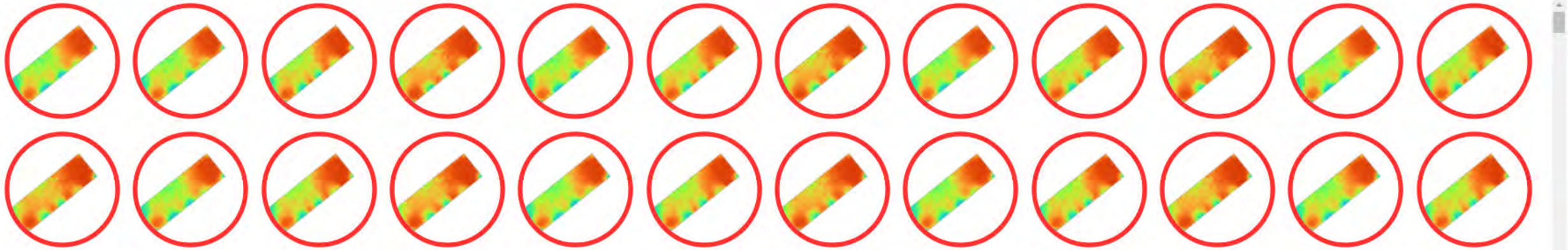
# QUESTION TWO & THREE



# BEYOND ENERGY & DAYLIGHTING

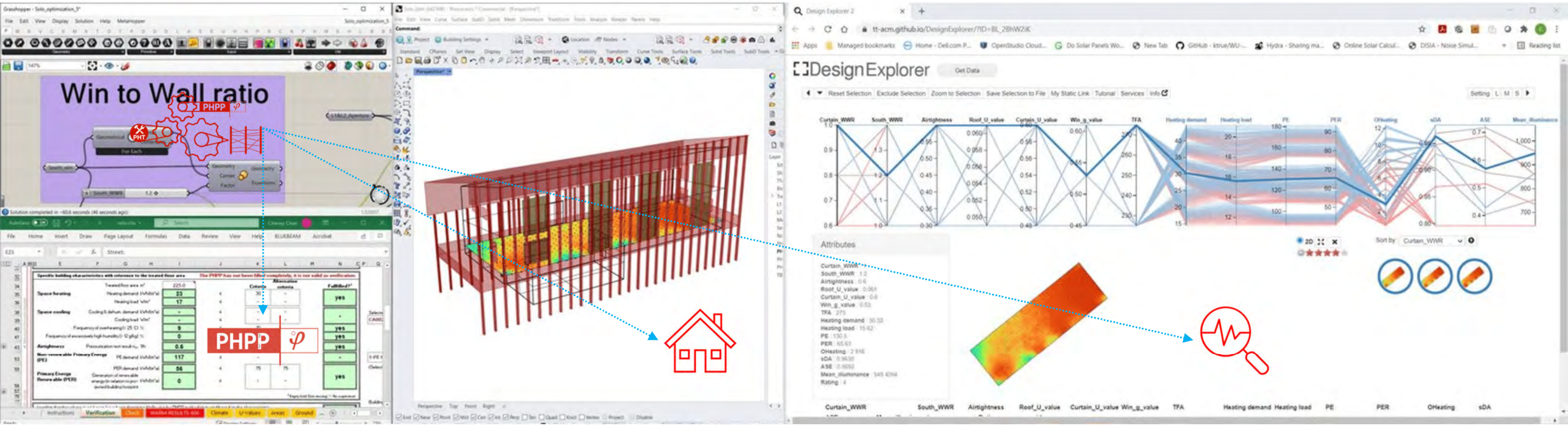



Sort by: Curtain_WWR



Energy & Daylighting

# IN PARALLEL PLATFORM



# CONCLUSION

## It's Fast

Energy calculation becomes fast and breaks the bottleneck of computational limit

## It's Early

It makes data driven design assistance happen at initial design stage

## It's Comprehensive

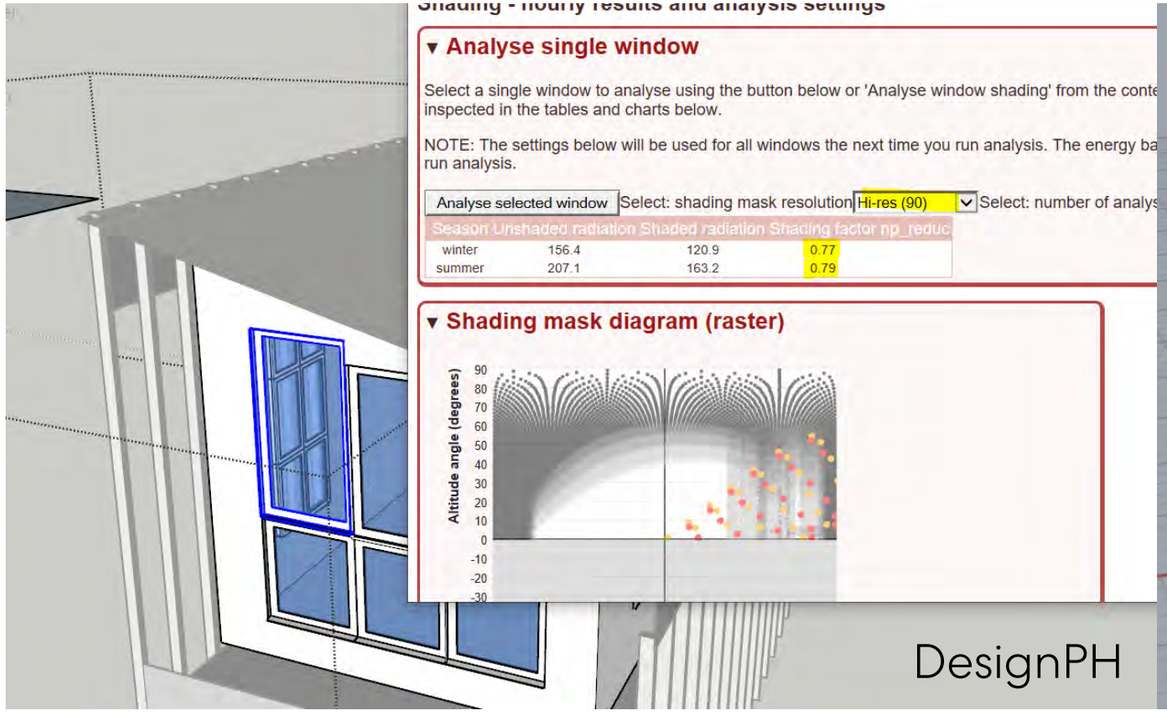
By taking the vehicle of DSC, multi-performance targets analysis is achievable

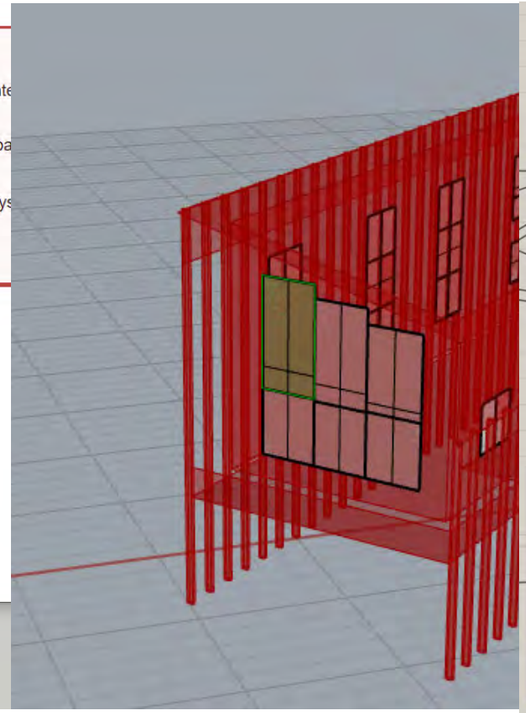
## It's Passive House

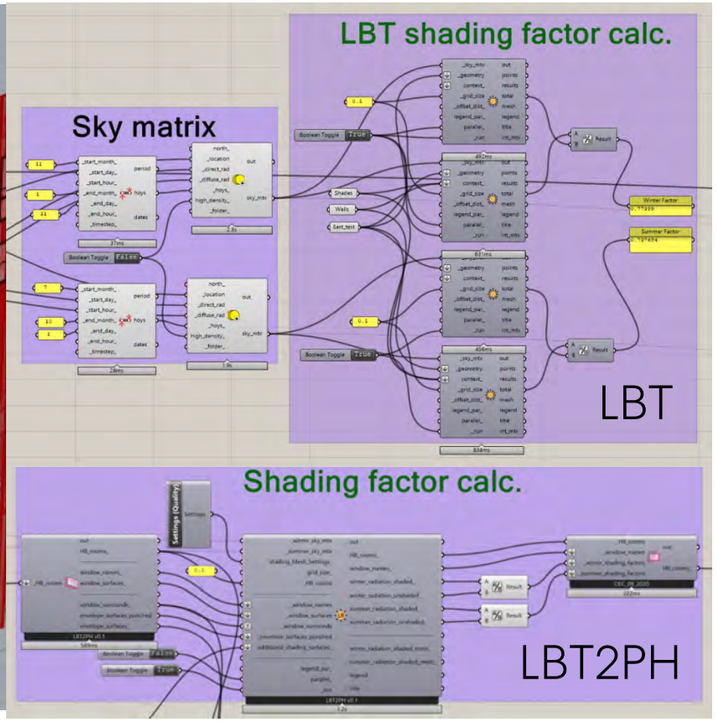
A dedicated workflow for Passive House and low energy design

# CHALLENGES




Shading - hourly results and analysis settings
Analyse single window
Select a single window to analyse using the button below or 'Analyse window shading' from the conte
inspected in the tables and charts below.
NOTE: The settings below will be used for all windows the next time you run analysis. The energy ba
run analysis.
Analyse selected window
Select: shading mask resolution
Hi-res (90)
Select: number of analys
Season Unshaded radiation Shaded radiation Shading factor np_reduc
winter 156.4 120.9 0.77
summer 207.1 163.2 0.79
Shading mask diagram (raster)
Altitude angle (degrees)
90 80 70 60 50 40 30 20 10 0 -10 -20 -30
DesignPH




LBT shading factor calc.
Sky matrix
LBT
Shading factor calc.
LBT2PH

# REFERENCES


1. https://perkinswill.com/news/celebrating-more-than-a-decade-of-carbon-neutral-business-operations/#:~:text=Climate%20Action%20Summit%2C%20we%20reaffirm,in%20a%20meaningful%2C%20measurable%20way.
2. https://perkinswill.com/news/perkins-and-will-commits-to-carbon-assessments-for-all-projects-in-western-canada/
3. https://perkinswill.com/news/solo-an-off-grid-mass-timber-house-earns-passive-house-certification/
4. https://github.com/PH-Tools/LBT-2-PH


# ACKNOWLEDGEMENTS


I. SoLo photographs by Andrew Latreille (https://www.andrewlatreille.com/ ), Courtesy: Perkins&Will

II. Acknowledgment and gratitude is extended to Ed May of BLDGTYP, LLC (http://www.bldgtyp.com/ ) who developed the IDF2PH,a set of tools to drive PHPP models from within grasshopper using Honeybee and EnergyPlus. Ed offeredinvaluable peer review and troubleshooting assistance during this research process.