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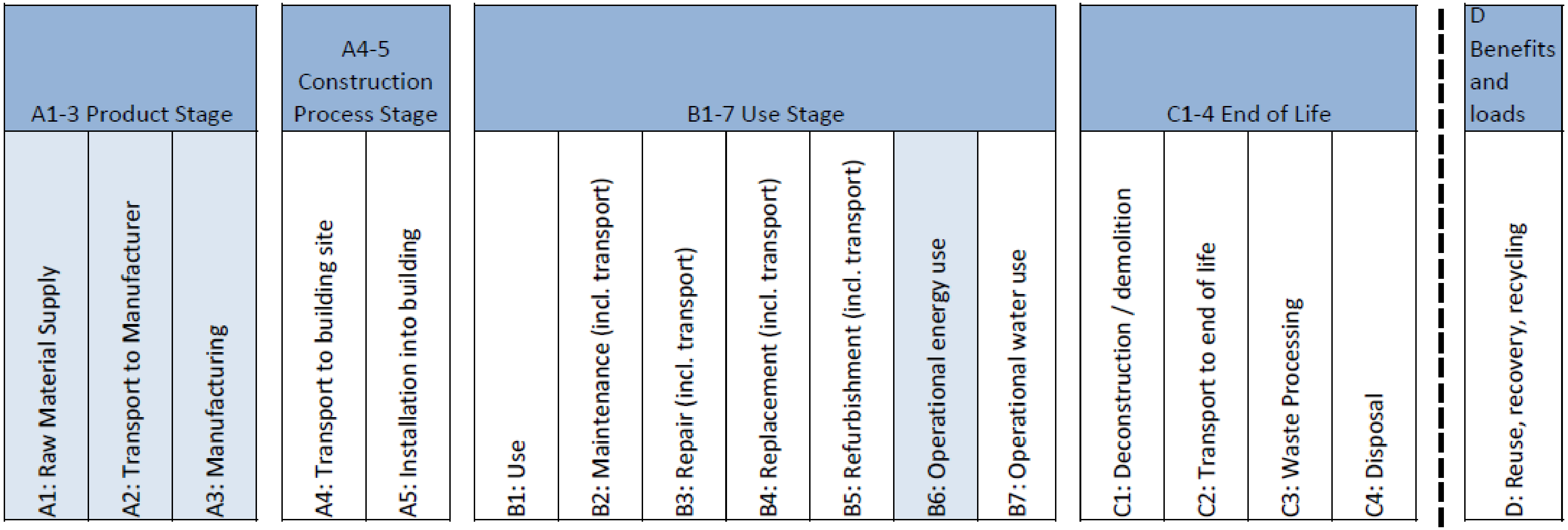
# A parametric tool for the assessment of operational energy use, embodied energy and embodied material emissions in building

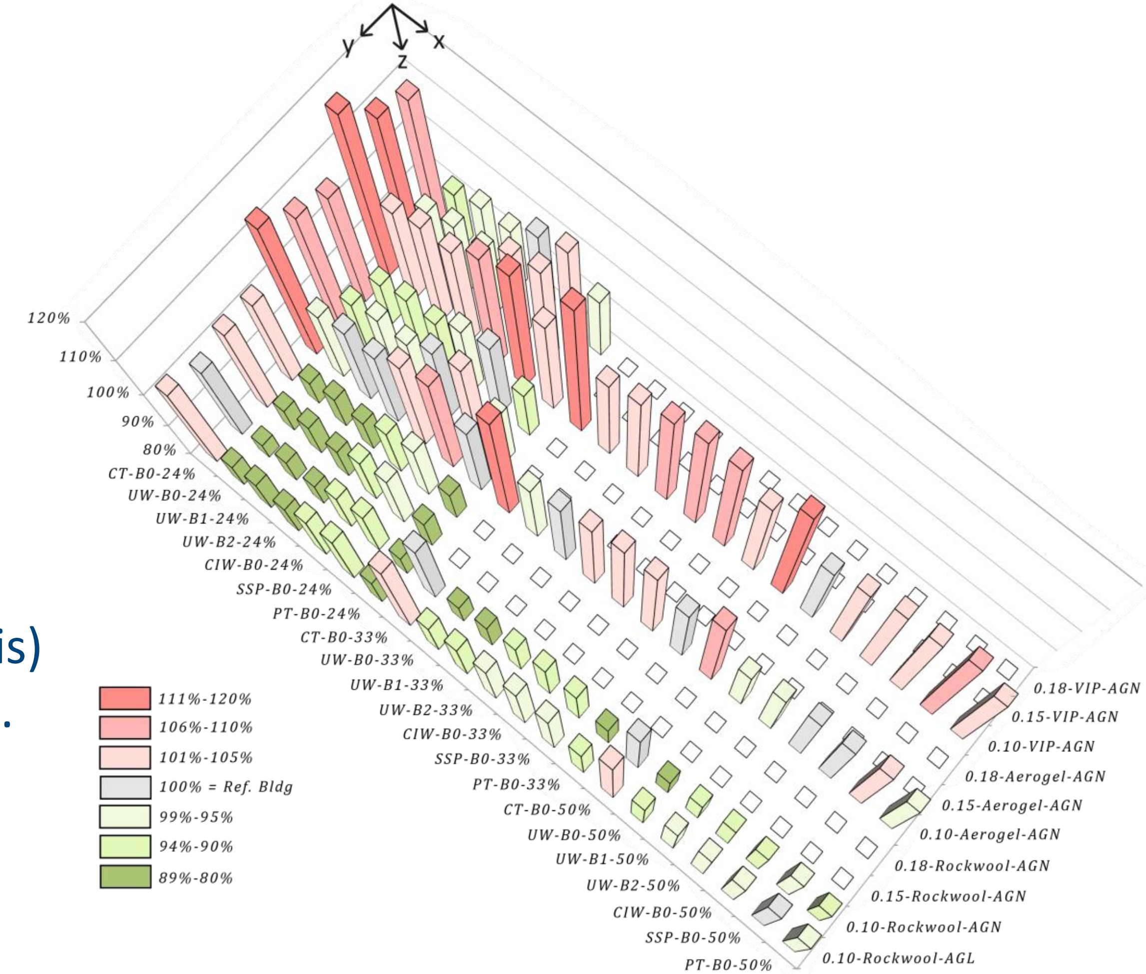
SINTEF Building and Infrastructure




*Lifecycle modules according to EN 15978: 2011*

- Current effort for **energy and emission abatement** in the building sector requires considering **energy** use in building in a **lifecycle perspective**.
- Energy Performance of Buildings Directive Recast (Directive 2010/31/EU)
- EU 2020 climate & energy package, Effort Sharing Decisions (406/2009/EC)
- Lifecycle assessment (**LCA**) evaluates resource inputs (**energy** and **mass** use) to calculate the building/component environmental impacts.

*A comparative study of different technical and the architectural retrofitting alternatives. Lifecycle emissions relative to the reference building. Lolli, N., Life cycle analyses of CO2 emissions of alternative retrofitting measures, NTNU, 2014.*




- **LCA** is a typically **comparative study** (multiple scenario analysis) and very time consuming.
- **Optimization** on operational energy and embodied energy/emissions may **differ**.
- Many existing LCA tools do not offer multiple scenario analysis.
- **LCA** and building **energy** calculations are often **performed separately** in existing tools.

This study focused on developing a **tool** that combines:

- Building energy modelling
- Environmental LCA method for buildings

- Allows **multiple scenario analysis** and comparison
- **Multiple outputs** (building embodied energy, lifecycle GHG emissions and energy use)

| |
|---|
| -EnergyPlus Weather Converter V7.1.0.010 |
| Statistics for NOR_Oslo.Fornebu.014880_IWEC |
| Location -- OSLO/FORNEBU - NOR |
| {N 59– 54'} {E 10– 37'} {GMT +1.0 Hours} |
| Elevation -- 17m above sea level |
| Standard Pressure at Elevation -- 101121Pa |
| Data Source -- IWEC Data |
| |
| WMO Station 014880 |
| |
| - Displaying Design Conditions from "Climate Design Data 2009 ASHRAE Handbook" |
| - ASHRAE design conditions are carefully generated from a period of record |
| - (typically 30 years) to be representative of that location and to be suitable |
| - for use in heating/cooling load calculations. |

## Part 1

Calculation of **monthly energy demand** (space heating and cooling, electricity for appliances, lighting and ventilation) ISO 13790:

- Uses standard weather files format (.EPW)
- Different geographical locations

| |
|---|
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| Data Source -- IWEC Data |
| |
| WMO Station 014880 |

| Temperature | *Weekday [C]* | *Weekend [C]* | *Night [C]* | *Day hours [h]* | *Night hours [h]* | *Setpoint [C]* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Heating | 21 | 21 | 19 | 18 | 6 | 20.5 | | | | | | |
| Cooling | 26 | 26 | 19 | 18 | 6 | 24.25 | | | | | | |
| | *Jan* | *Feb* | *Mar* | *Apr* | *May* | *Jun* | *Jul* | *Aug* | *Sep* | *Oct* | *Nov* | *Dec* |
| Heating | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES |
| Cooling | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES |

## Temperature set point schedule

- Workdays/weekend operative temperature
- Day/night hours of operations
- Monthly YES/NO scheduled operation

| |
|---|
| -EnergyPlus Weather Converter V7.1.0.010 |
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| Data Source -- IWEC Data |
| |
| WMO Station 014880 |

Temp

| [h] | Setpoint [C] | | | | | | |
|---|---|---|---|---|---|---|---|
| | 20.5 | | | | | | |
| | 24.25 | | | | | | |
| | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | YES | YES | YES | YES | YES | YES | YES |
| | YES | YES | YES | YES | YES | YES | YES |

**Internal Heat Gains**

| People | *Weekday* | *Weekend* |
|---|---|---|
| Number of People | 2 | 3 |
| Activity Level | Light manual work | Resting |
| Occupancy (hours) | 16 | 16 |
| Internal Heat Gain: People [W] | **171** | **167** |
| Internal Heat Gain: People [W] | **339** | |

## Internal heat gains from people

- Activity level
- Weekdays/weekend hours of activity

-EnergyPlus Weather Converter V7.1.0.010
Statistics for NOR_Oslo.Fornebu.014880_IWEC
Location -- OSLO/FORNEBU - NOR
{N 59– 54'} {E 10– 37'} {GMT +1.0 Hours}
Elevation -- 17m above sea level
Standard Pressure at Elevation -- 101121Pa
Data Source -- IWEC Data

WMO Station 014880

Internal Heat Gains

People

| Lighting | *Weekday* | *Weekend* | *Night* |
|---|---|---|---|
| Use | Office | Circulation areas | Security lights |
| Type | Fluorescent | Halogen | LED |
| Distance from luminaire to lit surface [m] | 2.5 | 3.5 | 3 |
| Density [W/m2] | 14.36016523 | 22.69659561 | 1.022820156 |
| Density - override values [W/m2] | | | |
| Operation (hours) | 16 | 16 | 8 |
| Control System | Manual on/off switch | Presence detector on/off | Manual on/off switch |
| Electricity Use [W] | 1 094.11 | 622.54 | 54.55 |
| Total Electricity Use [W] | 1 771.19 | | |
| Internal Heat Gain: Lighting [W] | **1 771** | | |

## Energy use for lighting

- Lighting types and lux levels
- Weekdays/weekend/nights hours of operations
- Control systems

| |
|---|
| -EnergyPlus Weather Converter V7.1.0.010 |
| Statistics for NOR_Oslo.Fornebu.014880_IWEC |
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| {N 59– 54'} {E 10– 37'} {GMT +1.0 Hours} |
| Elevation -- 17m above sea level |
| Standard Pressure at Elevation -- 101121Pa |
| Data Source -- IWEC Data |
| |
| WMO Station 014880 |

Internal Heat Gains

People

Lighting

**Appliances**

| | *Appliance 1* | *Appliance 2* |
|---|---|---|
| Type | LCD Monitor | Laptop Computer |
| Quantity | 10 | 10 |
| Daily hours of operation - weekday | 8 | 8 |
| Daily hours of operation - weekend | 0 | 0 |
| Density - design value [W/m2] | | |
| Electricity Use [W] | 71.90 | 60.00 |
| Total Electricity Use [W] | 131.90 | |
| Internal Heat Gain: Appliances [W] | **132** | |

## Energy use for appliances

- Appliance types
- Weekdays/weekend hours of use

## Ventilation and Infiltration Losses

| | Day: weekdays | Day: weekends | Night |
|---|---|---|---|
| Building Location | Urban areas centre | | |
| Window height above ground [m] | 5 | | |
| Width of zone/building [m] | 8 | | |
| Length of zone/building [m] | 10 | | |
| Floor to ceiling height [m] | 2.4 | | |
| Ventilation: volume [m3] | 420 | | |
| Building Type | Landscape office | No mechanical ventilation | No mechanical ventilation |
| Mechanical schedule hours | 8 | | |
| Mechanical air flow rate design value [m3/s] | | | |
| Mechanical air flow rate [m3/s] | 0.192 | 0 | 0 |
| Mechanical HR efficiency [%] | 85 | 85 | 85 |
| Mechanical SFP [W/m3/s] | 1000 | 1000 | 1000 |
| Mechanical Electricity Use [W] | **45.71** | **0.00** | **0.00** |
| Mechanical Total El Use [W] | **45.71** | | |
| Heat transfer coefficient [W/K] | **8.23** | **0.00** | **0.00** |
| Natural schedule hours | | | 8 |
| Natural type of ventilation | No natural ventilation | No natural ventilation | Cross ventilation |
| Natural fraction of window area | 0.5 | 0.5 | 0.1 |
| Natural air flow rate [m3/s] | 0 | 0 | 1.741849809 |
| Infiltration losses [1/h] | 0.3 | 0.3 | 0.3 |
| Heat transfer coefficient [W/K] | **42.00** | **42.00** | **738.74** |
| Total heat transfer coefficient [W/K] | **830.97** | | |

## Natural and mechanical ventilation heat transfer

- HR efficiency
- Fans efficiency
- Natural ventilation single side/cross ventilation
- Weekdays/weekend/night hours of operation

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Type 1 | Outdoor | Boundary | | | | | |
| | N | Orientation | | | | | |
| | 90 | Tilt Angle | | | | | |
| | 53.0 | m2 | | | | | |
| *Material Category* | *Product* | *GWP (kgCO2eq)* | *CED (MJ)* | *(W/mK)* | *Weight (kg)* | *Thickness (m)* | *(m2k/W)* |
| *Heat Transfer Resistance* | *Internal Rsi* | | | | | | 0.13 |
| b.Timber | Structural Timber of spruce and pine, exd. biogenic: Norwegian wood industry: NO | 199.49 | 40168.22 | 0.13 | 1580.83 | | 0 |
| b.Steel | Welded and coated trusses and beams made of cold-formed structural tubes and sections: Rukki Constru | 566.00 | 1356.00 | 17.00 | 200.00 | | 0 |
| c.InternalSurface | Knauf Danogips Solid Gypsum Board 12,5mm, indoor wall & ceiling, exd. biogenic: Knauf: DK | 20.25 | 922.78 | 0.58 | | 0.01 | 0.02 |
| c.Insulation | Glava glass wool, 350mm: Glava: NO | 316.91 | 5394.78 | 0.04 | | 0.35 | 10.00 |
| c.Membranes | Baca Vapour barrier, 0,15mm: Baca Plastindustri: NO | 18.23 | 983.84 | 0.33 | | 0.00 | 0.00 |
| c.Membranes | Norgips Windliner-X/Utvendig-X type EH2 (GU-X): Norgips: NO | 77.40 | 1535.10 | 0.58 | | 0.01 | 0.02 |
| c.Timber | Møre Royal Copper impregnated Pine Timber, Cladding, decking, exd. biogenic: Møre Tre, 21mm: NO | 160.64 | 15321.20 | 0.13 | | 0.02 | 0.16 |
| *Heat Transfer Resistance* | *External Rse* | | | | Quantity (m2) | | 0.04 |
| *Window and Door Openings:* | | | | | 10.00 | | U-value |
| *c.TripleGlazedUnit* | Pilkington Optitherm™ 4S(3)-18Ar-4-18Ar-S(3)4, U-value 0.5, g-value 50 | 723.91 | 16701.22 | | 10.00 | | **0.5** |
| *Choose Opening* | | 0.00 | 0.00 | | | | **0.0** |
| | | **2082.85** | **82383.14** | | | **0.39** | **0.10** |

*EPDs of materials*

*Environmental impact*

*Energy calculation*

## Part 2

Calculation of a building's **embodied energy** and **embodied** material **emissions**, for phases (A1-A3) according to EN 15804:

- Impact calculation for **different building parts** (external walls, internal walls, floors, roof) and for technical equipment
- Data sourced from **EPDs** from multiple sources (EPD-Norge, IBU-Germany, EPD-Sweden) and from Ecoinvent

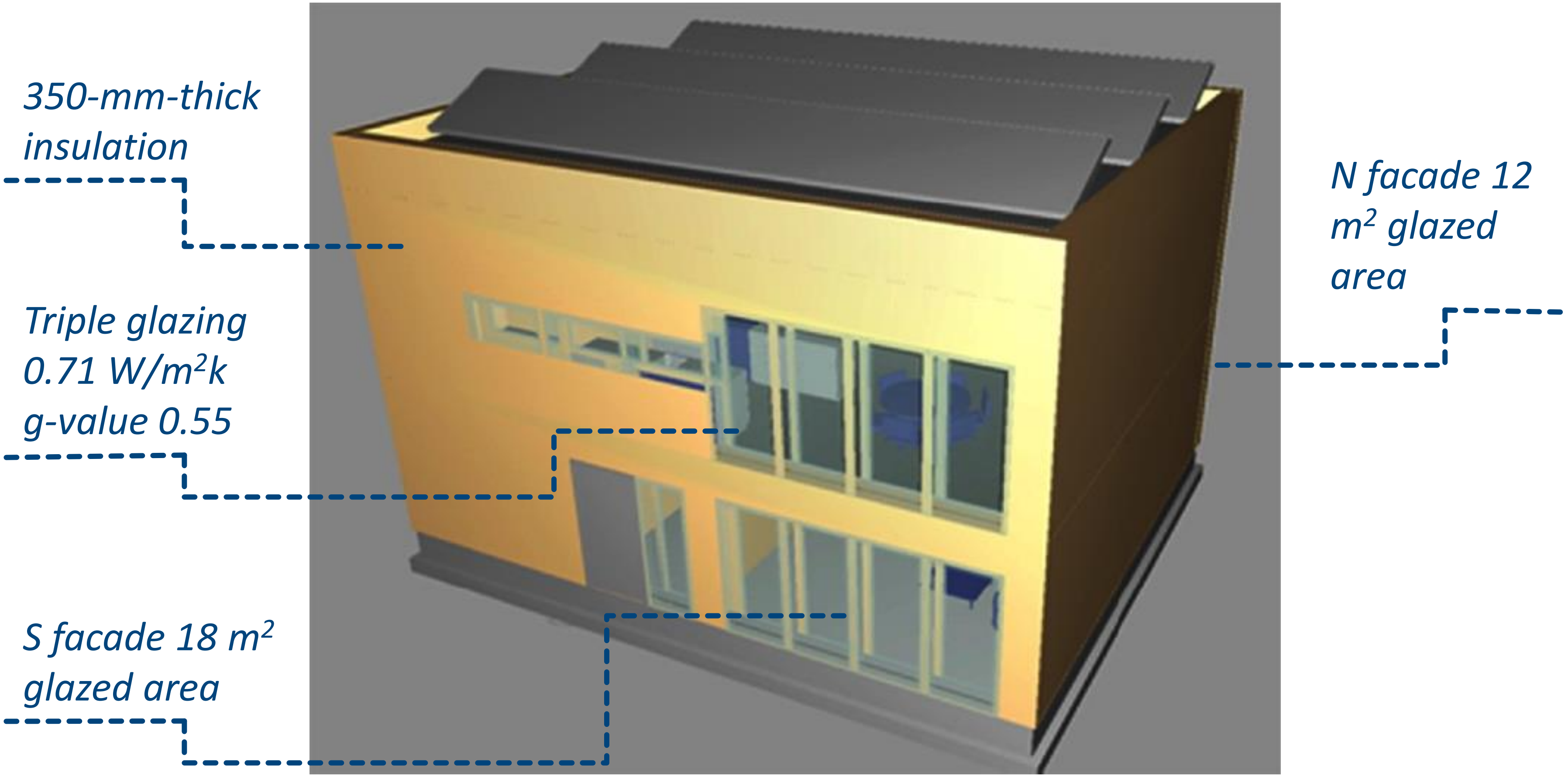
| | | |
|---|---|---|
| Type 1: | Outdoor | Boundary |
| | N | Orientation |
| | 90 | Tilt Angle |
| | 53.0 | m2 |

| | | |
|---|---|---|
| Building Lifetime | 60 | *years* |
| Building Perimeter | 36 | *m* |
| Heated Ground Floor Area | 80 | *m2* |
| Heated Building Area | 160 | *m2* |
| Heated Building Volume | 420 | *m3* |
| Floor to Ceiling Height | 2.4 | *m* |

| | *Embodied Emissions GWP (kgCO2eq)* | *Embodied Energy CED (MJ)* | *Heat Transfer Co-efficient (W/m2K)* | *Operational Energy Use (kWh)* | Operational Energy Emissions (kgCO2eq) |
|---|---|---|---|---|---|
| *1. Groundwork and Foundations* | 0 | 0.00 | - | | |
| *2. Outer Walls* | 7373 | 234471.38 | 0.10 | | |
| *3. Inner Walls* | 1759 | 62866.21 | - | | |
| *4. Floor Structure* | 4826 | 237945.84 | 0.85 | | |
| *5. Outer Roof* | 2479 | 118961.33 | 0.09 | | |
| *6. Stairs and Balconies* | 0 | 0.00 | - | | |
| *7. Technical Equipment* | 12144 | 91821.61 | - | | |
| ***Whole Building (A1 - A3)*** | **16437** | **654245** | | **2 011 620** | **583 370** |
| *Appliances* | | | | | |
| *FU: /m2* | 102.73 | 4089.03 | | 12572.63 | 3646.06 |
| *FU: /yr* | 273.96 | 10904.08 | | 33527.00 | 9722.83 |
| *FU: /m2/yr* | 1.71 | 68.15 | | 209.54 | 60.77 |

## Results of single variable analysis

- Two impact categories for material use: CED and GWP
- Operational energy use/emissions




- **Tool tested on a case study**: net zero emission building concept. From Houlihan Wiberg, A., et al. (2014). "A net zero emission concept analysis of a single-family house." Energy and Buildings **74**: 101-110.
- Located in Oslo, Norway.

| Parameter | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 | Option 6 | Option 7 |
|---|---|---|---|---|---|---|---|
| Insulation | 50mm | 100mm | 150mm | 200mm | 250mm | 300mm | 350mm* |
| Window type | 3-ply* 0.71 W/$m^2$k g-value 0.55 | 2-ply 2.6 W/$m^2$k g-value 0.78 | 3-ply 0.50 W/$m^2$k g-value 0.50 | 2-ply 1.30 W/$m^2$k g-value 0.62 | - | - | - |
| North window area | 10 $m^2$ | 12 $m^2$* | 15 $m^2$ | 20 $m^2$ | 25 $m^2$ | 30 $m^2$ | 35 $m^2$ |
| South window area | 10 $m^2$ | 15 $m^2$ | 18 $m^2$* | 20 $m^2$ | 25 $m^2$ | 30 $m^2$ | 35 $m^2$ |

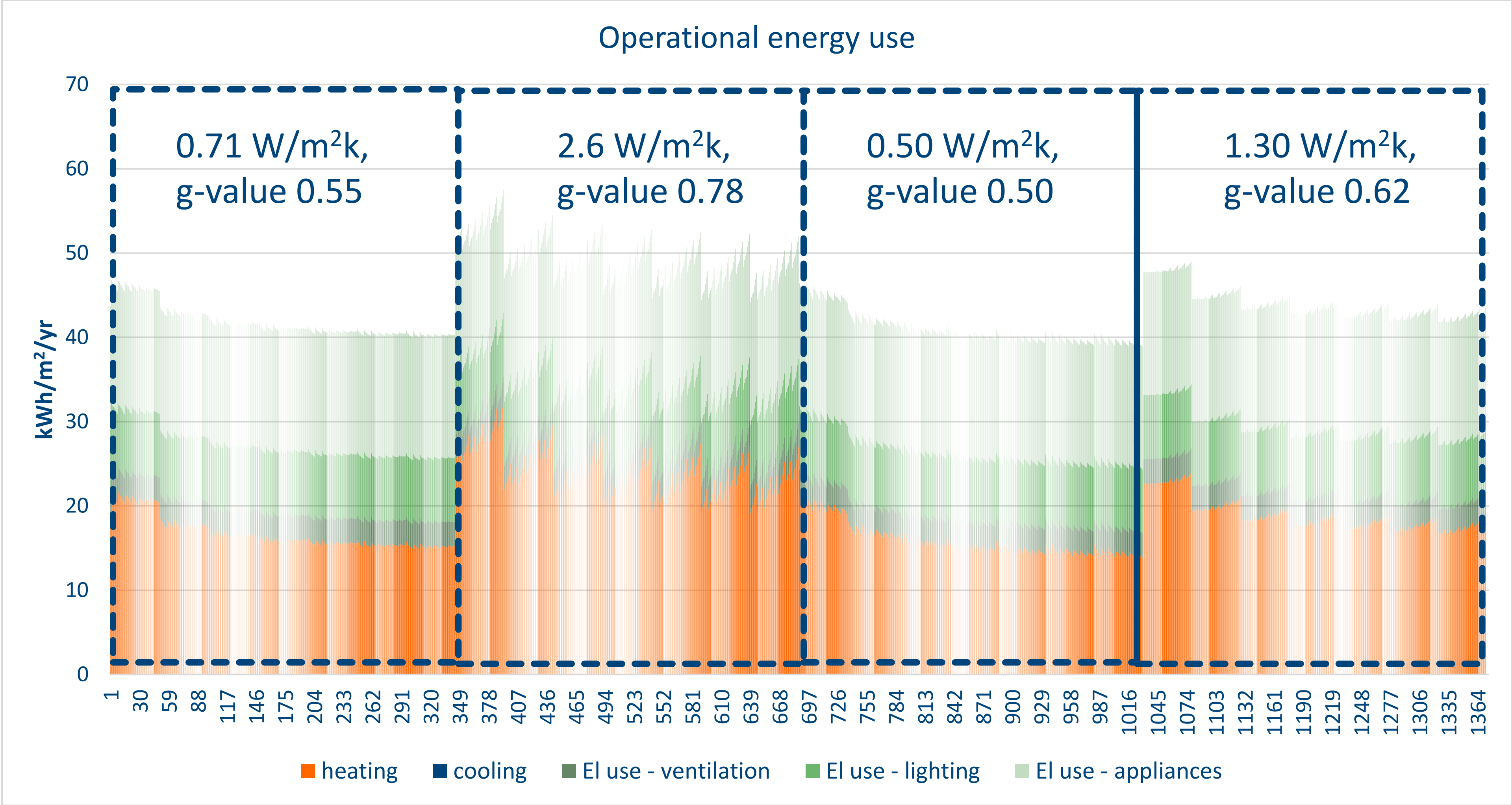
- **Variation of parameters** of case study: window type, wall insulation thickness, and glazing areas in N and S facades.
- To test the **mutual influence** of the different **parameters**
- Find **optimal results** within a given set of variations

| Parameter | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 | Option 6 | Option 7 |
|---|---|---|---|---|---|---|---|
| Insulation | 50mm | 100mm | 150mm | 200mm | 250mm | 300mm | 350mm* |
| Window type | 3-ply* | 2-ply | 3-ply | 2-ply | | | |

| | | | | | |
|---|---|---|---|---|---|
| 2 way opening inwards window, Triple glazed, with Al clad, 105mm frame, excl. biogenic: Lian Trevarefabrikk: NO | Stone wool high bulk density (121-250kg/m3), 50mm: ROCKWOOL Mineralwoll GmbH & Co: DE | 10 | 0 | 10 | 0 |
| Pilkington Optifloat™ Clear 4-16Ar-4, U-value 2.6, g-value 78 | Stone wool high bulk density (121-250kg/m3), 100mm: ROCKWOOL Mineralwoll GmbH & Co: DE | 12 | | 15 | |
| Pilkington Optitherm™ 4S(3)-18Ar-4-18Ar-S(3)4, U-value 0.5, g-value 50 | Stone wool high bulk density (121-250kg/m3), 150mm: ROCKWOOL Mineralwoll GmbH & Co: DE | 15 | | 18 | |
| Pilkington Optitherm™ 4-12Ar-S(3)4, U-value 1.3, g-value 62 | Stone wool high bulk density (121-250kg/m3), 200mm: ROCKWOOL Mineralwoll GmbH & Co: DE | 20 | | 20 | |
| | Stone wool high bulk density (121-250kg/m3), 250mm: ROCKWOOL Mineralwoll GmbH & Co: DE | 25 | | 25 | |
| | Stone wool high bulk density (121-250kg/m3), 300mm: ROCKWOOL Mineralwoll GmbH & Co: DE | 30 | | 30 | |
| | Stone wool high bulk density (121-250kg/m3), 350mm: ROCKWOOL Mineralwoll GmbH & Co: DE | 35 | | 35 | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Window type | Insulation thickness | Glazing area N | Glazing area E | Glazing area S | Glazing area W |

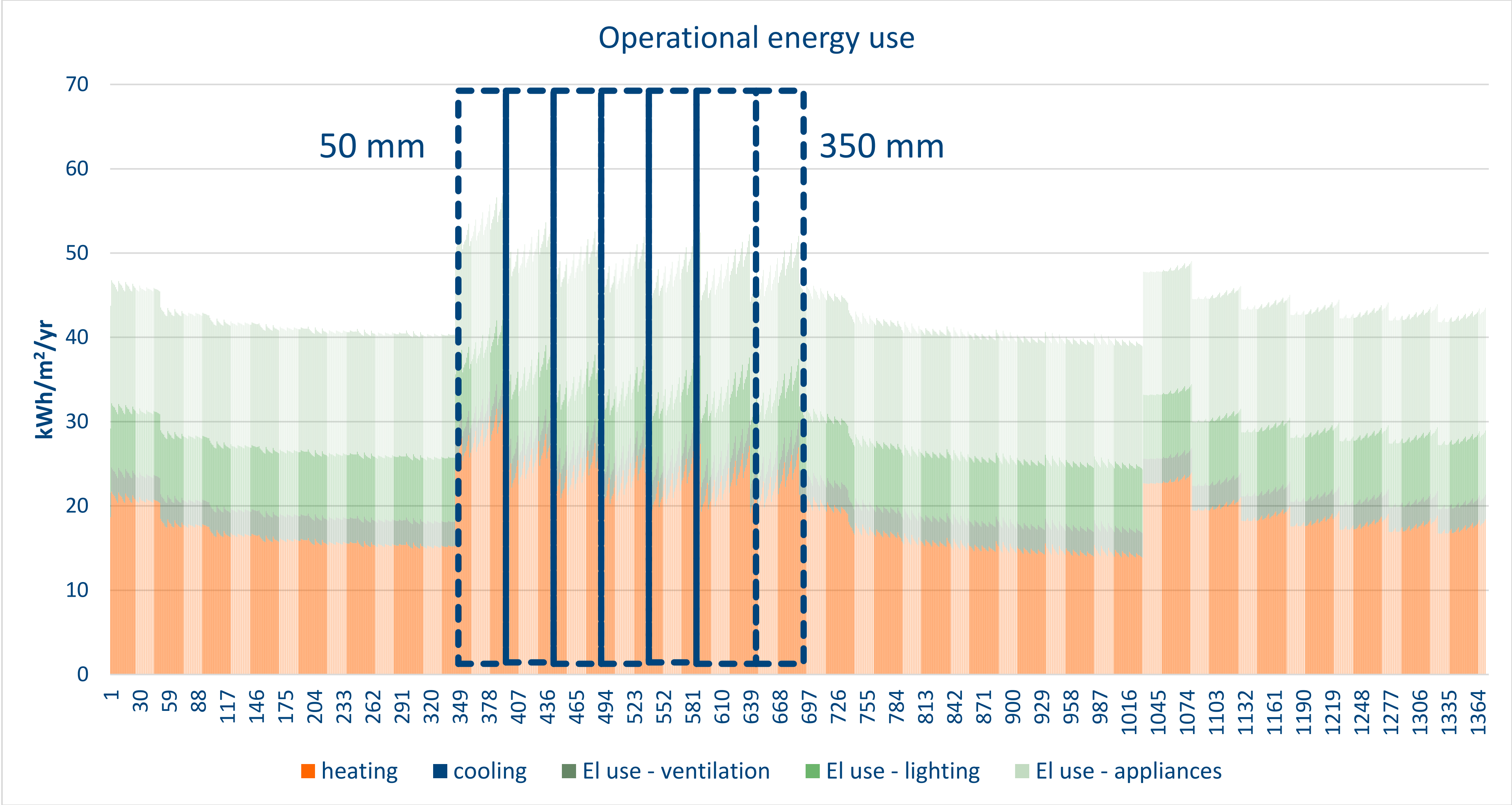
## Part 3

- Parameters are fed in the console for the **analysis of multiple variables**.
- Initial values are replaced and simulations based on all permutations.
- **1372 iterations**. Outputs for operational energy use, $CO_{2\text{-eq}}$ emissions, CED.

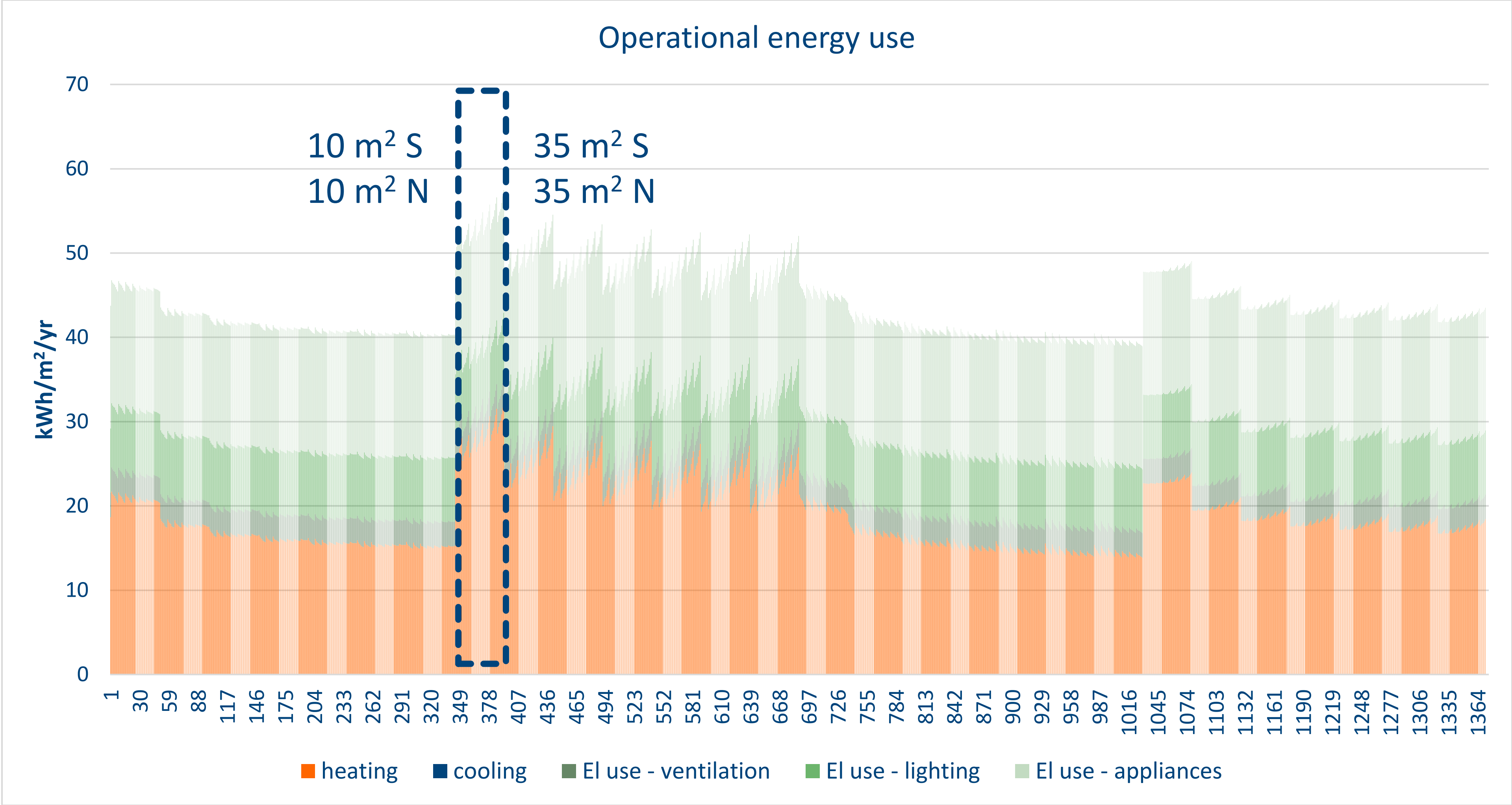



## Result of multiple variables analysis

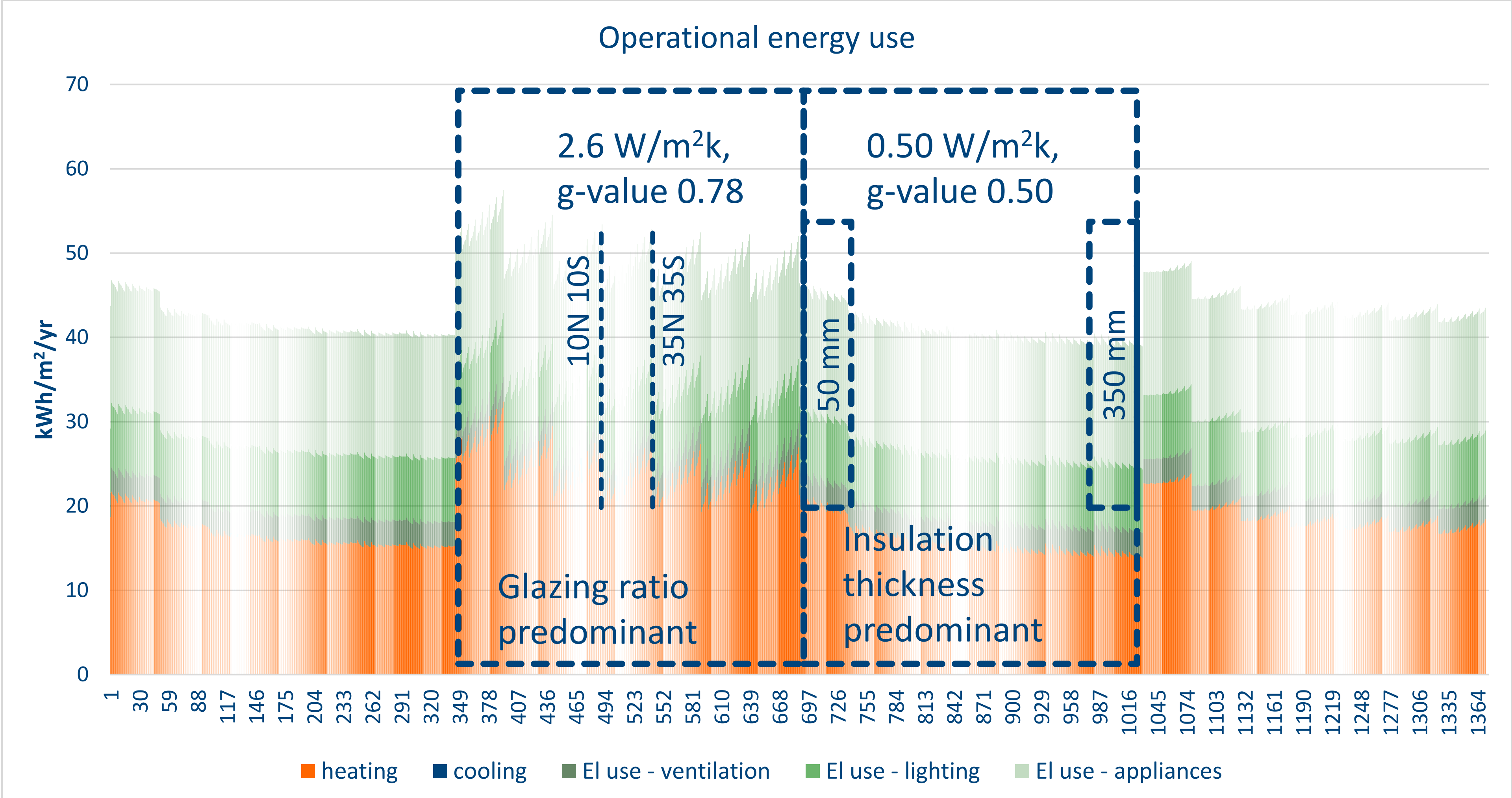
- Variation of 4 window types.



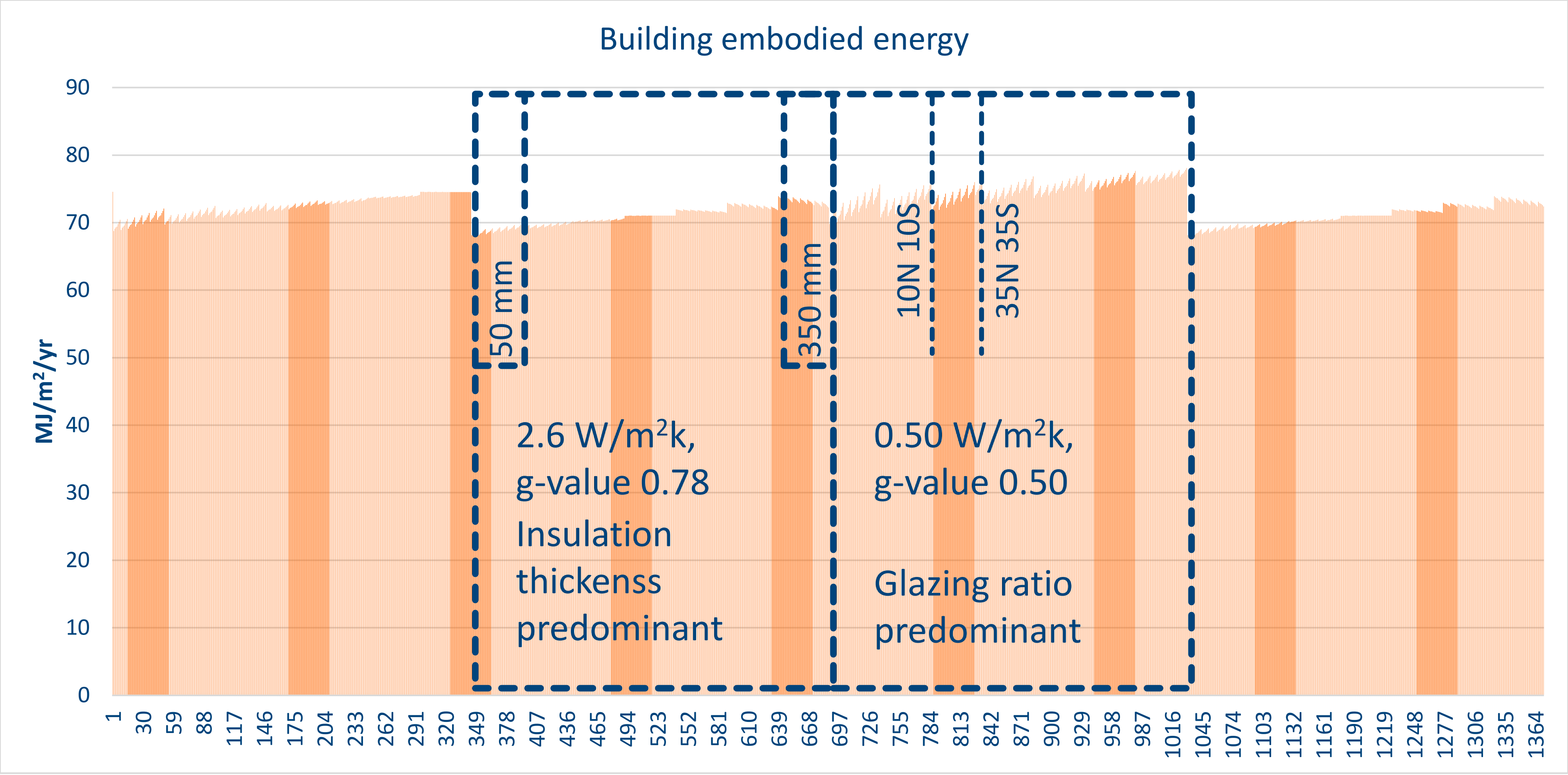

- Variation of 7 insulation thicknesses.



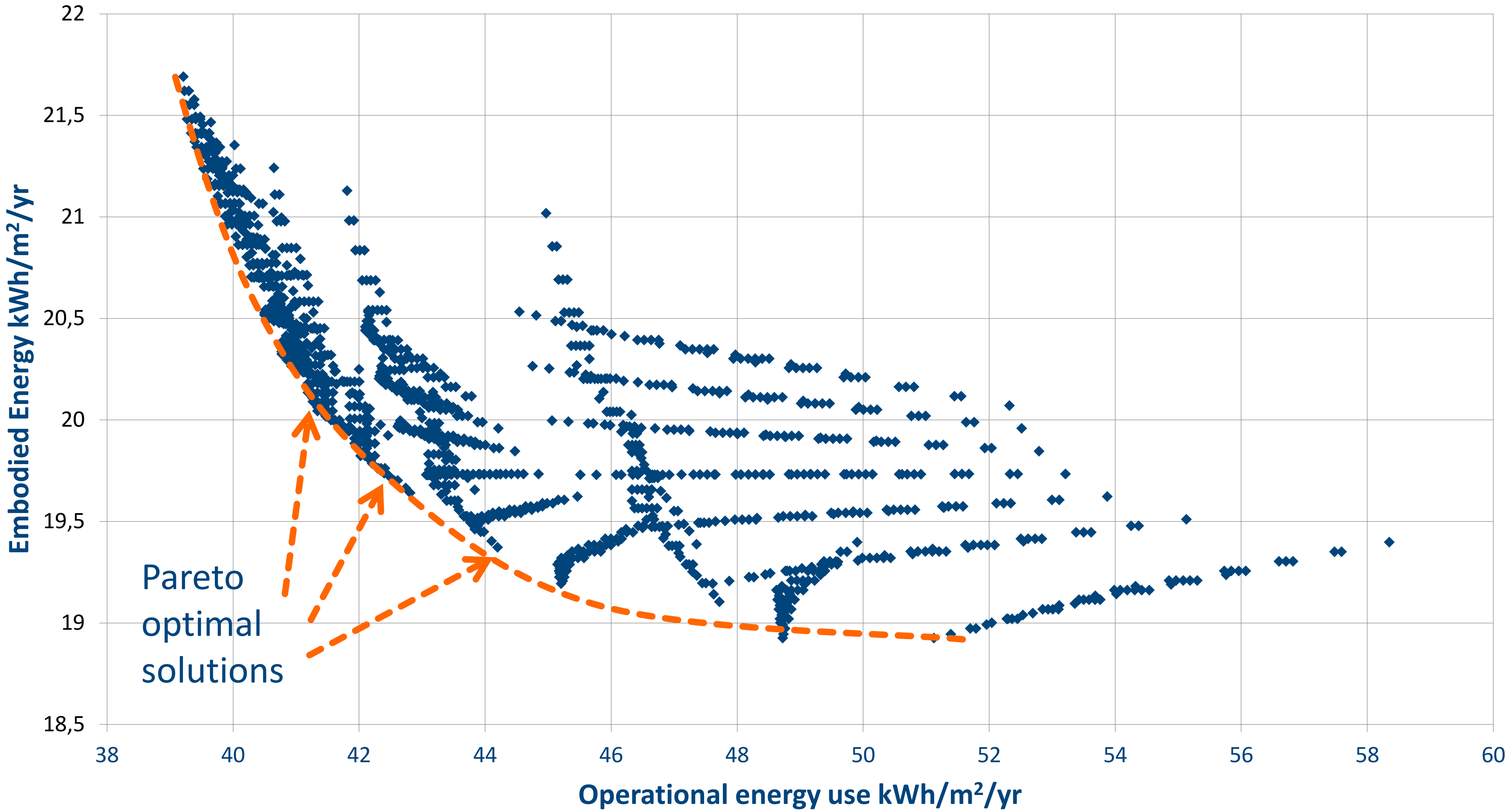

- Variation of 7 glazed areas in N facade and 7 glazed areas in S facade (49 different simulations).



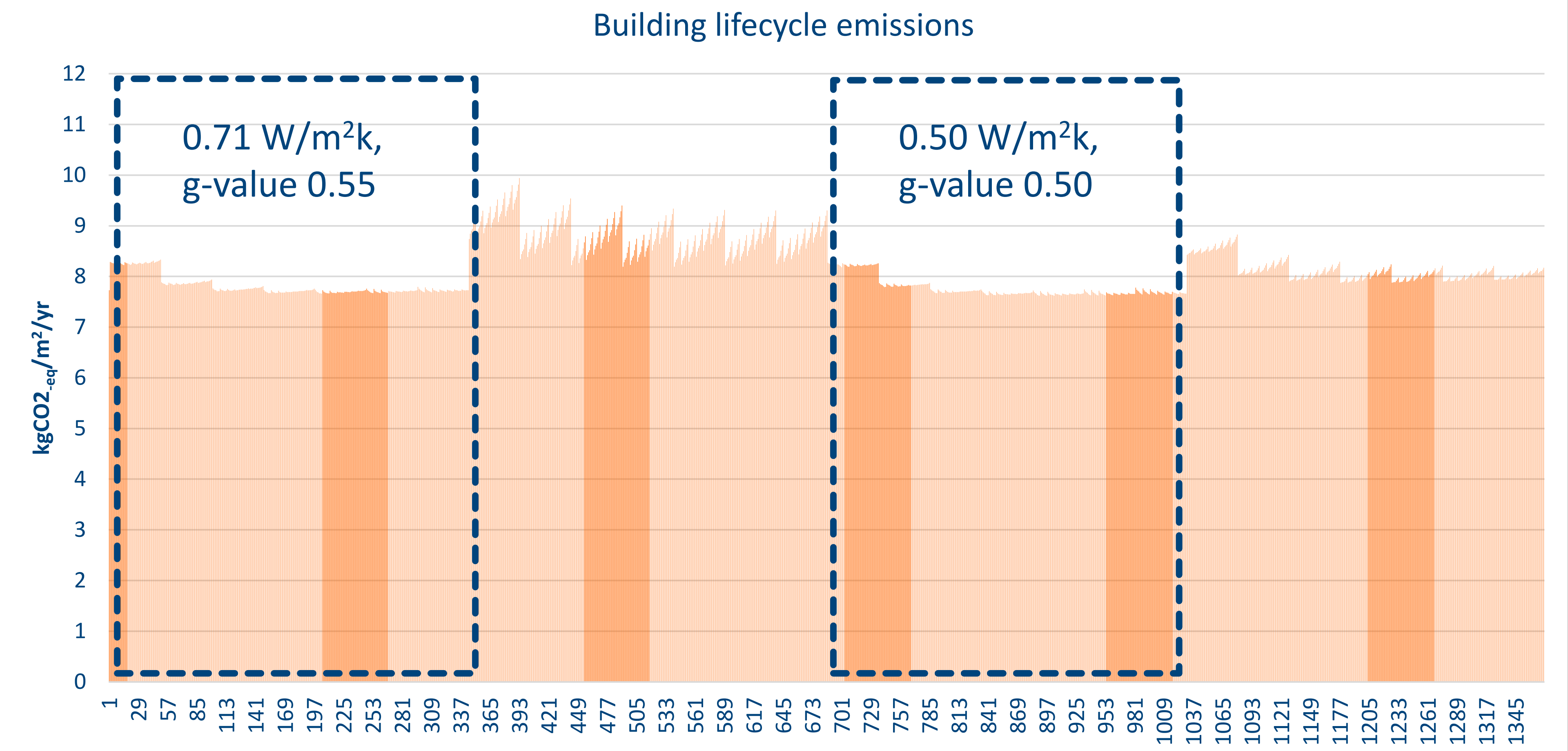

- Comparison of results for different combinations of paramenters: operational energy use




- Comparison of results for different combinations of paramenters: embodied energy.




- Comparison of results for different combinations of paramenters: embodied energy vs operational energy use.




- Comparison of results for different combinations of paramenters: lifecycle emissions.
- Glazing ratio and insulation thickness (more than 100 mm) are unifluential with high insulating window types.

Current limitations:

- Energy production and Embodied energy/emissions from on-site **PV** systems not included yet
- Embodied energy/emissions of **appliances**, **luminaires,** and **energy systems** not included yet
- Simplified models of **energy systems** (currently theoretical COP only)
- **Limited** number of **variables** (wall insulation, glazing area, window type, shading strategy)
- **Maintenance** and material replacement phase is not included yet
- Material **transportations** is not included yet
- **End-of-life** phase is not included yet

**Conclusions**:

Useful potential for evaluating different options in **zero energy/emissions balance.**

User target: **professionals, students/educators**