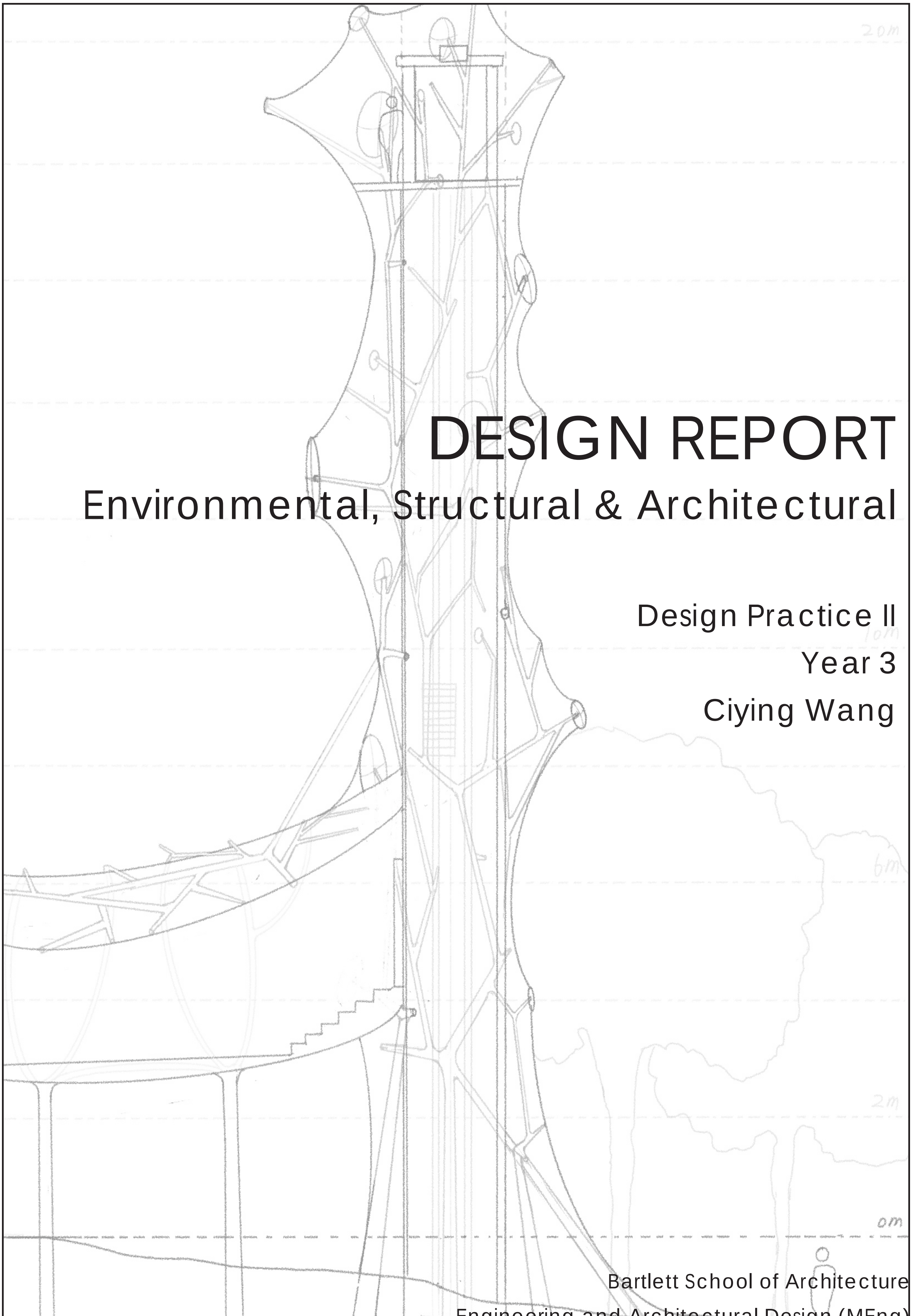


# DESIGN REPORT

## Environmental, Structural & Architectural

Design Practice II

Year 3

Ciying Wang

Bartlett School of Architecture

Engineering and Architectural Design (MEng)

# *ABSTRACT*




The project starts by looking into what Highgate residents care about. A search into local forums shows that Highgate residents are very proud of North Hill which is considered to be the most architecturally diverse street in the UK. This is why a proposed development in Townsend Yard has triggered worries that it will destroy a historic cottage, Shepherd's Cottage, which is the only building of this kind that has not been significantly altered. There has always been conflicts in this area. Local elites and foreign investors - can Highgate residents stop foreign billionaires who want to make their way into the community? Housing crisis - how can London solve its shortage of affordable housing while preserving the quality of new development and coordinating its relationship with existing buildings? Old and new architecture - how can they coexist in the urban environment and share the same sky?

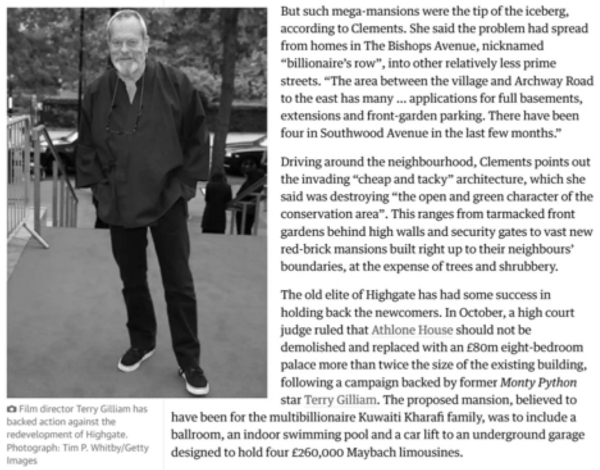
This project proposes a gallery, combined with a workshop and an observation tower, located at Townsend Yard. The design of a gallery is inspired by Haringey Council's 'Making The Difference' programme, where local residents proudly publicises Highgate architecture and tries to attract visitors. A gallery documenting and exhibiting local architecture will celebrate Highgate heritage. A workshop enables visitors to immersively experience the craftsmanship and details of the exhibitis. The observation tower will provide a space in this crowded area to look around and enable the appreciation of what is considered as normal on the streets. Townsend Yard is where the controversial development is located, and this project tries to re-purpose the usage of the site.A series of installations will echo the brief of 'sutures of urban fabrics', where scattering heritage architecture will be connected along the architecture journey.

The project has posed a series of structural challenges. The topology of the site is a slope approximately 8 degrees, and the design should respond to this fact.  Daylight will serve as the main design tool: how should light be designed to imrpove wellbeing both within and outside the building's spaces. The project is informed by a series of  influences, including articles, observations, materials, occupants and research, which drive the iterations of designs.

The clients of this projects are foreign billionires. While local elite residents, including the film director Terry Gilliam, are protesting against foreign investors destroying the community, Russian billionaires are trying to make their way into Highgate by investing in this project and showing their respect to the local heritage.









We respect Highagte heritage

We have taste

And we are very green

(before 24/02/22)

# Highscape

## - Townscape from the height:
## how can old and new buildings share the same sky?

A critique to the conflicts between: local elites and foreign investors; housing shortage and new development; Old and new architecture; preservation and construction

**What** - This project proposes a gallery combined with a workshop and an observation tower.

**Why** - A new development of residential buildings has provoked concern that heritage architecture in Highgate, which local residents are so proud of, will be affected. It is proposed in this project that a gallery of local architecture can be designed to celebrate Highgate heritage, and an observation tower can enable a bird view above this crowded area and an appreciation what is considered to be normal.

**Where** - The site is in Townsend Yard where the new development in the news is located. It is a rarely found area where busy high streets are just adjacent but rural charm can also be found in the garden behind.

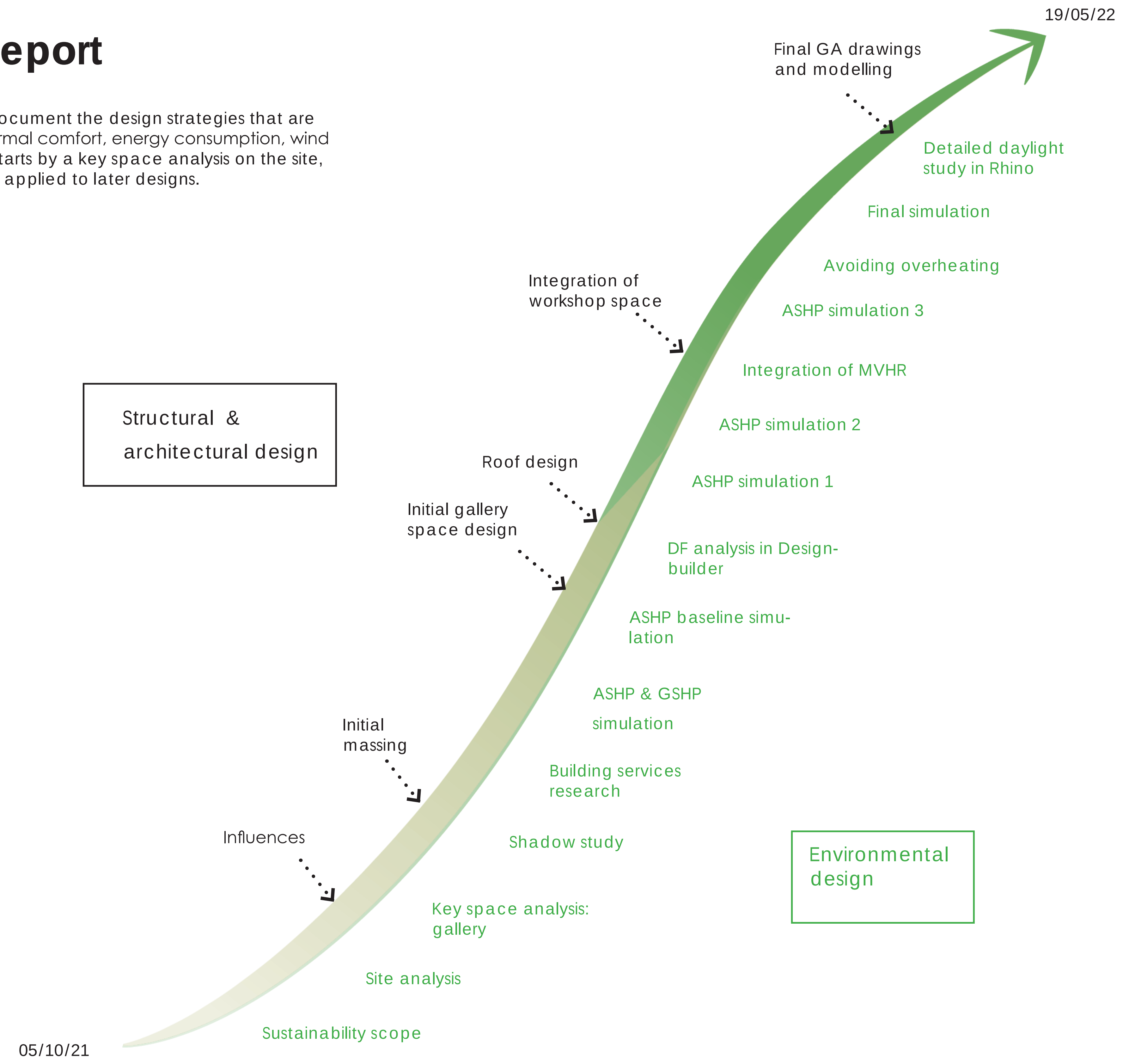
**When** - The construction starts from 2025 and should finish before 2028. The life span of the gallery is designed to be over 100 years.

**Who** - The client of this project is three Russian billionaires who want to make their way into the Highgate community. Highgate, famous for its elite residents and local pride, has protested against new investment from overseas billioniares. As a gesture of showing respect for local heritage and demonstrating architectural taste, they want to fund this gallery project and don't care too much about its cost.

**How** - Daylight, which the local site is deprived of, will serve as the main environmental parameter and design tool. The project is informed by 5 influences - articles, observations, performance materials, occupats of buildings & research - which drive the iterations of designs. Local heritage buildings scattering around streets and corners in Highgate, a series of installations will suture the urban fabric along the architecture journey.

# Environmental Report

The primary aim of the environmental report is to organise and document the design strategies that are influenced by environmental considerations, whether they are thermal comfort, energy consumption, wind resistance or psychological effect by daylight design. The report starts by a key space analysis on the site, where the implications of design strategies can be applied to later designs.



# Project scope

The scopes for thermal comfort and energy consumption are what environmental design decisions will be based on. These benchmarks and targets are set at the beginning of thep project.

## Energy and carbon goals

Heating and hot water:
50kWh/m2

Cooling and mechanical ventilation:
20kWh/m2

U values:
wall-0.15
window-1.1
roof-
30kWh/m2

Lighting:
30kWh/m2

## Thermal comfort goals

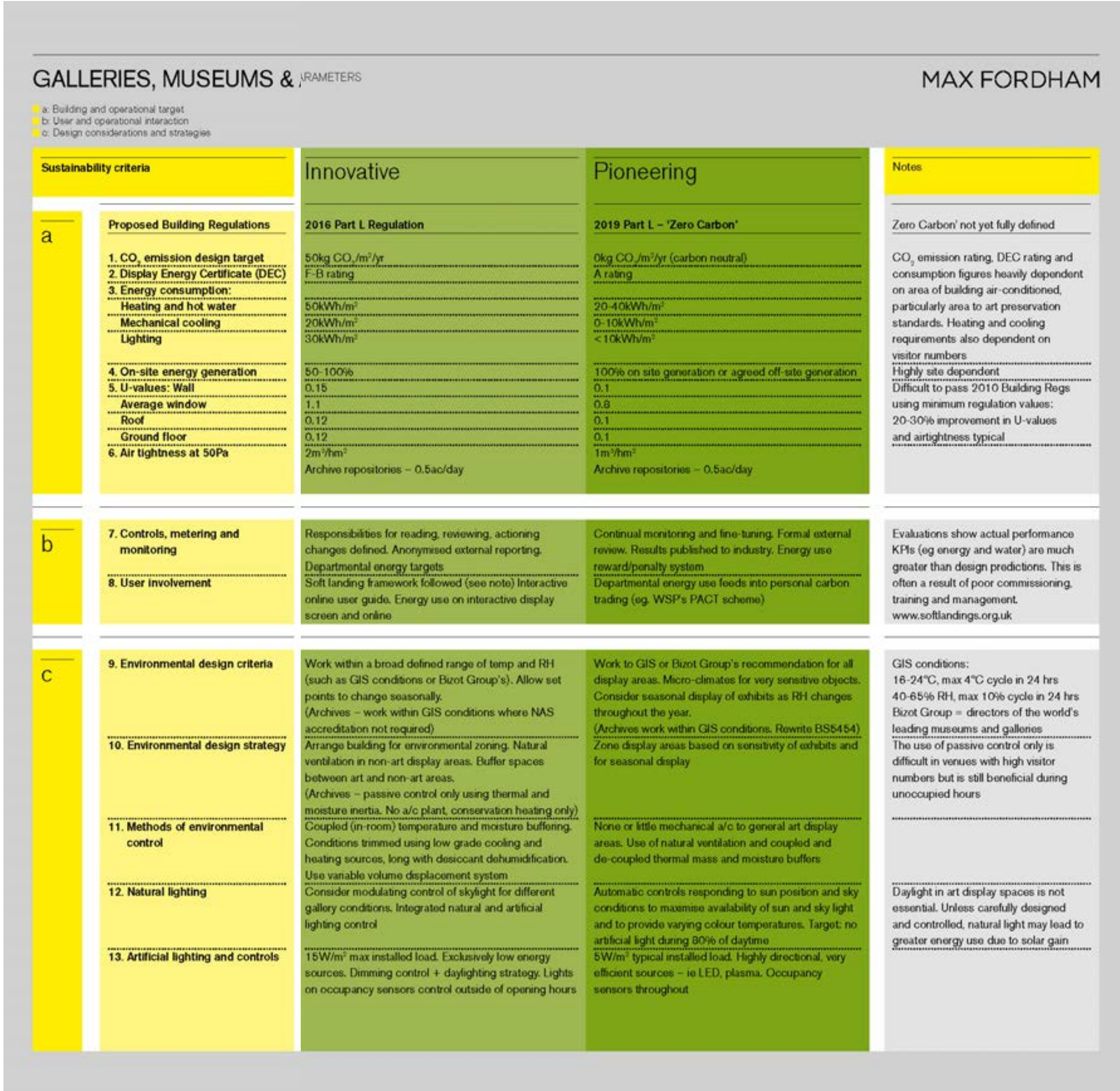
Summer temperature:
20-24 oC, with 5% hours exceptions above or below within occupied hours

Illuminance:
350 lux (gallery)

Minimum fresh air:
10L/s/person

Winter temperature:
20-24 oC, with 5% hours exceptions above or below within occupied hours

Thermal comfort model:
PMV



GALLERIES, MUSEUMS & ARAMETERS

MAX FORDHAM

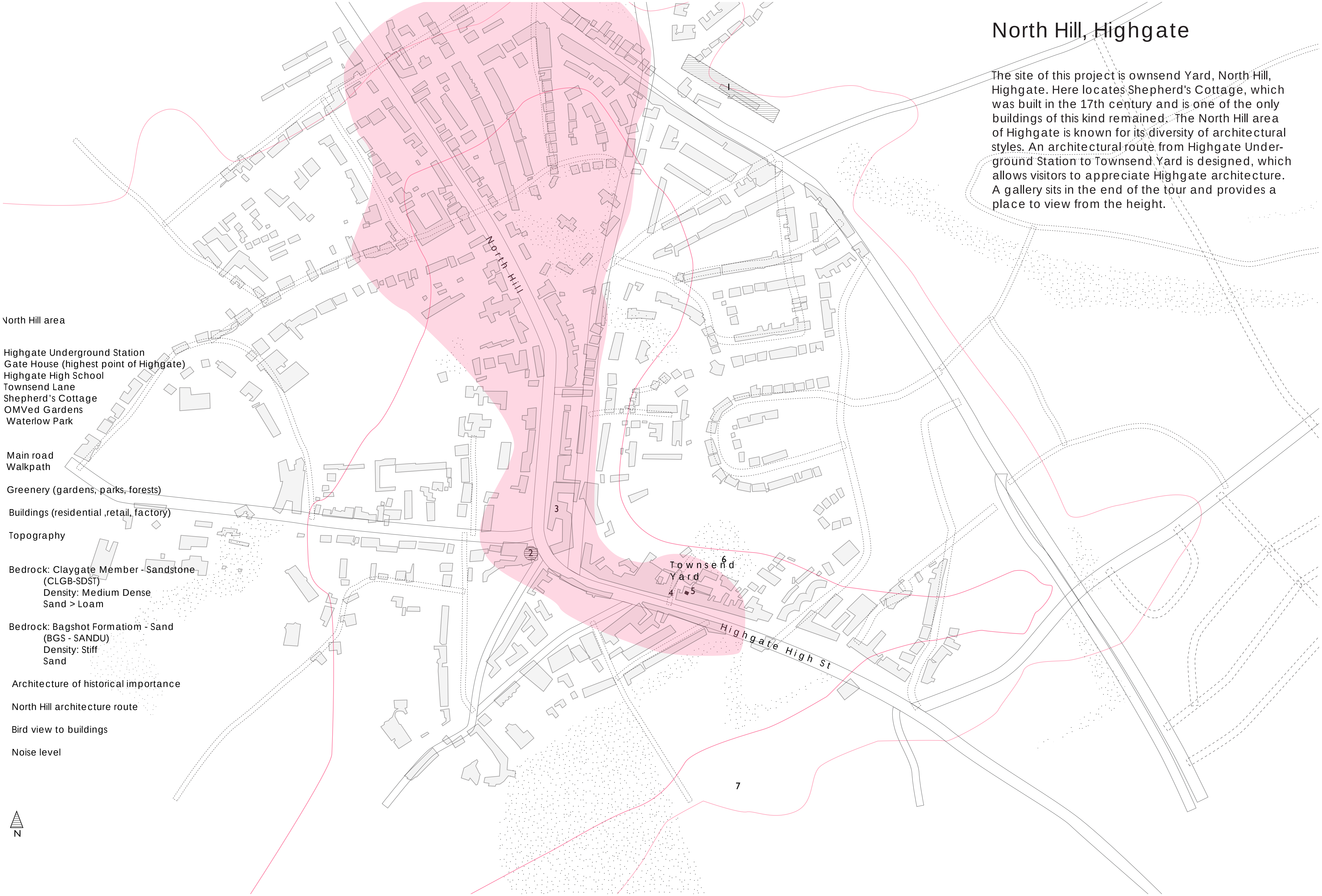
a: Building and operational target
b: User and operational interaction
c: Design considerations and strategies

| | Sustainability criteria | Innovative | Pioneering | Notes |
|---|---|---|---|---|
| a | Proposed Building Regulations | 2016 Part L Regulation | 2019 Part L – 'Zero Carbon' | Zero Carbon' not yet fully defined |
| | 1. $CO_2$ emission design target | 50kg $CO_2/m^2/yr$ | 0kg $CO_2/m^2/yr$ (carbon neutral) | $CO_2$ emission rating, DEC rating and consumption figures heavily dependent on area of building air-conditioned, particularly area to art preservation standards. Heating and cooling requirements also dependent on visitor numbers |
| | 2. Display Energy Certificate (DEC) | F-B rating | A rating | |
| | 3. Energy consumption: | | | |
| | Heating and hot water | $50kWh/m^2$ | $20\text{-}40kWh/m^2$ | |
| | Mechanical cooling | $20kWh/m^2$ | $0\text{-}10kWh/m^2$ | |
| | Lighting | $30kWh/m^2$ | $<10kWh/m^2$ | |
| | 4. On-site energy generation | 50-100% | 100% on site generation or agreed off-site generation | Highly site dependent |
| | 5. U-values: Wall | 0.15 | 0.1 | Difficult to pass 2010 Building Regs using minimum regulation values: 20-30% improvement in U-values and airtightness typical |
| | Average window | 1.1 | 0.8 | |
| | Roof | 0.12 | 0.1 | |
| | Ground floor | 0.12 | 0.1 | |
| | 6. Air tightness at 50Pa | $2m^3/hm^2$ Archive repositories – 0.5ac/day | $1m^3/hm^2$ Archive repositories – 0.5ac/day | |
| b | 7. Controls, metering and monitoring | Responsibilities for reading, reviewing, actioning changes defined. Anonymised external reporting. Departmental energy targets | Continual monitoring and fine-tuning. Formal external review. Results published to industry. Energy use reward/penalty system | Evaluations show actual performance KPIs (eg energy and water) are much greater than design predictions. This is often a result of poor commissioning, training and management. www.softlandings.org.uk |
| | 8. User involvement | Soft landing framework followed (see note) Interactive online user guide. Energy use on interactive display screen and online | Departmental energy use feeds into personal carbon trading (eg. WSP's PACT scheme) | |
| c | 9. Environmental design criteria | Work within a broad defined range of temp and RH (such as GIS conditions or Bizot Group's). Allow set points to change seasonally. (Archives – work within GIS conditions where NAS accreditation not required) | Work to GIS or Bizot Group's recommendation for all display areas. Micro-climates for very sensitive objects. Consider seasonal display of exhibits as RH changes throughout the year. (Archives work within GIS conditions. Rewrite BS5454) | GIS conditions: 16-24°C, max 4°C cycle in 24 hrs 40-65% RH, max 10% cycle in 24 hrs Bizot Group = directors of the world's leading museums and galleries |
| | 10. Environmental design strategy | Arrange building for environmental zoning. Natural ventilation in non-art display areas. Buffer spaces between art and non-art areas. (Archives – passive control only using thermal and moisture inertia. No a/c plant, conservation heating only) | Zone display areas based on sensitivity of exhibits and for seasonal display | The use of passive control only is difficult in venues with high visitor numbers but is still beneficial during unoccupied hours |
| | 11. Methods of environmental control | Coupled (in-room) temperature and moisture buffering. Conditions trimmed using low grade cooling and heating sources, long with desiccant dehumidification. Use variable volume displacement system | None or little mechanical a/c to general art display areas. Use of natural ventilation and coupled and de-coupled thermal mass and moisture buffers | |
| | 12. Natural lighting | Consider modulating control of skylight for different gallery conditions. Integrated natural and artificial lighting control | Automatic controls responding to sun position and sky conditions to maximise availability of sun and sky light and to provide varying colour temperatures. Target: no artificial light during 80% of daytime | Daylight in art display spaces is not essential. Unless carefully designed and controlled, natural light may lead to greater energy use due to solar gain |
| | 13. Artificial lighting and controls | $15W/m^2$ max installed load. Exclusively low energy sources. Dimming control + daylighting strategy. Lights on occupancy sensors control outside of opening hours | $5W/m^2$ typical installed load. Highly directional, very efficient sources – ie LED, plasma. Occupancy sensors throughout | |

Energy benchmark for galleries and museums. 2016 Part L Regulation

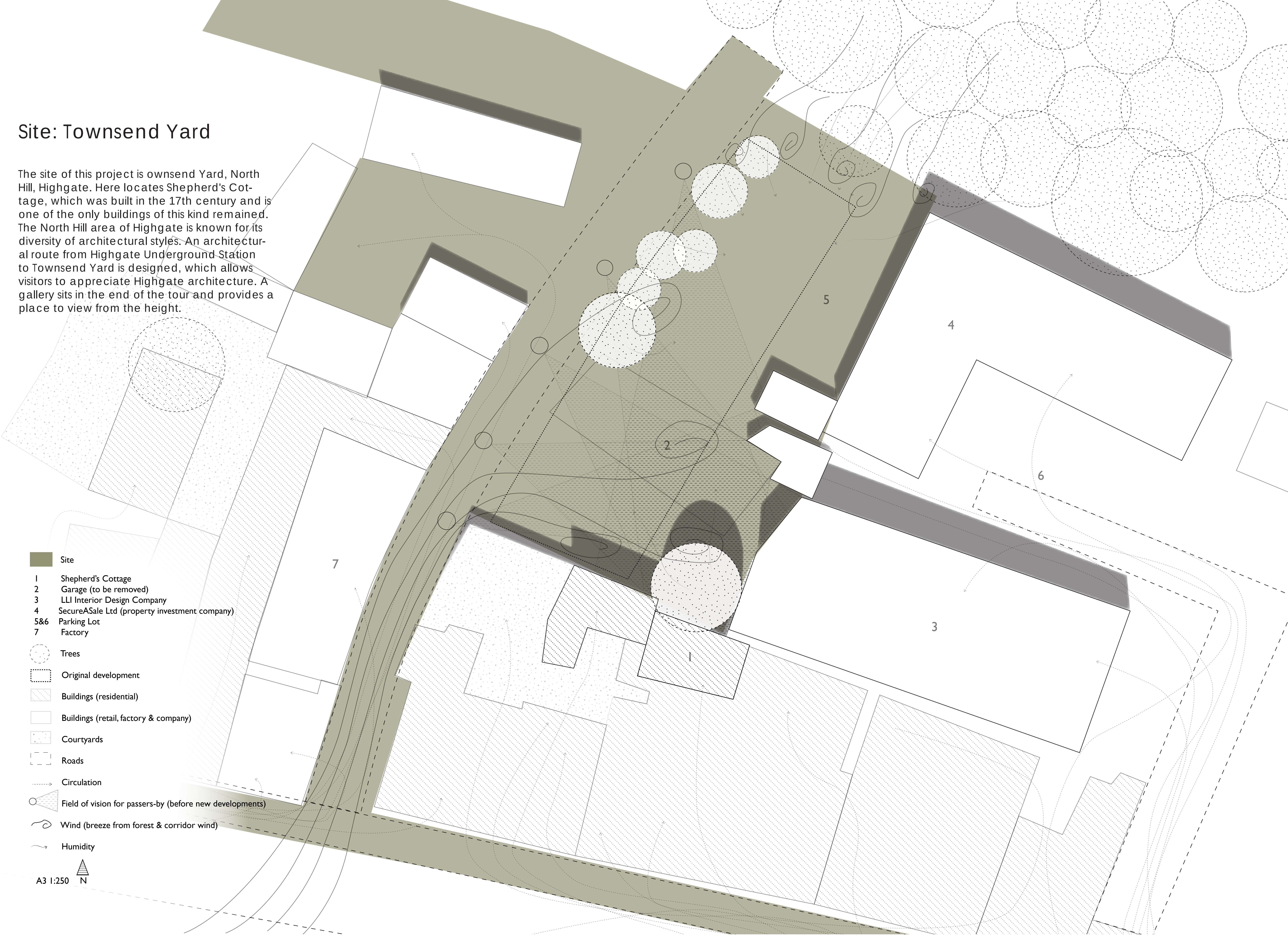
# North Hill, Highgate

The site of this project is ownsend Yard, North Hill, Highgate. Here locates Shepherd's Cottage, which was built in the 17th century and is one of the only buildings of this kind remained. The North Hill area of Highgate is known for its diversity of architectural styles. An architectural route from Highgate Underground Station to Townsend Yard is designed, which allows visitors to appreciate Highgate architecture. A gallery sits in the end of the tour and provides a place to view from the height.



# Site: Townsend Yard

The site of this project is ownsend Yard, North Hill, Highgate. Here locates Shepherd's Cottage, which was built in the 17th century and is one of the only buildings of this kind remained. The North Hill area of Highgate is known for its diversity of architectural styles. An architectural route from Highgate Underground Station to Townsend Yard is designed, which allows visitors to appreciate Highgate architecture. A gallery sits in the end of the tour and provides a place to view from the height.

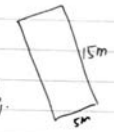


# PHASE I

## Key space analysis

A gallery space is used for primitive analysis. The main parameters for testing are orientation, glazing ratio, window positions and materials choices. Designbuilder is used to simulate daylight factor results in the space (case 1-4).

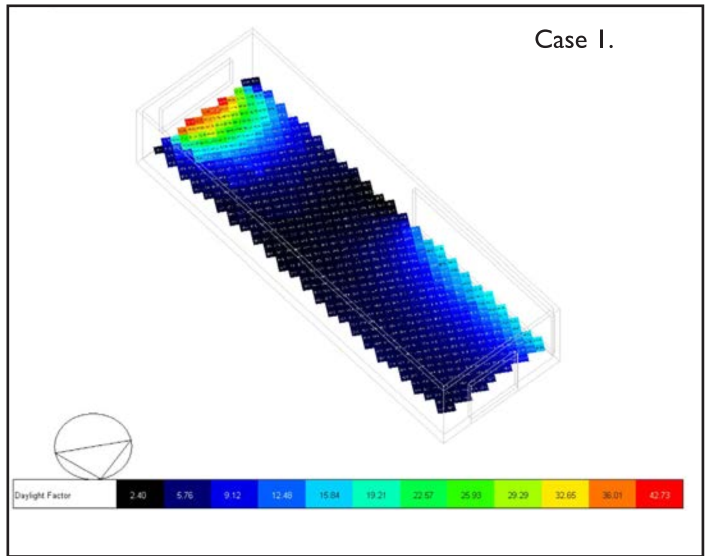
Key space calculation.



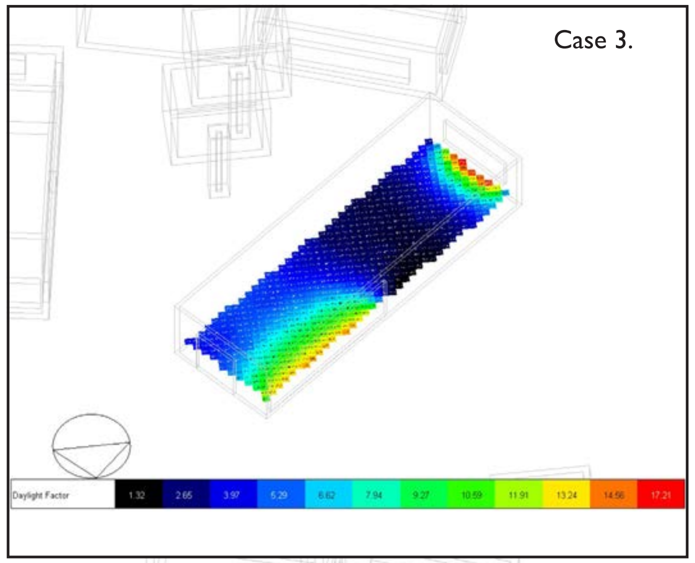

(oriented according to site geometry)
use of space: archive / gallery.
number of occupants: 5
activity type: walking, standing.

| | winter | summer |
|---|---|---|
| temperature: | 18-22 | 18-22. |
| humidity: | 30-50% | 35-55% |

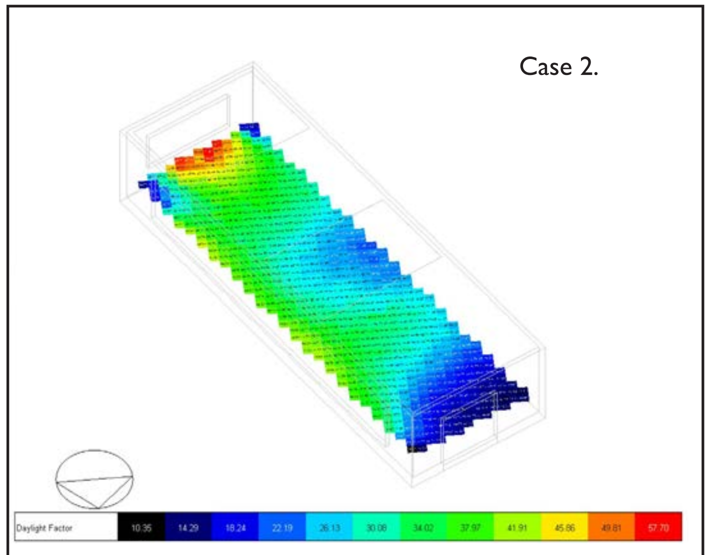
minimum luminance: 50-100 lux.
fresh air requirement: 10 L/s per person
infiltration rate: 0.05 ach. schedule 24/7
metabolic gain: 93 W/person.
lighting gain: 10 W/m².
equipment gain: 5 W/m²
solar gain: assume g value is low.
Assume heating season: 01/10 to 31/06.
Assume energy efficiency: 90%.



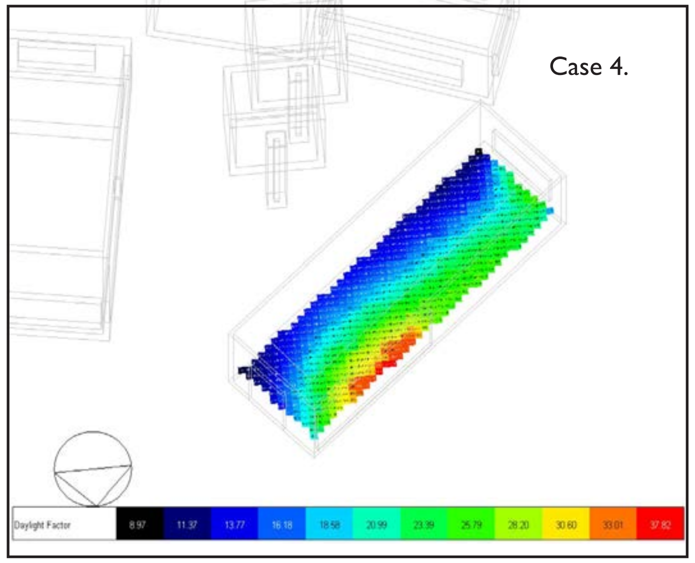

Case 1.




Case 3.




Case 2.




Case 4.





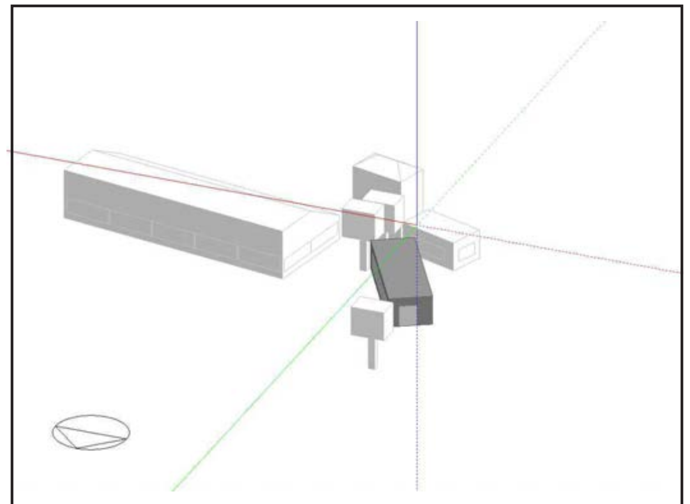
### Use and occupancy

| | |
|---|---|
| **use of space** | Archive / Gallery |
| **number of occupant** | 5 |
| **activity type** | Walking, standing |
| **expected internal gain** | in hand calc |

### Taget environmental conditions

| | **winter** | **summer** |
|---|---|---|
| **temp** | 18-20 | 18-22 |
| **humidity** | 30-50 % | 35-55 % |
| **minimum lumminance** | 50-100 | 50-100 |
| **minimum fresh air requirements** | 10 L/s per person | 10 L/s per person |

Combinations of orientations and window positions (4 cases) are tested. A daylight factor of 5 should be reached throughout the space, and this can only be achieved by having roof windows (case 2&4). There can be a problem of overheating by windows, so shadings should be applied. A key space design is developed from case 2. Glazing ratio of roof light is adjusted, and U values of surfaces are set to the same values as in hand calculation. Summer cooling is turned off, and surrounding buildings are also modelled.



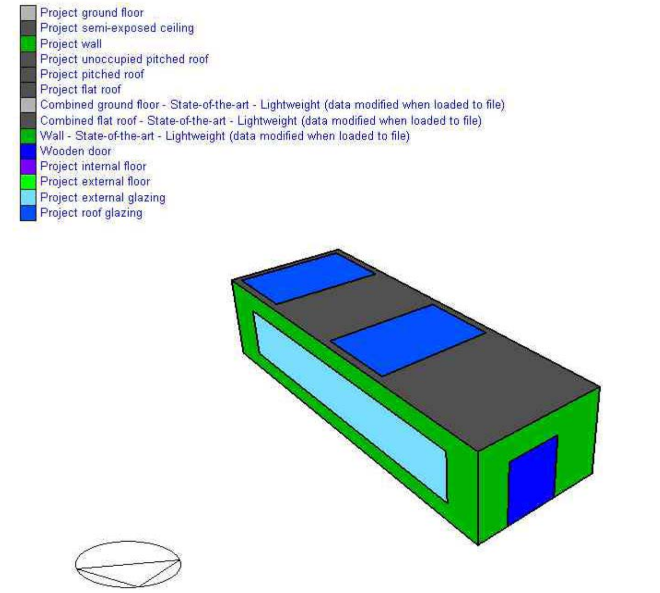
**Skylight-Roof Ratio**

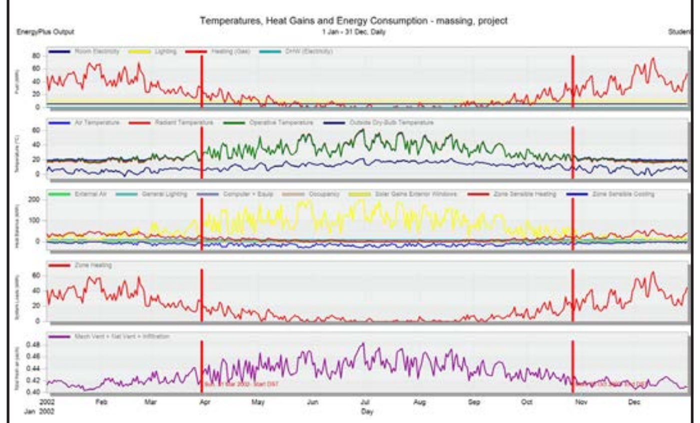
| | Total |
|---|---|
| Gross Roof Area [m2] | 83.22 |
| Skylight Area [m2] | 28.00 |
| Skylight-Roof Ratio [%] | 33.64 |

**Building Area**

| | Area [m2] |
|---|---|
| Total Building Area | 77.51 |
| Net Conditioned Building Area | 77.51 |
| Unconditioned Building Area | 0.00 |

Simulation settings




Simulation results.

**Utility Use Per Conditioned Floor Area**

| | Electricity Intensity [kWh/m2] | Natural Gas Intensity [kWh/m2] | Gasoline Intensity [kWh/m2] | Diesel Intensity [kWh/m2] | Coal Intensity [kWh/m2] | Fuel Oil No 1 Intensity [kWh/m2] | Fuel Oil No 2 Intensity [kWh/m2] | Propane Intensity [kWh/m2] | Other Fuel 1 Intensity [kWh/m2] | Other Fuel 2 Intensity [kWh/m2] | District Cooling Intensity [kWh/m2] | District Heating Intensity [kWh/m2] | Water Intensity [m3/m2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lighting | 43.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| HVAC | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 83.75 | 0.01 |
| Other | 13.59 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 57.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 83.75 | 0.01 |

DesignBuilder simulation results

Key space calculation.

(oriented according to site geometry)

use of space: archive / gallery.

number of occupants: 5

activity type: walking, standing.

15m

5m

N

| | winter | summer |
|---|---|---|
| temperature: | 19-22 | 19-22. |
| humidity: | 30-50% | 35-55% |

minimum luminance: 50-100 lux.

fresh air requirement: 10 L/s per person

infiltration rate: 0.05 ach. schedule 24/7.

metabolic gain: 93 W/person.

lighting gain: 10 W/m².

equipment gain: 5 W/m²

solar gain: assume g value is low.

Assume heating season: 01/10 to 31/06.

Assume energy efficiency: 90%.

transmission heat losses:

| surface | U-value (W/m²·K) | area. | UA (W/·K) |
|---|---|---|---|
| floor | ~~2.49+0.156~~ 0.319. | 75 | 23.55 |
| roof | 0.346 | 37.5 | 12.975 |
| walls | 0.263 | 140 ~~152.5~~ | 36.812 |
| window | 1.96 | 37.5 | ~~147~~ 73.5 |
| doors. | 2.823 | 2.5 | 7.06 |

$\Sigma(UA) = 153.9$

Fabric heat loss $= \Sigma UA\,(T_{internal} - T_{external})$

$= 153.9 \times (19-(-3)) = 3.386$ kW.

ventilation heat loss $= m \cdot c \cdot (T_{int} - T_{ext})$

$= \rho V c\,(T_{int} - T_{ext})$

$= 1.2\,(kg/m^3) \times V_{air} \times 1005\,(J/kg \cdot K) \times (19-(-3))$

$= 0.33 \times ACH \times V_{room} \times (19-(-3))$

$= 0.33 \times 0.05 \times 262.5 \times 22 = 0.095$ kW.

Total heat loss = Fabric heat loss + ventilation heat loss

$= 3.386 + 0.095 = 3.481$ kW.

Normalised heating load $= 3.481\ kW / 75 m^2 = 46.41\ kW/m^2$

this doesn't take into account of internal gains

Calculation of internal gain:

- metabolic: $5 \times 93$ W/person $= 465$ W
- lighting: $10\ W/m^2 \times 75\ m^2 = 750$ W.
- equipment: $5\ W/m^2 \times 75\ m^2 = 375$ W.
- solar gain: ~~negligible~~ difficult to calculate.

total internal gain = 1.59 kW. allow for 50% diversity.

Heat loss calculation:

- assume average outdoor temperature during heating season is 6°C. for typical UK climate.
- Fabric heat loss $= \Sigma UA \times (T_{int} - T_{ext}) = 153.9 \times (19-6) = 2$ kW.
- Ventilation heat loss $= 0.33 \times ACH \times V_{room} \times (T_{int} - T_{ext})$

$= 0.33 \times 0.05 \times 75 \times (19-6) \times 3.5$

$= 0.056$ kW.

Specific heat loss (S.H.L) $= \dfrac{(\text{Fabric heat loss} + \text{ventilation heat loss})}{(T_{int} - T_{ext})}$

$= \dfrac{2\ kW + 0.056\ kW}{(19-6)°C} = 0.158\ kW/°C$

$= 158\ W/°C$.

For worst case ~~for~~ scenario, internal gain is at its min = 0.795 kW.

Temperature increase due to internal gain $= \dfrac{795\ W}{158\ W/°C} = 5°C$.

Internal temperature as a result of internal gain = 6°C + 5°C = 11°C.

Therefore, the heating system only needs to raise the temperature from 11°C to 19°C, instead of from 6°C to 19°C.

- Total heat loss $= S.H.L \times \Delta T = 158\ W/°C \cdot 8°C = 1.264$ kW.

The heating system needs to provide the heat loss.

- Heating season from 01/10 to 31/06 (6 months)

number of hours: 6 months × 30 days/month × 24 hrs/day = 4320 hrs per heating season.

- Energy demand = 1.264 kW × 4320 hrs = 5460.5 kWh
- Assume gas-fired boiler has efficiency 90%.

estimated energy use $= \dfrac{5460.5}{90\%} = 6067.2$ kWh.

- Normalised heating energy use $= \dfrac{6067.2\ kwh}{75\ m^2} = 80.9\ kwh/m^2$.
- Assume gas price is 4p/kwh,

estimated heating cost $= 0.04$ £/kwh × 80.9 kwh/m² = 3.236 £ per year per square meter

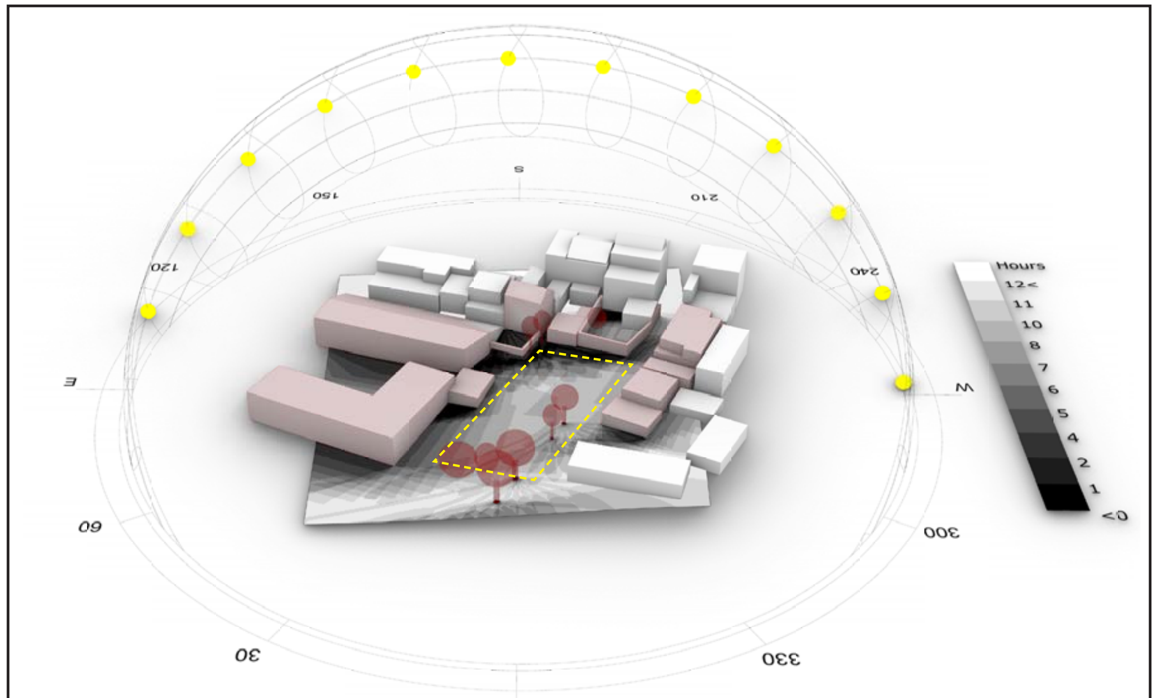
Sustainability criteria:

| | 2016 Part L | 2019 Part L - zero carbon |
|---|---|---|
| heating consumption. | 50 kwh/m² | 20-40 kwh/m² |
| mechanical cooling. | 20 kwh/m² | 0-10 kwh/m² |
| lighting | 30 kwh/m² | <10 kwh/m² |
| U values: wall | 0.15 | 0.1 |
| window. | 1.1 | 0.8 |
| roof. | 0.12 | 0.1 |
| ground floor. | 0.12 | 0.1 |

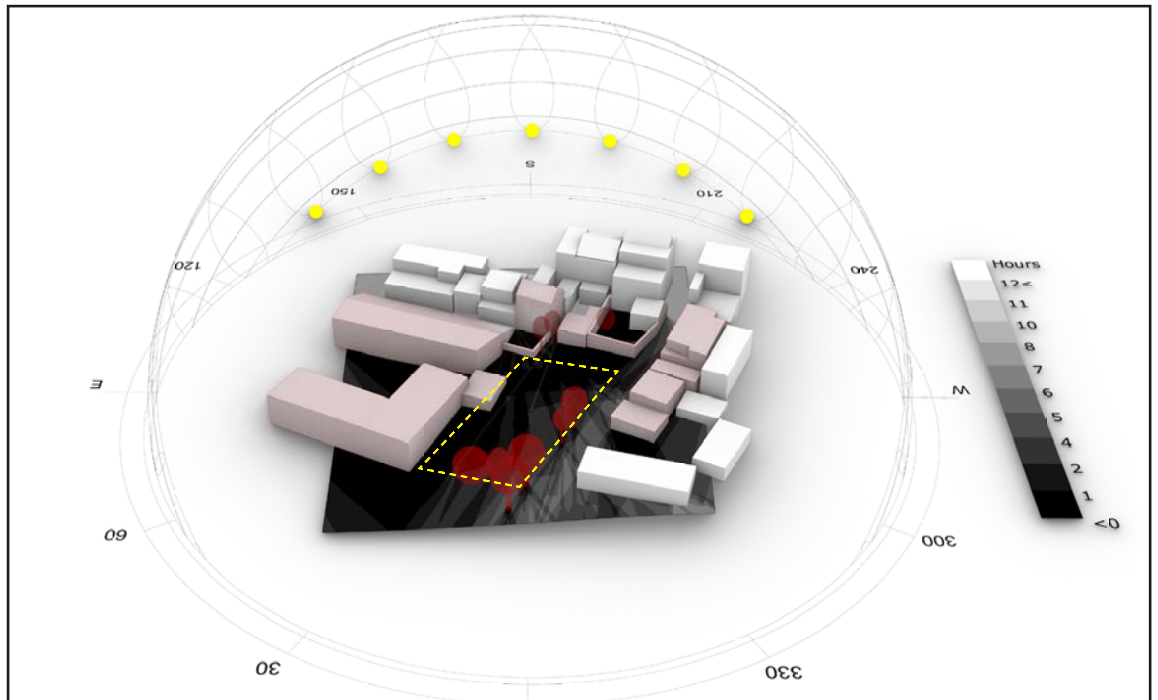
The result of key space is 80.9 kwh/m² of normalised heating energy, which is more than two times higher than a zero-carbon criteria. This can be caused by the high U-values of window and door, and by the large ~~glass~~ glazing area on the roof. To reach better energy performance, glazing areas should be reduced (good daylight factor has been achieved), and better U values should be used for materials.

Hand calculation :energy consumption of the key space

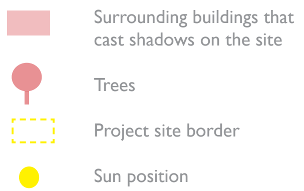
The results of normalised heating load for Design Builder simulation and the hand calculation are similar (83.75 kwh/m2 and 80.9 kwh/m2), which means that the hand calculation can be used to validate simulation results, given the correct parameters are used or generated. According to the environmental design guide for gallery spaces publishsed by Max Fordham, the key space can meet the standard of 'innovative' criteria where Part L regulation is applied and a maximum energy consumption of 80 kwh/m2 (heating adn lighting) should be achived. However, the key space has an energy consumption more than two times higher than a zero-carbon 'pioneering' criteria, which means that on-site resources must be applied to achieve a carbon neutral design.



Shadow range and sunlight hours on Mar 21



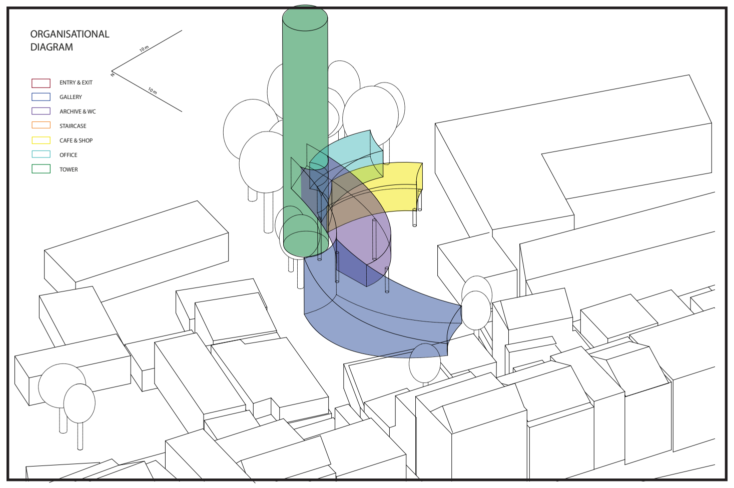
Shadow range and sunlight hours on Dec 22



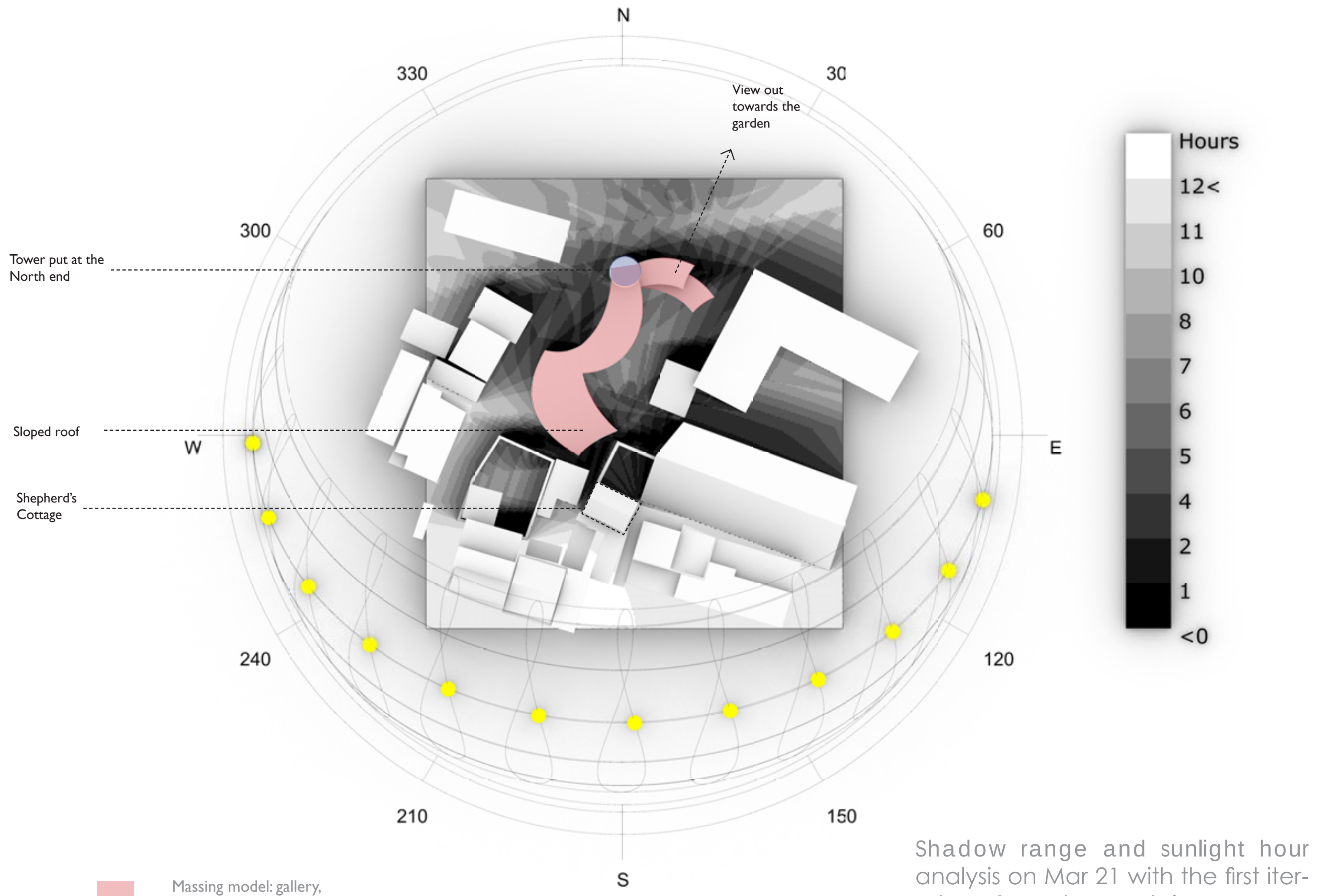

Both surrounding buildings and trees are modelled to simulate the sunlight hours and shadings on the site. On Dec 22 when the sunlight hour is at its minimum, only an average of 1h of sunlight is received on the site. And on March 21 it is about 10 hours. It can be observed that most shadows are generated around the corners of the surrounding buildings, and the most shaded area is the Southern part of the site. Therefore, a sloped design with lower height on the south and higher height on the north is appropriate for the site. The tower should be put at the north end to minimise its impact on the light for existing buildings and it can hide itself among the trees in the OMVed gardens.



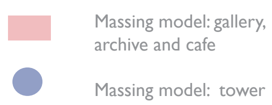




Preliminary mass model




Shadow range and sunlight hour analysis on Mar 21 with the first iteration of massing models




The simulation looks into how an open-plan design can maximise its sunlight penetration. March 21 is selected as a typical day of a year. The tower is put at the North end of the site so that the shadow it casts will not affect existing buildings, and the South end of the structure is lower to minimise its impact on the view towards Shepherd's Cottage.

# Building service systems

It has been analysed in Phase 1 that a passive system alone is not enough to meet the requirement of the gallery space. Case studies for mechanical systems are conducted to explore the most site-appropriate and low-energy-consumption system.

A ranking of mechanical systems by CIBSE shows that best MEP systems include:

1. central ASHP +heat network + direct-electric DHW

2. individual ASHP with direct-electric DHW top-up

3. two-stage MVHR+EAHP (mechanical ventilation with heat recovery+exhaust air heat pump)

The analysis into case studies inform the choice for this project:

- lighting: maximised daylight with assisting artificial lighting during the day, LED ambient lighting during the night.

- ventilation: natural ventilation through the roof openings for 9 months of a year.

- cooling: ventilation + chilled beam during summer

- heating: two-stage MVHR+EAHP.

These systems are simulated in Design Builder in order to compare their performance, features and restrictions.

**Case study: Packard Foundation HQ:**

- lighting: low-energy LEDs, and ambient light levels are dimmed in response to daylight levels

- Water: rainwater collection stored in underground tank

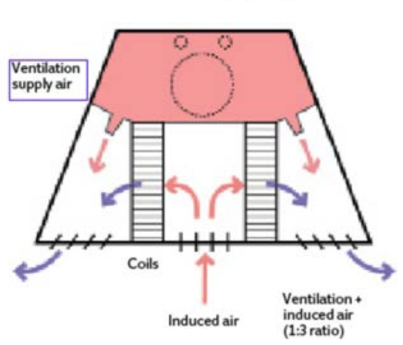
- Passive design for 9 months of a year, enabling the building to be naturally ventilated

- Cooling: in August / September two-pipe active chilled beam system is used. Roof-mounted photovoltaic array is used to minimise energy demand. Chilled beams, designed correctly and incorporating waterside economisers, use significantly less energy than VAV.

- Fresh air: dedicated outside air ventilation unit

- Heating: perimeter heating system, where hot water pipes deliver heat to the chilled beam. Downsizing and simplifying the mechanical system.

**Chilled and hot water piping**




| System | Zero carbon future | Energy saving | Service charge | Bills | Capital cost | Sum |
|---|---|---|---|---|---|---|
| 1. Individual gas boilers | 1 | 1 | 3 | 3 | 5 | 13 |
| 2. Gas boiler district heating | 1 | 1 | 2 | 2 | 2 | 8 |
| 3. Gas boiler + CHP district heating | 1 | 2 | 1 | 1 | 1 | 6 |
| 4. Gas boiler + ASHP district heating | 3 | 3 | 1 | 1 | 1 | 9 |
| 5. Gas boiler + GSHP district heating | 3 | 3 | 1 | 1 | 1 | 9 |
| 6. Central ASHP + heat network + direct-electric DHW | 4 | 3 | 2 | 2 | 3 | 14 |
| 7. Central ASHP + heat network + individual WSHP | 5 | 4 | 2 | 4 | 2 | 17 |
| 8. Individual ASHP with direct-electric DHW top-up | 4 | 3 | 5 | 3 | 5 | 20 |
| 9. One-stage EAHP + direct-electric heating | 4 | 2 | 4 | 2 | 4 | 16 |
| 10. One-stage EAHP + gas boiler district heating | 1 | 3 | 2 | 3 | 2 | 11 |
| 11. Two-stage MVHR+EAHP | 5 | 5 | 4 | 5 | 4 | 23 |
| Ranking: 1 Poor, 2, 3 Mid, 4, 5 Best; Key considerations: | Grid electricity accessibility; peak demand management; smoothing of demand peaks | Code compliance; standing losses; COPs; source temperature; network temperature | System extent; network losses; component count; interface units; billing system; gas servicing | Energy billed; service charges; standing losses; outsourcing overhead | System extent; component count; construction interfaces; modularisation potential | |

Rankings of systems published by CIBSE



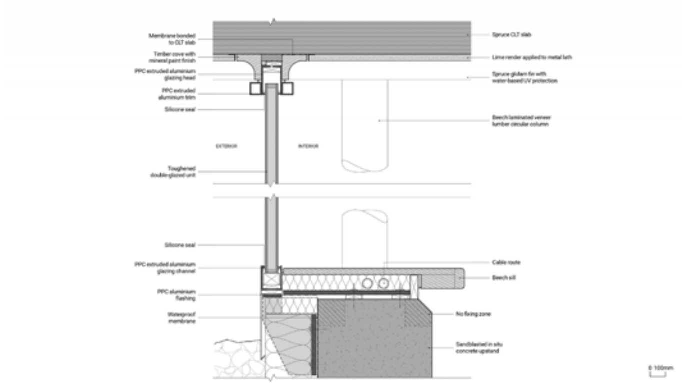


**Case study: Maggie's centre:**

- Farbric-first design approach, with excellent airtightness makes the heating demand very low. Large glazing areas favour the low winter sun, making good use of solar heat.

- Well positioned openings draw air through the building, eliminating the need for intensive summer cooling.

Fixed glazing typical detail section



## Case study: Advanced engineering building (University of Queensland)

Building services and facilities are carefully exposed and displayed. The building itself provides a research and teaching opportunity in engineering and sustainability. Instruments were integrated into built elements to allow real-time monitoring of its structural and climatic performance. The building has thereby become a learning tool.

**Case study: Cambridge Mosque**

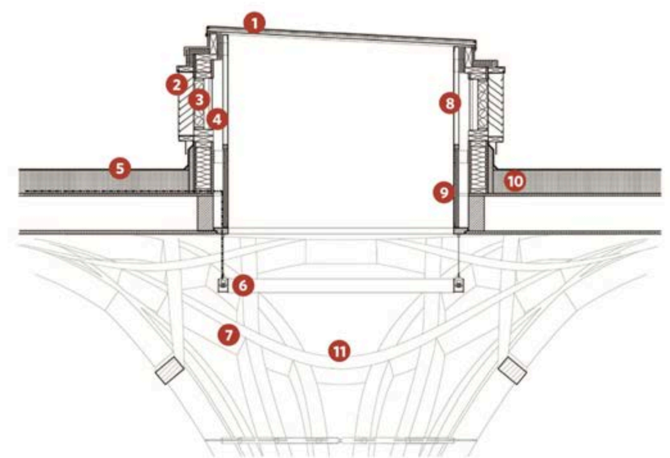
- Lighting: no artificial light needed during daytime, 150-200 lux is maintained. Bespoke circular LED light is fitted around the rooflight.

- Ventilation: challenging, because of the variation of occupancy. Fresh air is drawn at low level through square grilles which are set into walls.

- Heating & cooling: underfloor heating and cooling system .Two roof-mounted, air source heat pumps supply the system with heat and coolth, via buffer vessels housed in the basement plant room.

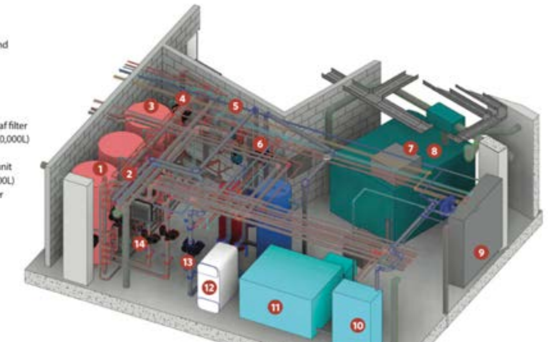
- Hot water: no gas on site, so heat pumps are used. Direct hot water heater is created to meet the large

Section view of the mosque's rooflight design



1 Fixed glazed low g-value roof light, modelled with a deep reveal to maximise daylighting while minimising direct sunlight into the prayer hall
2 Attenuated external louvre, complete with access to damper motor
3 Thermal damper with U-value and air tightness better than façade system – opens according to $CO_2$ levels and temperature within the prayer hall
4 Axial fan located behind thermal damper to boost airflow in peak summertime conditions
5 Rainwater run-off used both for flushing WCs and garden irrigation
6 Bespoke LED lighting rings (with central battery backup) to boost daylight levels when needed, with daylight dimming and scene control
7 Spokes of 'tree' help to diffuse natural and artificial light and control reverberation times within the prayer hall
8 Pressure differential across the perforated lining allows opposite extract fan to run without short-circuiting
9 Acoustic lining to window reveal to help reduce fan noise and control noise breakout from prayer
10 Air tightness of < $3m^3 \cdot h^{-1} \cdot m^{-2}$ @ 50Pa and U-value < $0.15W \cdot m^{-2} \cdot K^{-1}$
11 Prayer hall height > 8m provides driving force for natural ventilation stack effect, and ample volume for stratification of hot air above occupants

Plant room
1 Low-loss header
2 Incoming primary heating and cooling pipework
3 Three 1,500L thermal stores
4 Primary heating pumps
5 Pressurisation unit
6 Primary cooling pumps
7 Rainwater harvesting tank leaf filter
8 Rainwater harvesting tank (10,000L)
9 Mechanical control panel
10 Chlorine dioxide treatment unit
11 Cold water storage tank (1,700L)
12 Cooling plate heat exchanger
13 Secondary cooling pump
14 Tertiary heating pumps



# Heat pumps

Heat pumps are currently the frontrunner to replace gas boilers over the coming decades as the country moves towards net zero. Other common HVAC systems such as CAV, VAV and FCUs can also achieve good efficiency if properly designed, installed and operated. However, they still require heating or cooling coils which use gas boilers or electricity to heat/ cool water or air. Heat pumps, on the other hand, use compressors to heat or cool air/water, which are considered to be more efficient and applicable to future designs.

There are three main types of heat pumps: ground /water source heat pumps, air source heat pumps, and exhaust air heat pumps. Exhaust air heat pumps combine the functions of ASHPs and MVHR systems, which an effectively use and recycle energy. This project mainly uses DesignBuilder for energy simuilation, and starts with default ASHP and GSHP options. More components and schedules will then be modified.

Pros and cons of ASHP and GSHP are analyzed and compared. The decision making is not only dependent on the results of energy simulation, but also on who the client is. It is decided that the client of this project will be foreign investors who want to contribute to Highgate communities. They will probably want the most efficient and least energy-consuming options.

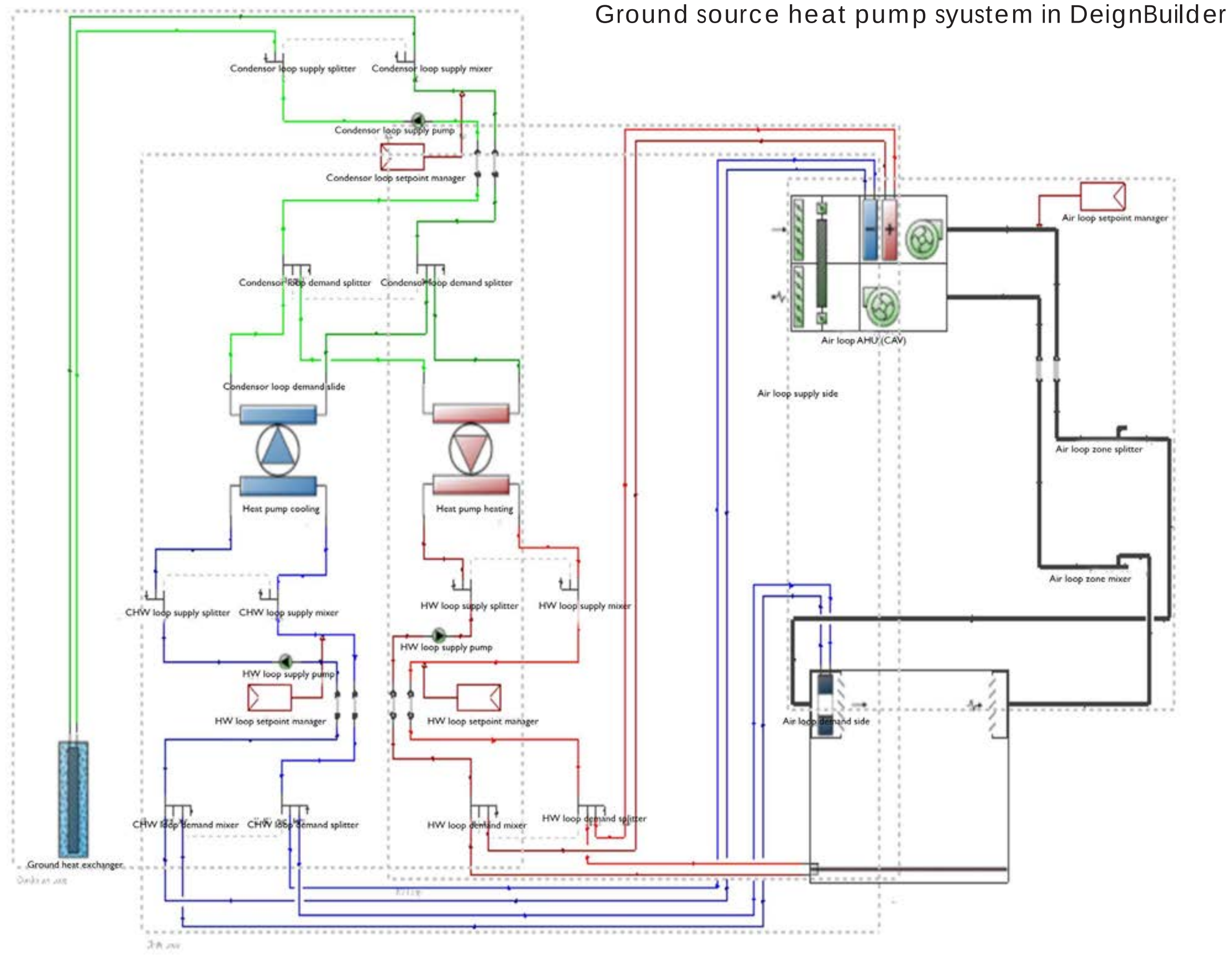
The components and configurations of GSHP and ASHP systems are shown on the page on the right. The default GSHP system has built-in heated floors and chilled beams, whereas the defult ASHP system only uses natural ventilation, radiators and no cooling. These settings will be adjusted according to the service systems selected for this project.

| | GSHP | ASHP |
|---|---|---|
| **Energy efficiency** | Generally more efficient. In climates with very low winter temperatures, ground source heat pumps may seem a more suitable choice, as they extract heat from the ground and perform well in freezing cold temperatures. | Generally less efficient. Works best in moderate climates. The efficiency of an air to water heat pump is most optimal at 7°C, as opposed to dry and cold locations, where outside temperatures fall below -20°C. |
| **Risk & uncertainty** | More risk during pipe boring because of potential unpredicted geotechnical difficulties. | Less risk of installation. More precedent examples. |
| **Cost** | More expensive for installation. Extra cost for underfloor heating. Low maintenance cost. Life span of 25 years. | Cheaper for installation. Low maintenance cost. Life span of 20 years. |
| **Intervention on surroundings** | Less noisy during operation. More intervention during construction because deep holes need to be bored. | More noisy, more impact on surrounding residential buildings during operation. Less intervention during installation. |
| **Aesthetics** | Facilities are mostly buried underground, making it less visible to visitors. | Large heat pumps have to be hung outside to extract air, potentially making it more messy. |

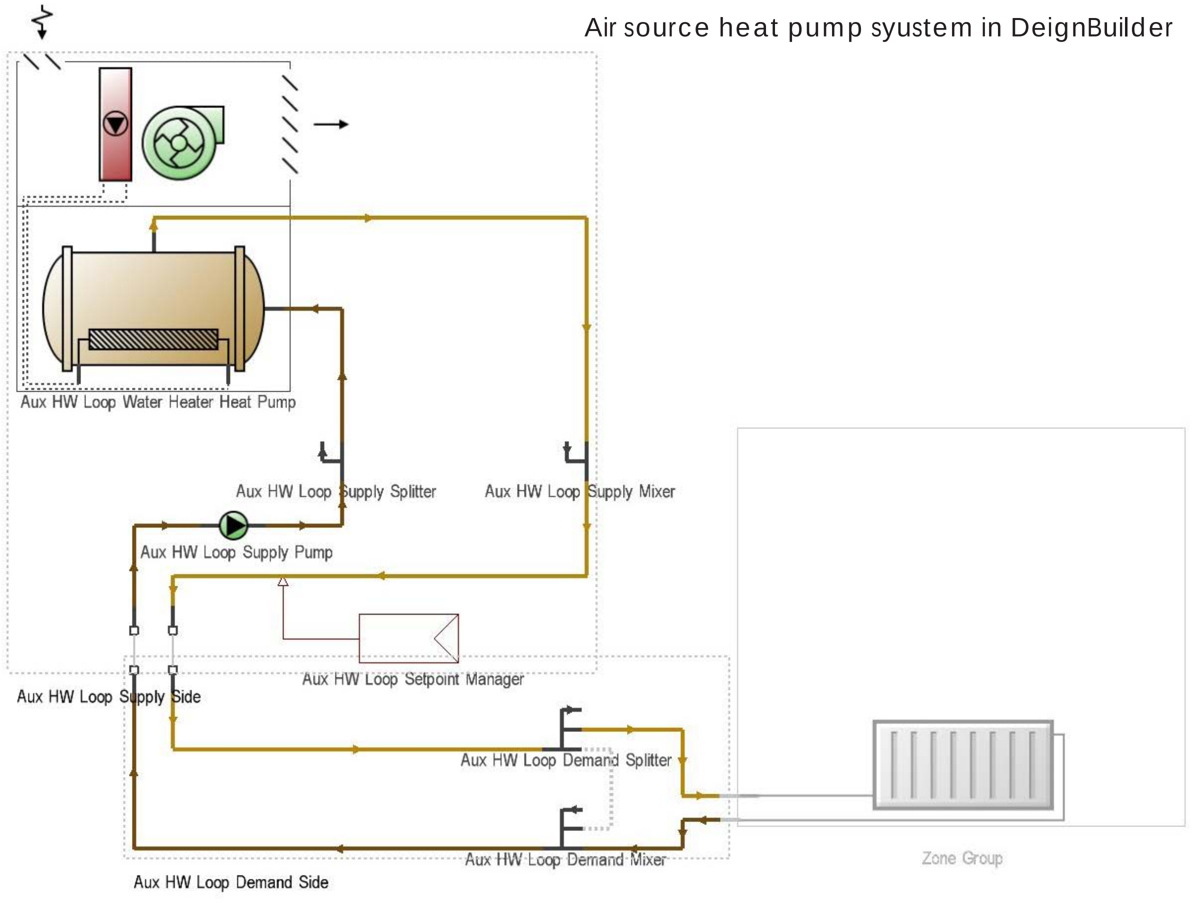




Ground source heat pump syustem in DeignBuilder



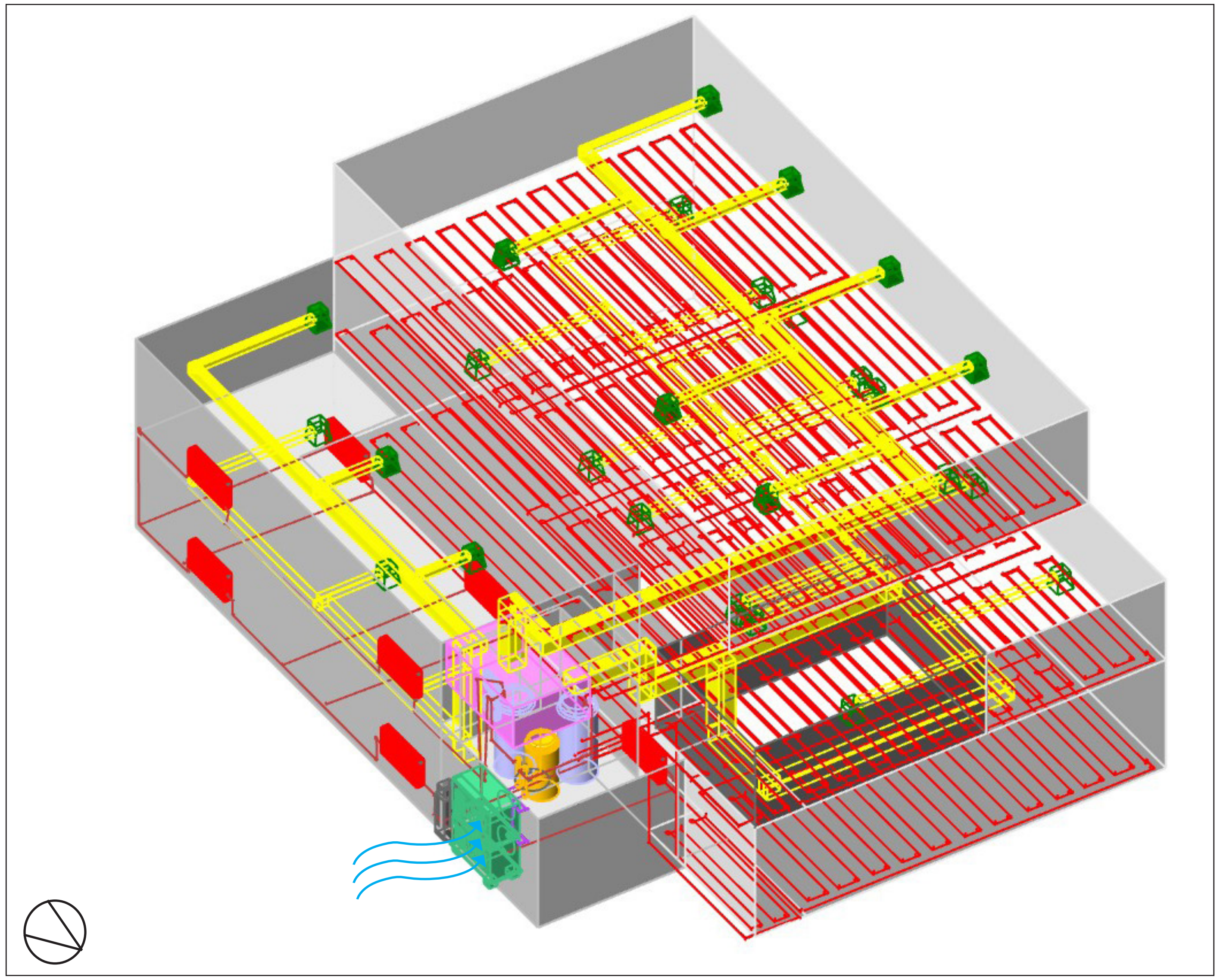

Air source heat pump syustem in DeignBuilder



# PHASE II

## GSHP & ASHP: general arrangement

Arrangement of facilities are explored. Plants and services are put to the North side to reduce their impact on surrounding buildings. Lighting and DHW supply are yet to be considered.



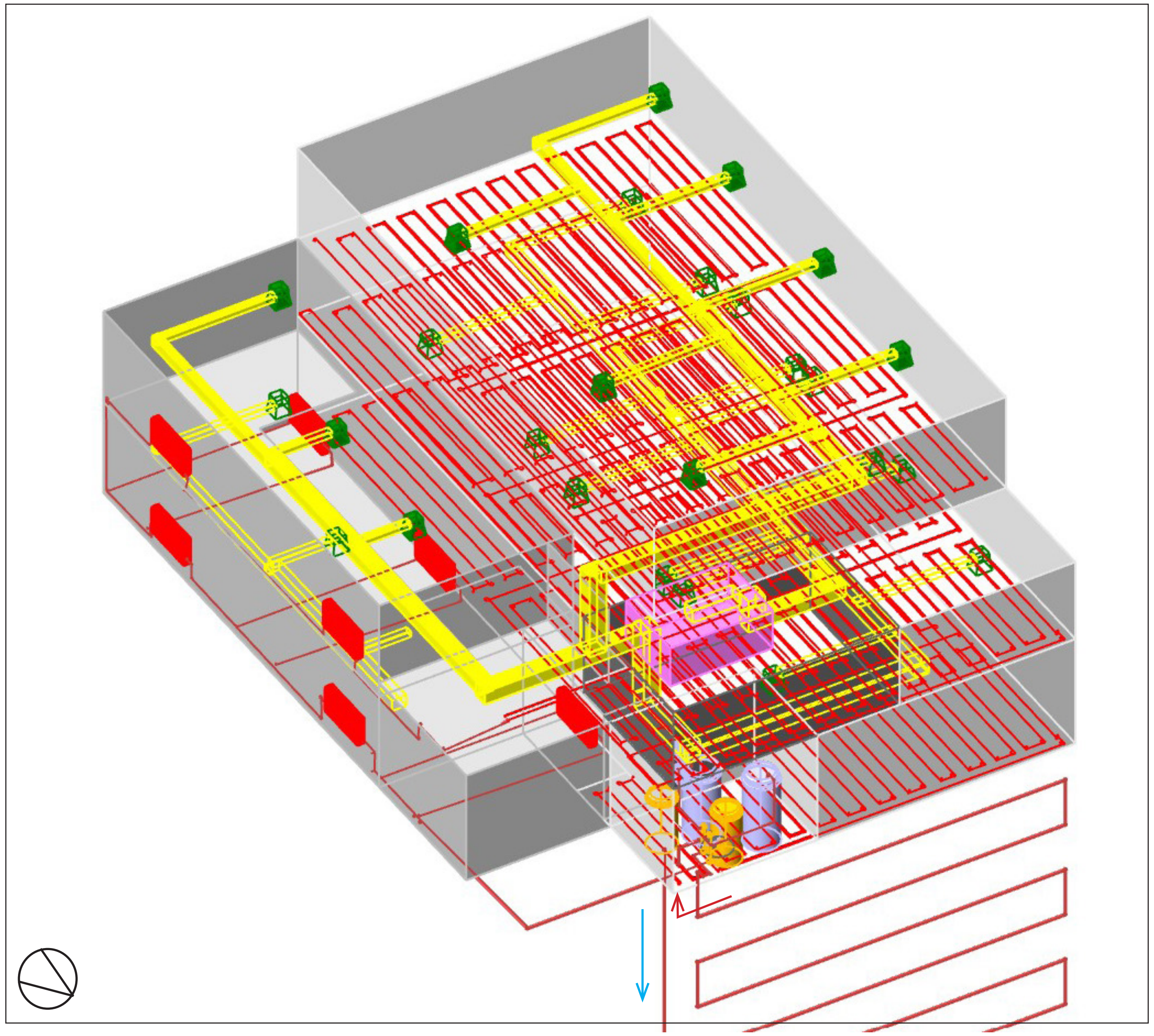
- Air source heat pumps
- Hot air
- Water tanks
- Convectors
- Air handling units
- Ventilation ducts
- Ventilation diffusers
- Radiators in the workshop
- Hot water in nderfloor heating in the gallery

### ASHP schematic

A plant room of 20m2 is designed to contain water tanks, convectors and relevant facilities. Heat pumps that extract air need to be installed outside of the plant room, and a seperate AHU should be installed on the roof. The heat pumps need to be at a distance from surrounding buildings to enable enough fresh air to be extracted, which sets a series of constraints. Noise can also be a problem.







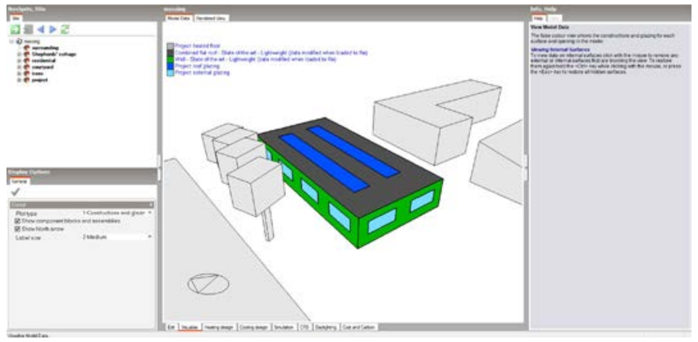
- Hot pipe
- Cold pipe
- Water tanks
- Convectors
- Air handling units
- Ventilation ducts
- Ventilation diffusers
- Radiators in the workshop
- Hot water in nderfloor heating in the gallery

### GSHP schematic

Ground source heat pumps can use heat from deep underground. A vertical system instead of a horizontal one is more suitable for the crowded site. A plant room is also needed to contain water tanks and relevant facilities. A GSHP system is less noisy and has less constraints of minimum distance from surrounding buildings. However, it is more expensive and risky, and can cause much disturbance when boring holes on the site.

# GSHP & ASHP: Simulation

Default systems of GSHP and ASHP are simulated in DesignBuilder on a single zone model. The comparison is only used for reference for early system analysis and system design.



**1**. Without mechanical ventilation, the radiant temperature becomes exceptionally high in the ASHP simulation. This means that given the glazing ratio of the model, mechanical vent and cooling are essential to keeping the air temperature at an ideal level in summer.

**2**. Without chillers and dehumidification measures, the humidity ratio in the ASHP simulation becomes too high in winter times. In the GSHP system, however, the humidity ratio is too low in Feb and March. This means that humidification measures should be applied, which can be set up in Deignbuilder HVAC settings.

**3**. The solar gains are too high during the summer, which leads to huge cooling loads in the GSHP system. The size of roof windows should be decreased, and shadings should be applied.

**4**. The latent load of the ASHP system in the summer is very high, which may have led to the over-dehumidification, as shown in **2**. The reason for this can be a wrong setting of dehumidifiers, which does not switch off when the humidity ratio is below 50%.

**5**. The results of lighting and room electricity of both systems are constant, which means the schedule setting of the simulations are not appropriate. The system fans operate constantly in the GSHP system and variably in the ASHP system, and the heat pumps operate normally in the GSHP system, but they barely work in the ASHP system. This also means that the settings need to be more carefully adjusted.

**Summary:**

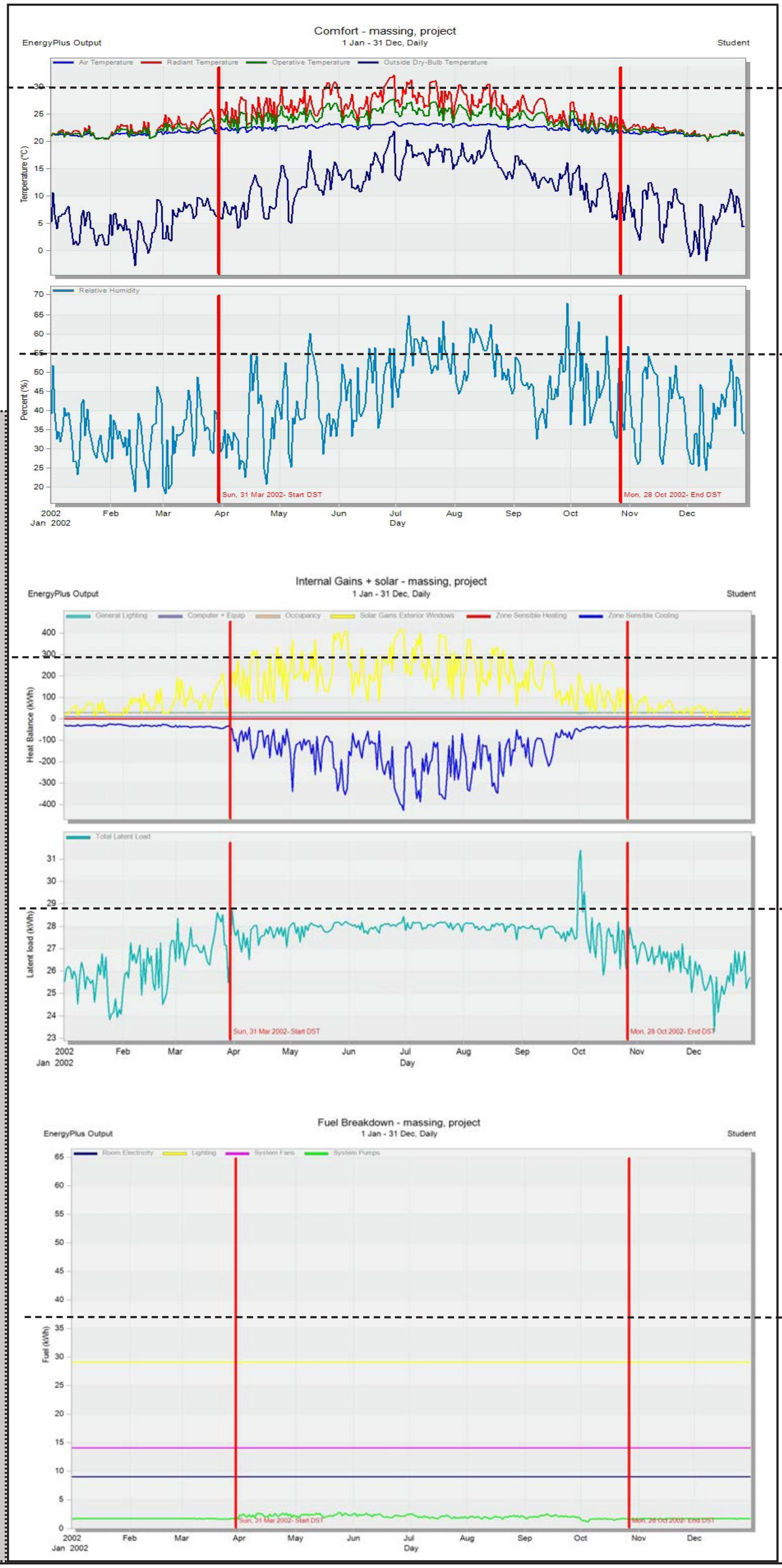
**1. mechanical ventilation and cooling are essential**

**2. Windows should be resized to reduce solar gains**

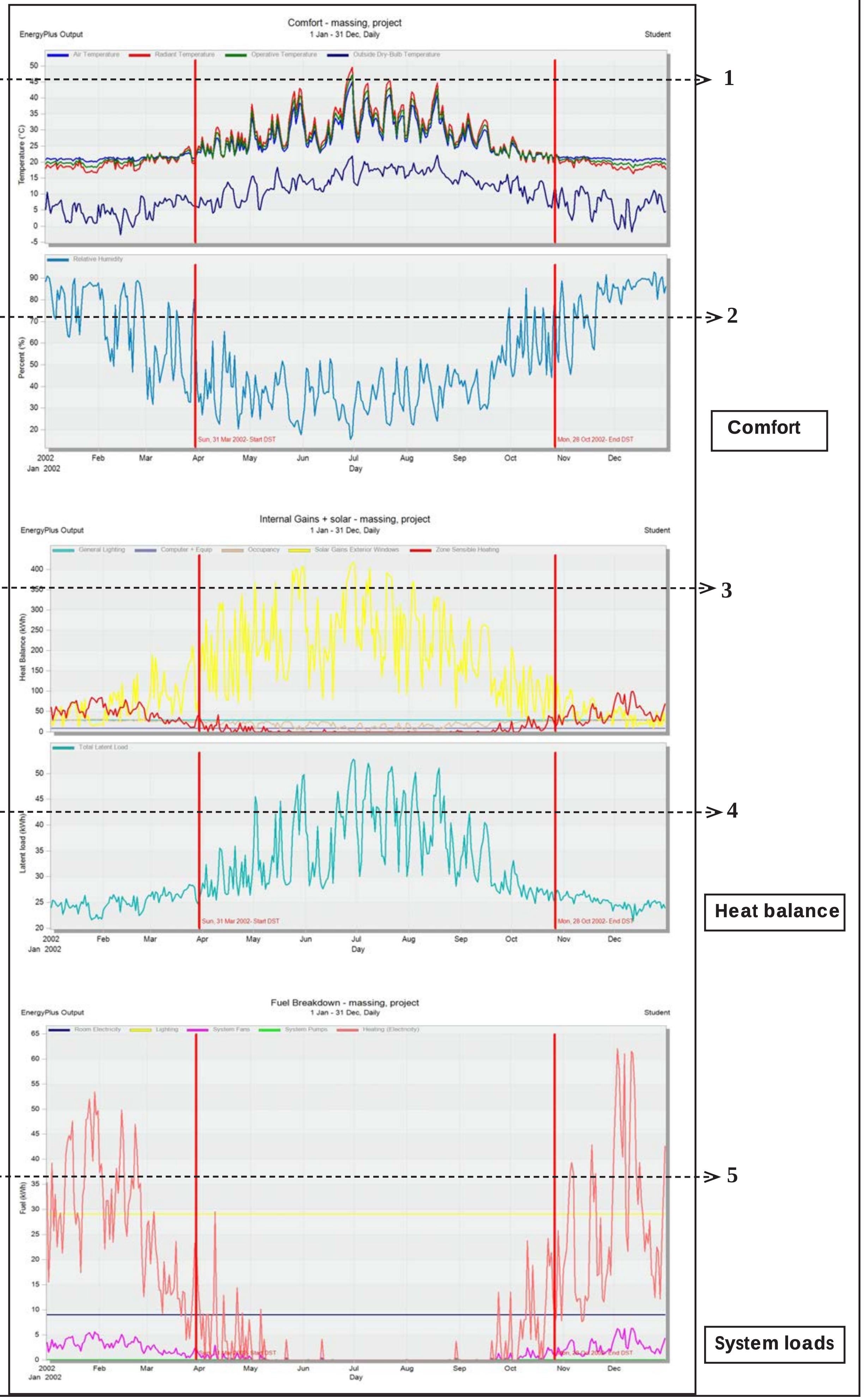
**3. dehumidifiers need to be set**

**4. lighting and electricity settings are wrong and schedules need to be reset**

**GSHP with heated floor and chilled beam**




**ASHP with convectors, natural vent**



# Project HVAC system:

**Air to water ASHP with heated floor, cooled beam and displacement ventilation**

Air Source Heat Pumps (ASHP) and Mechanical Ventilation with Heat Recovery (MVHR) systems are selected for this project based on the following factors:

**Efficiency**: Heat pump systems generally stand out from other HVAC systems for their better efficiency, less energy bill and less carbon footprint.

**Budget**: ASHPs are cheaper than GSHPs, which is a more suitable choice for our clients.

**Risks**: ASHPs are less risky than GSHPs. The installation and operation of GSHPs can face more uncontrollable risks including hitting rocks during installing pipework, meeting unexpected difficulties when drilling deep holes, etc.

**Climate**: Cooling systems will be essential considering global warming and future trends. Compared with an air-to-air ASHP, an air-to-water system can be intergated with heated floor and chilled beams, which can reach better energy efficiency.

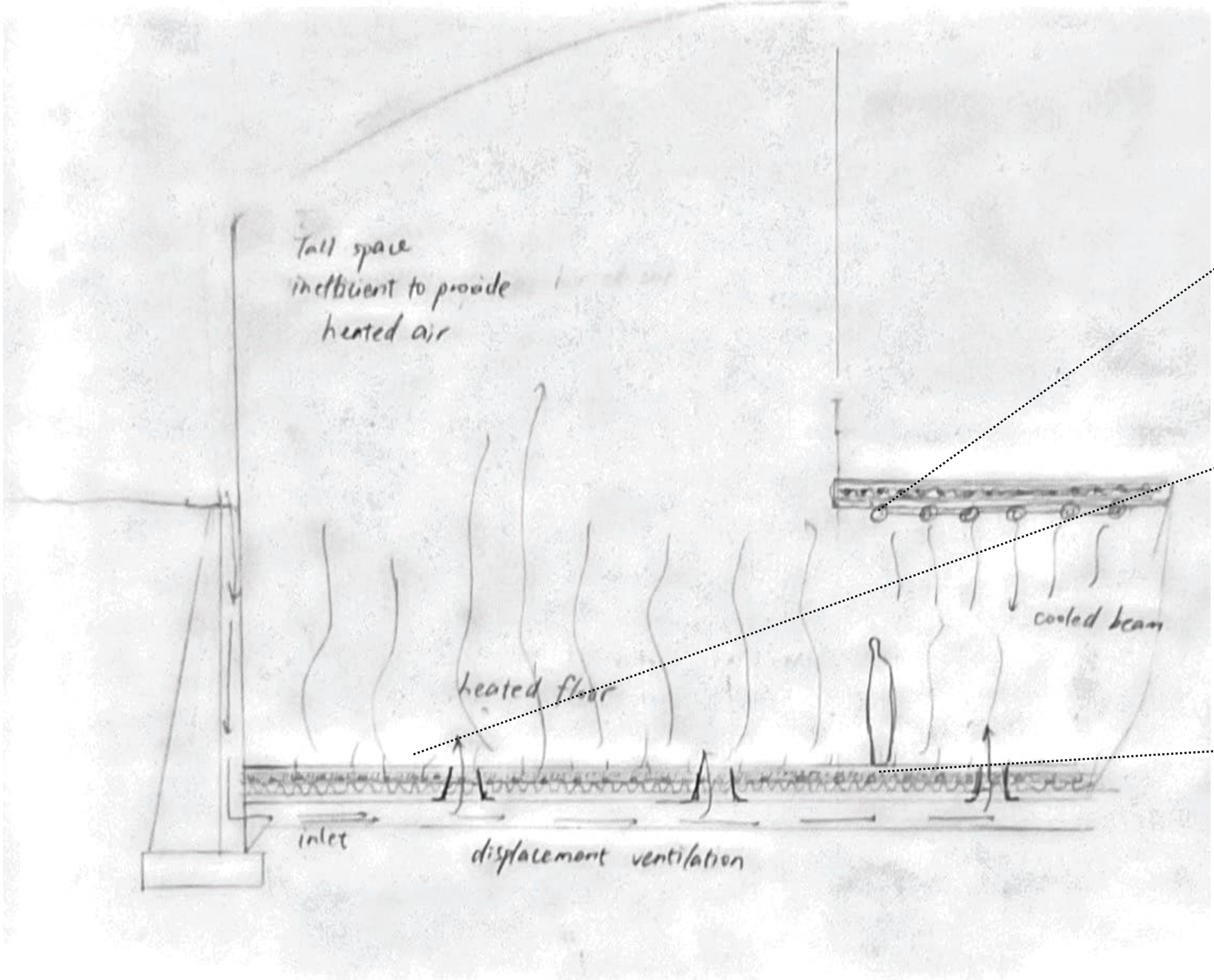
There are also a series of constraints in the design:

1. ASHPs have more constraints of minimum distance from other buildings, which needs careful design in such a crowded site.

2. ASHPs are noisier to operate compared with GSHPs, which will potentially cause more disturbance to surrounding residents and thus noise mitigation measures will be required.

3. ASHPs have limited power of raising temperature below certain temperatures, and can be ineffective in extreme weathers.

Therefore, an MVHR system can be incorporated to assist the heating capacity of the HVAC system. MVHRs work well with ASHPs and are very suitable for this project, because the eccessive heat generated in the workshop space can be efficiently redistributed to other zones.

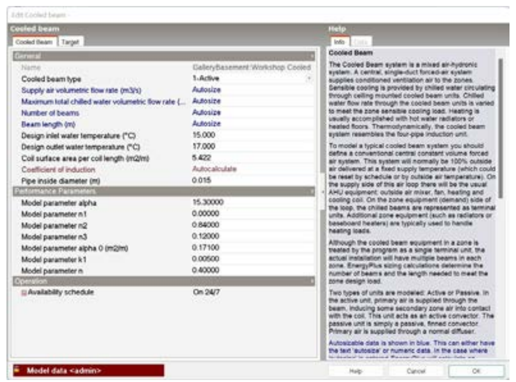
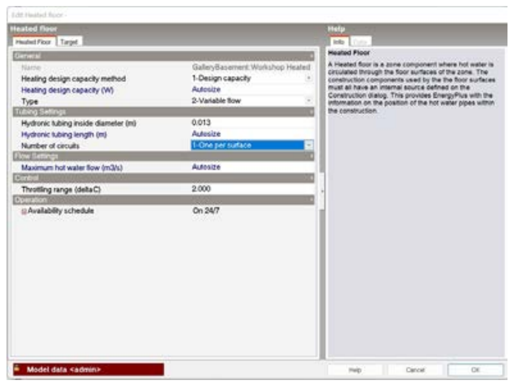



Chilled beams and heated floor use the same water system, whose heating and cooling effect is provided by ASHPs.

In the tall space of the gallery, heated floor is more efficient than distributed heated air, because it does not need to warm up the whole space and takes less time.

Displacement ventilation systems supply low-velocity ventilation air at low level, close to the floor, creating a pool of cool, fresh air in the zone where people are likely to be. Displacement ventilation is typically used in high-occupancy, open plan spaces that allow thermal stratification.

DesignBuilder settings

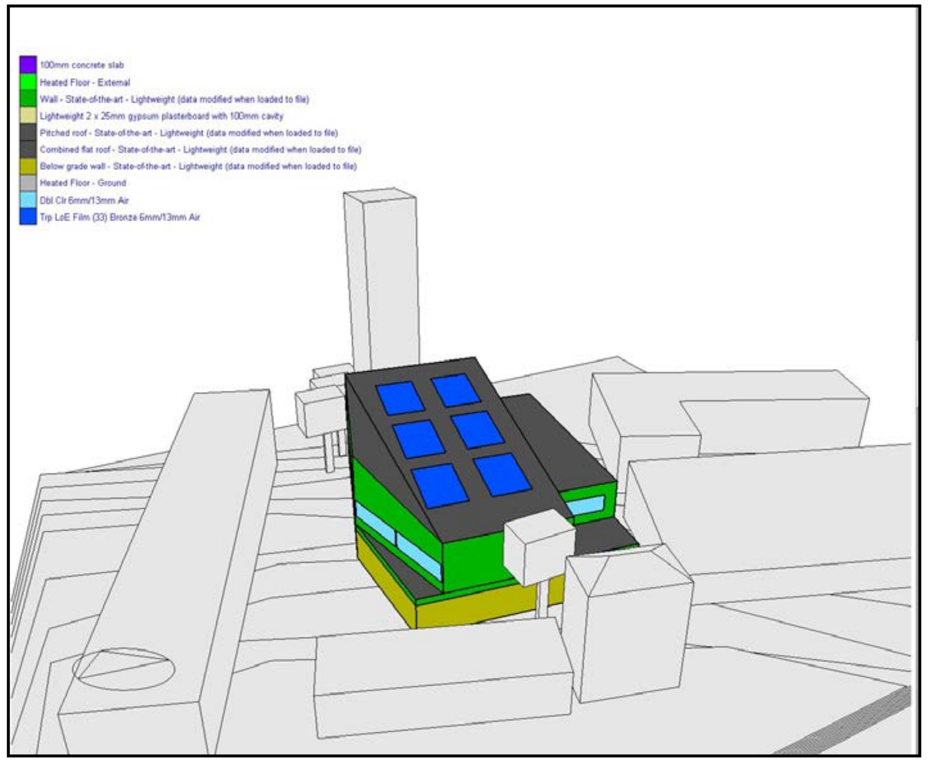




Designbuilder settings

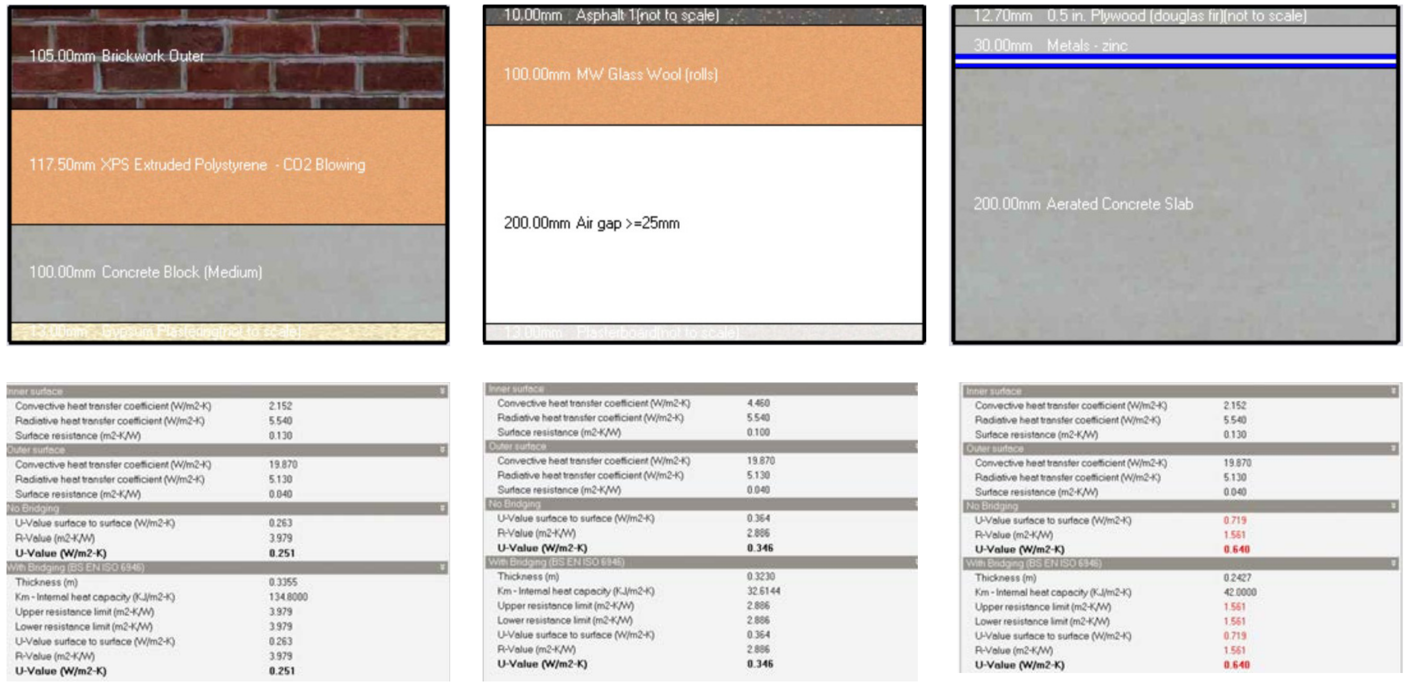
# ASHP Baseline simulation

A simulation with ASHP, heated floor& chilled beams is run with adjusted materiality and schedules. Problems with lighting and humidifiers in the previous simulations are fixed.

## Layout

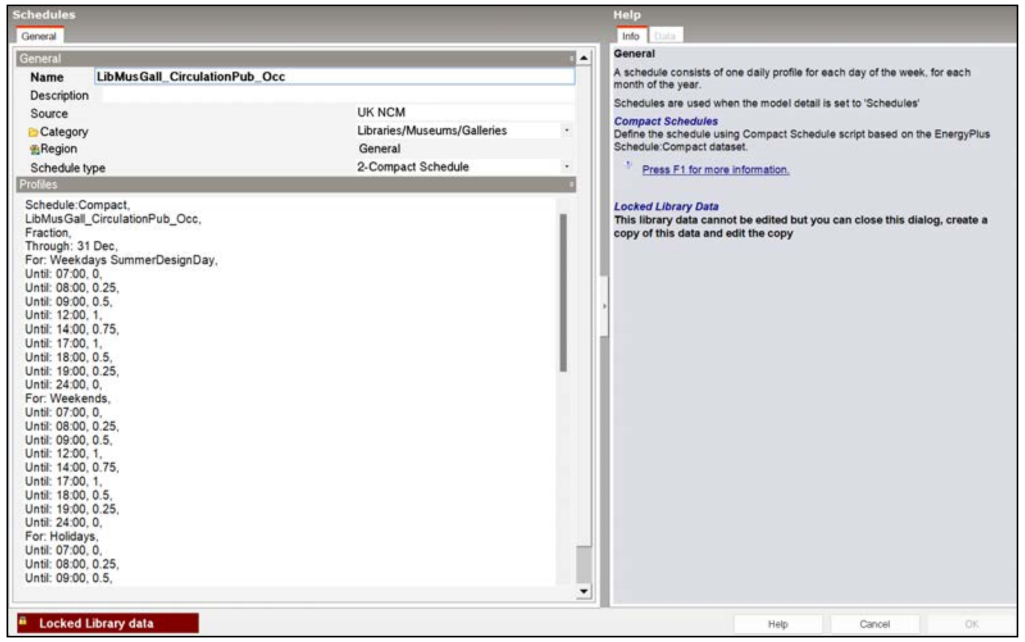



## Materials

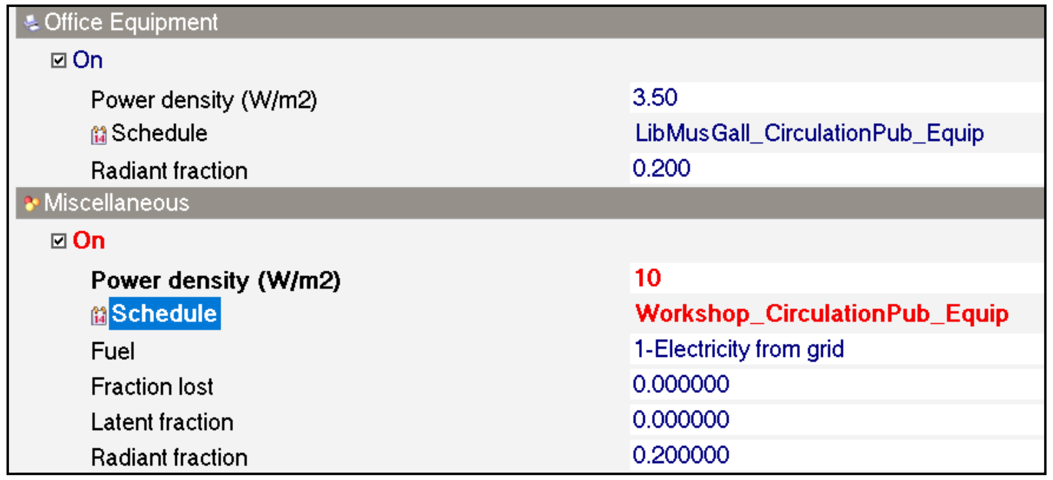



Wall Roof Floor with heating tubes

## Schedule




## Internal gain in workshop



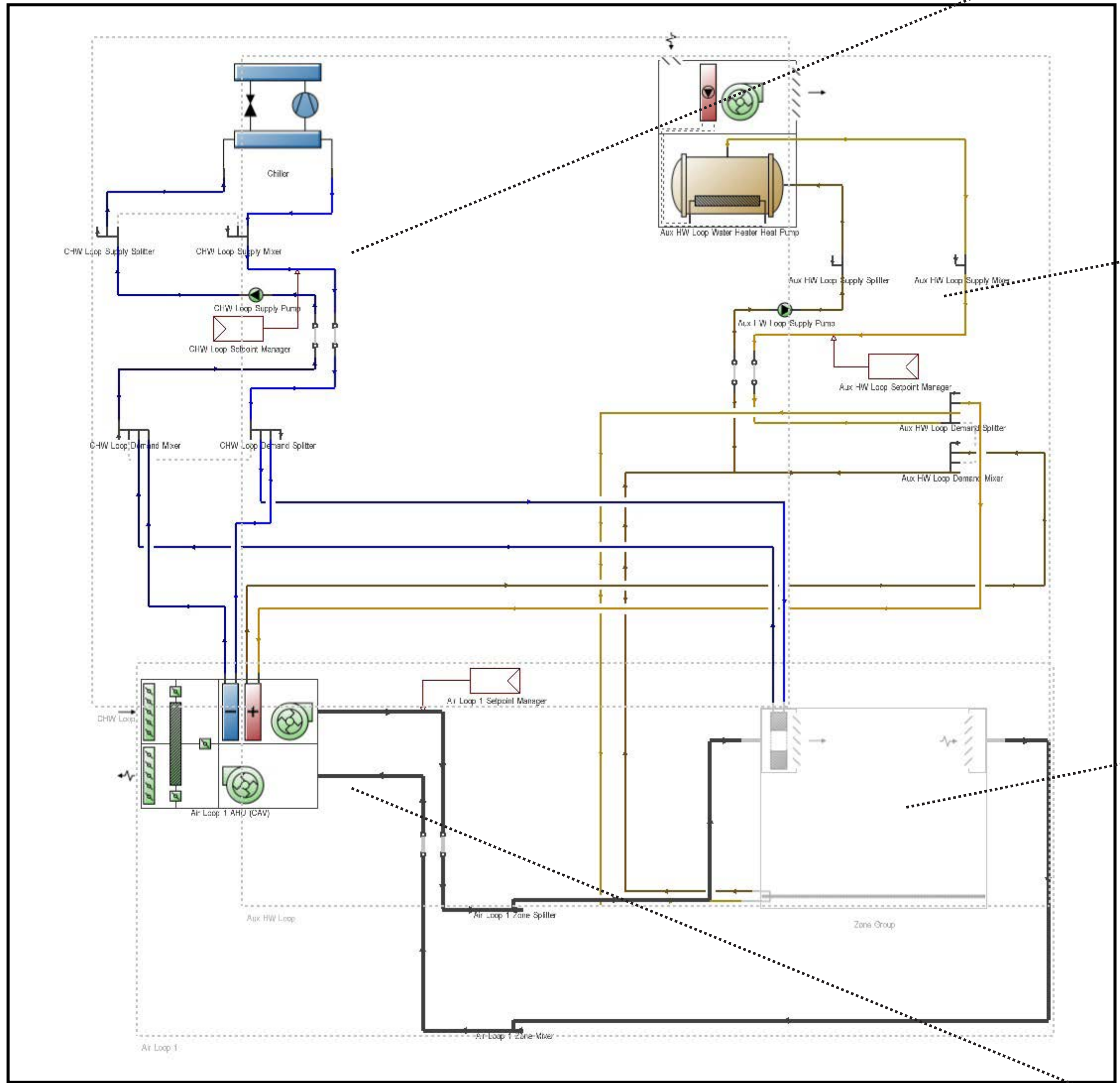
# Detailed HVAC settings in DesignBuilder

AHU - CAV ventilation system with preheating, precooling and dehumidification

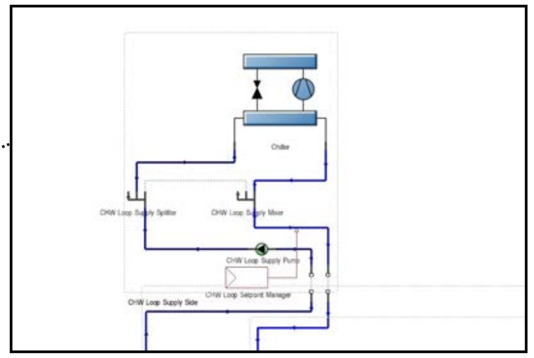
ASHP - cooling : provide cooled water to (1) the chilled beam in zones; (2) cooling coil in the AHU

- heating : provide heated water to (1) the heated floor in zones; (2) heating coil in the AHU

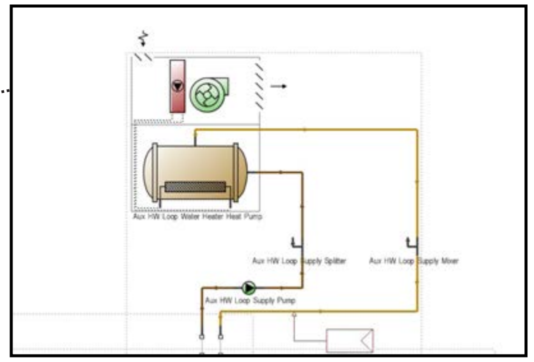
Zone - heated floor, chilled beam for the gallery



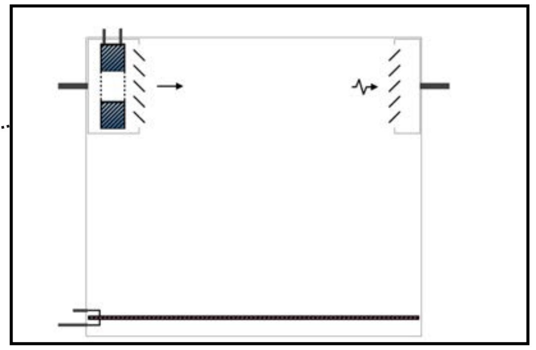
General layout of the detailed HVAC system.



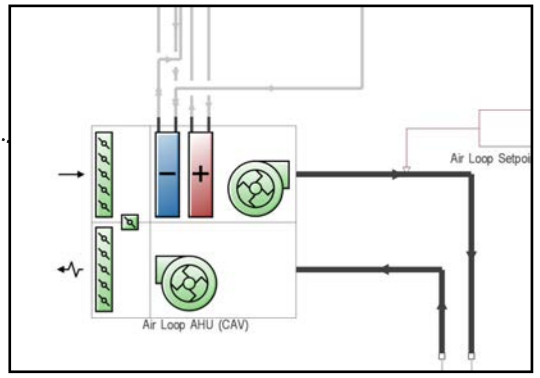
An air source chiller provide s cooled water to AHU and chilled beams in the zone.



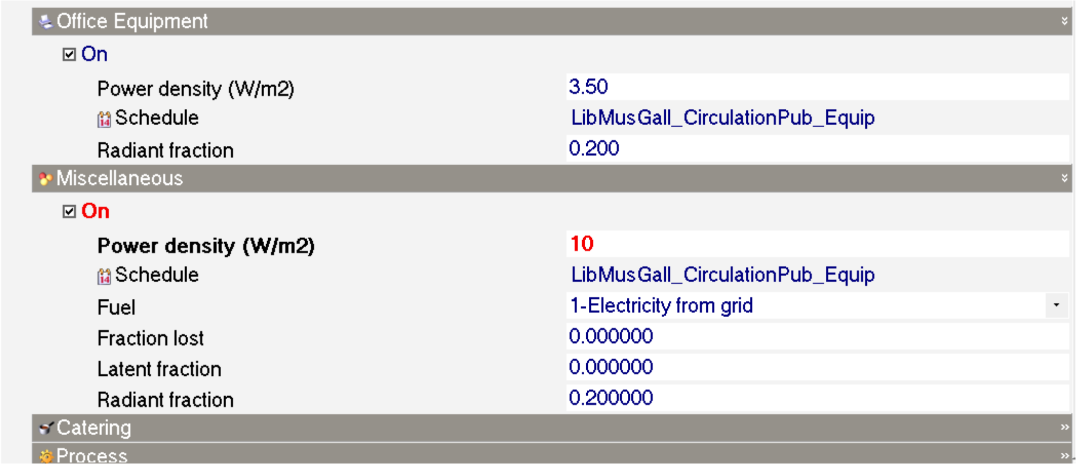
An air-to-water ASHP generates heated water and provides it too AHU and zones.

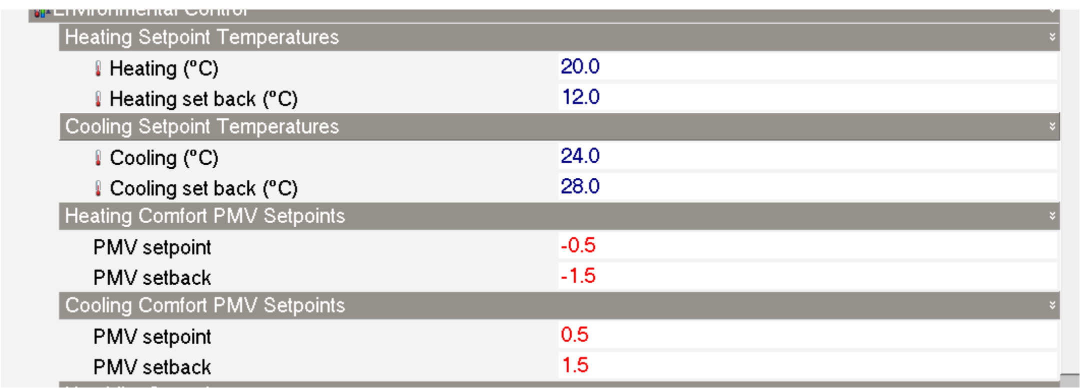


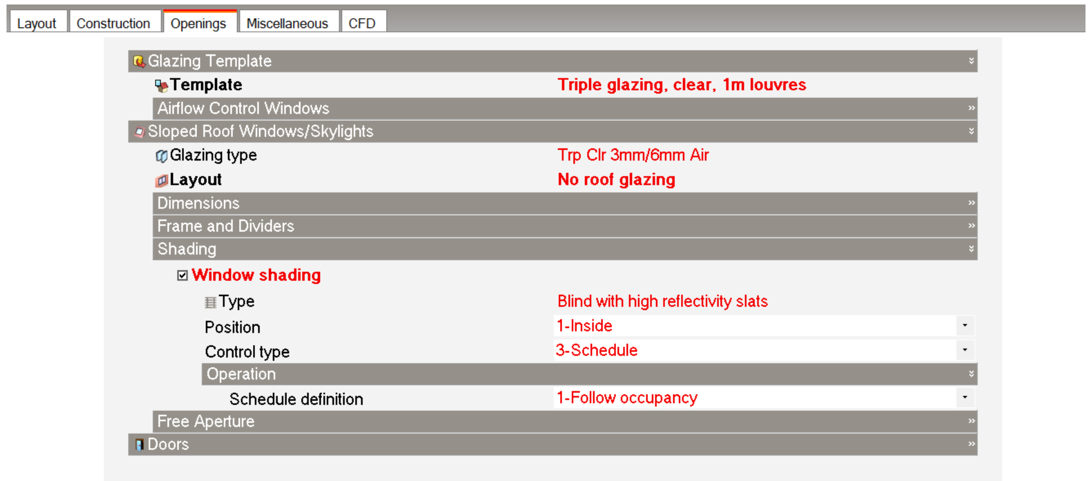
Heated floor, chilled beam and conditioned air from AHU all together determine the thermal comfort of this zone.

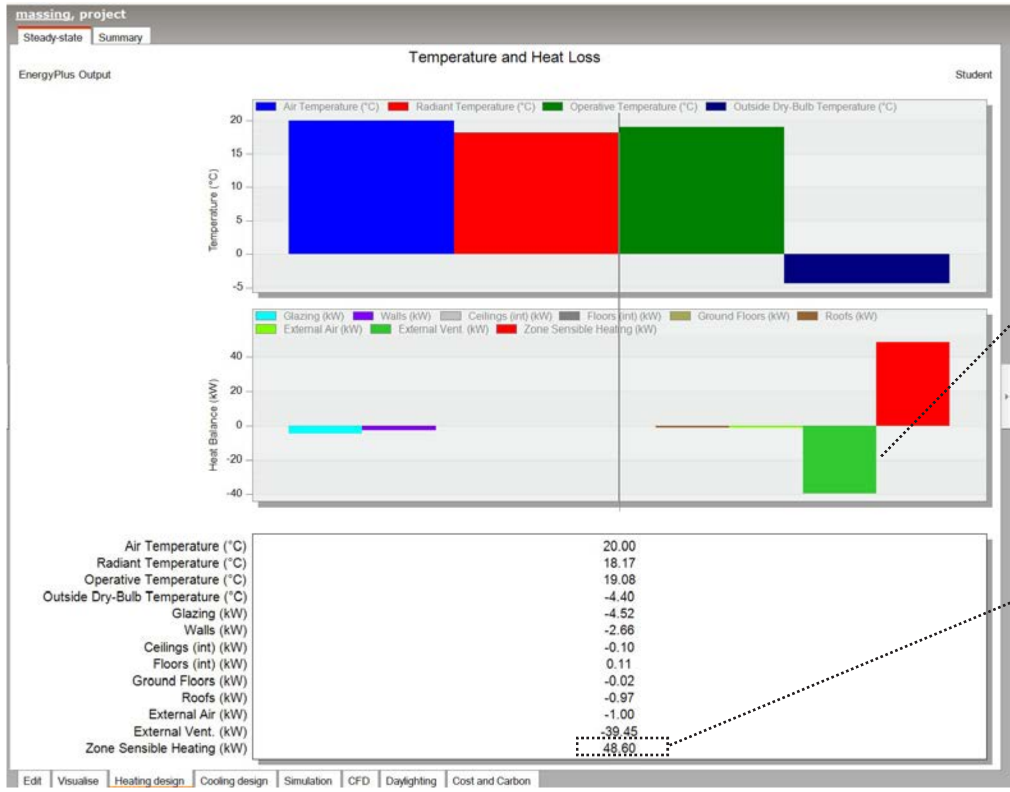


A central AHU plant preheats, precools and dehumidifies external air and provides it to zones. No heat recovery is provided.



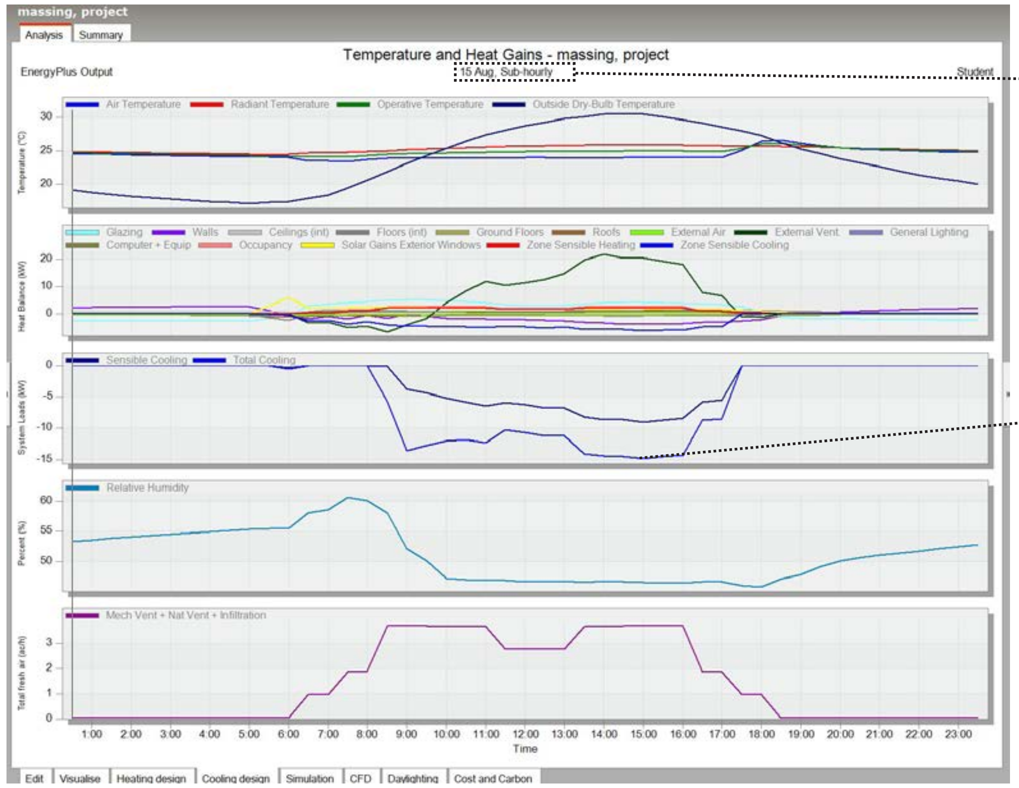




Heating design

External ventilation has caused the majority of heat loss through fabric

The heating load of the gallery space is 48.6 kW. It is required that ASHP should achieve this capability, or otherwise other strategies such as supplementary boilers and heat recovery sould be incorporated.

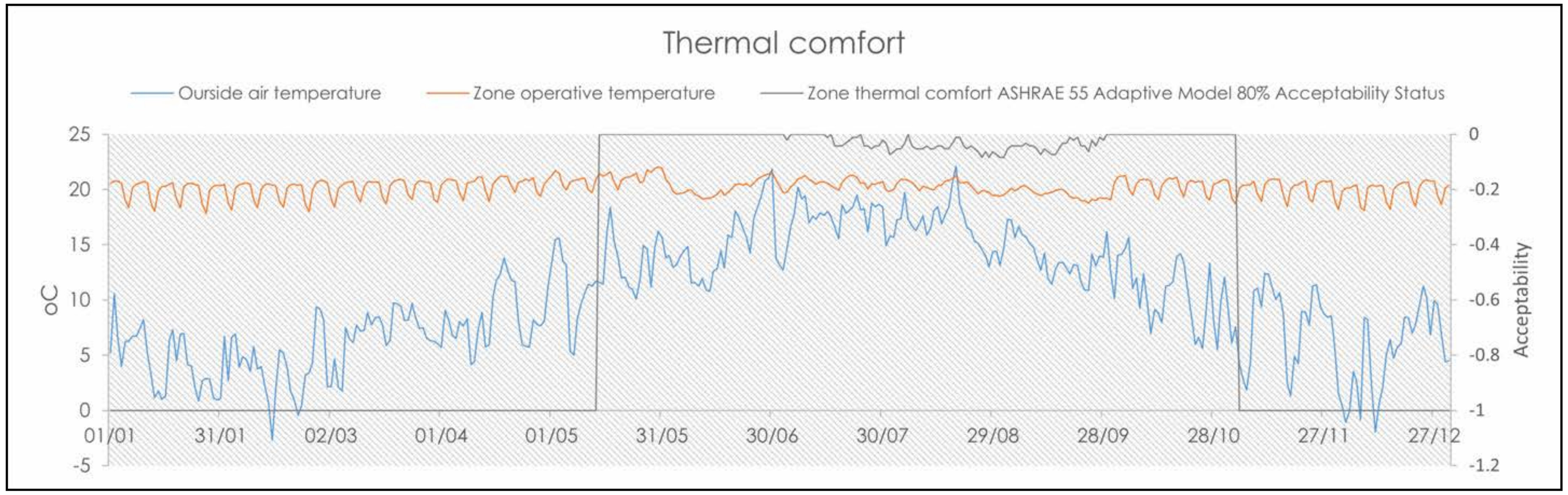


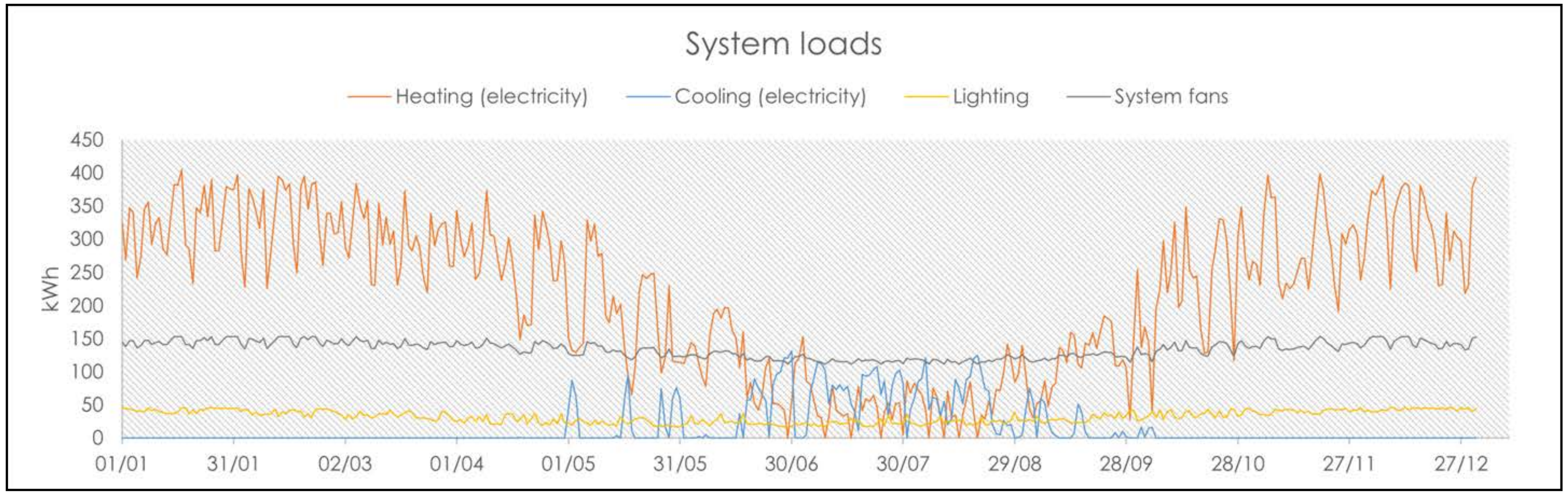

Cooling design

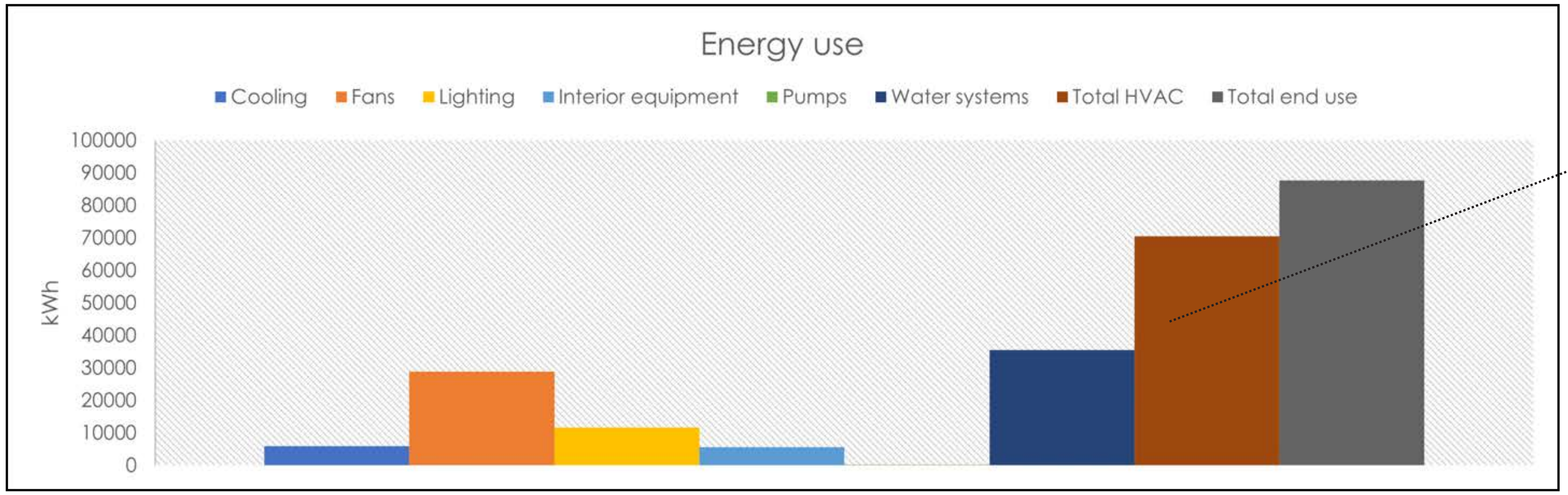
15 Aug is a peak day for cooling load, according to the simulation result

The peak cooling load is 14kW,which means the chilled beams should achieve this capability

# ASHP Simulation 1




Change summary:

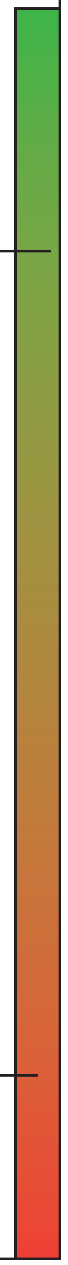
1. Glazing ratio is reduced according to DF analysis.

2. Shading schedule is changed to '*Shading is used when solar irradiance > 200W/m2 and outside air temperature > 24 oC*'.

3. Glazing material is changed to *triple LoE bronze (33) film, 6mm/3mm air*

4. Shading material is changed to *medium reflectance and low transmittance*

Total HVAC consumption: 140.9 kWh/m2/yr



Innovative standard:
70 kWh/m2/yr

Baseline simulation total HVAC: 140.9 kWh/m2/yr

# Designbuilder DF analysis
# - exhibition space

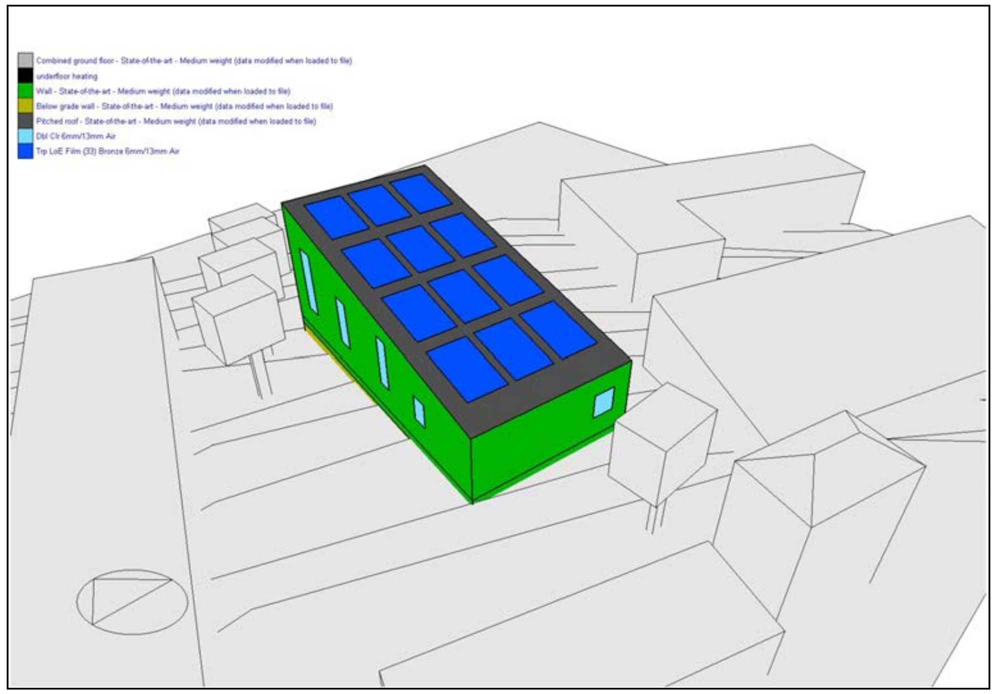
According to EN 17037, the DF criteria for London is:

- medium-level minimum target DF: 2.1%
- medium-level medium target DF: 3.5 %

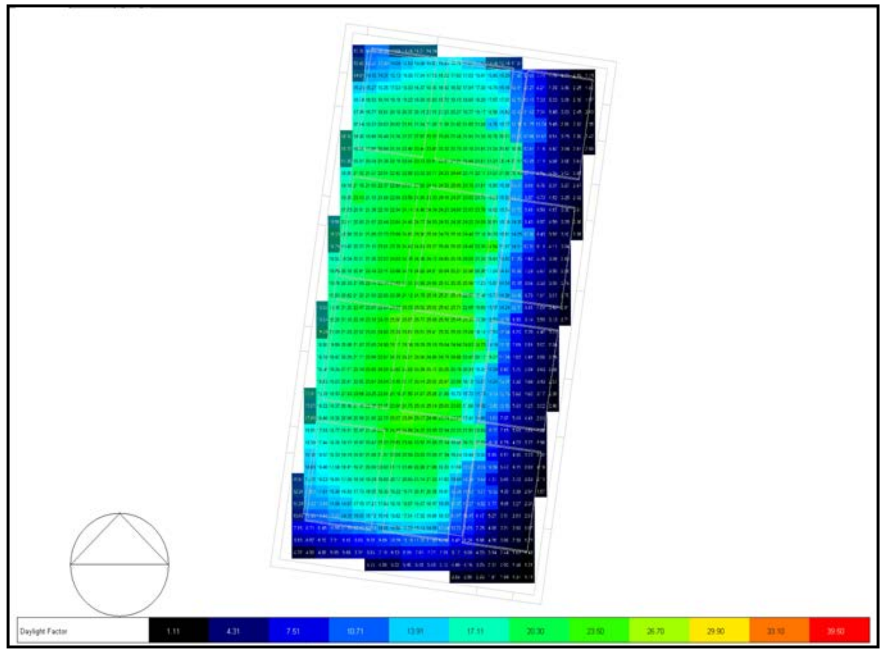
This means that all space should reach at least 2.1% DF, and should have an average DF of 3.5%. In DesignBuilder, an initial model is constructed, with two long roof windows and different glazing & shading strategies. The simulation details are listed below:

- Simulation type: BREEAM Credit HEA 01
- Sky model: standard sky, overcast day (zenith illuminance: 1000lux)

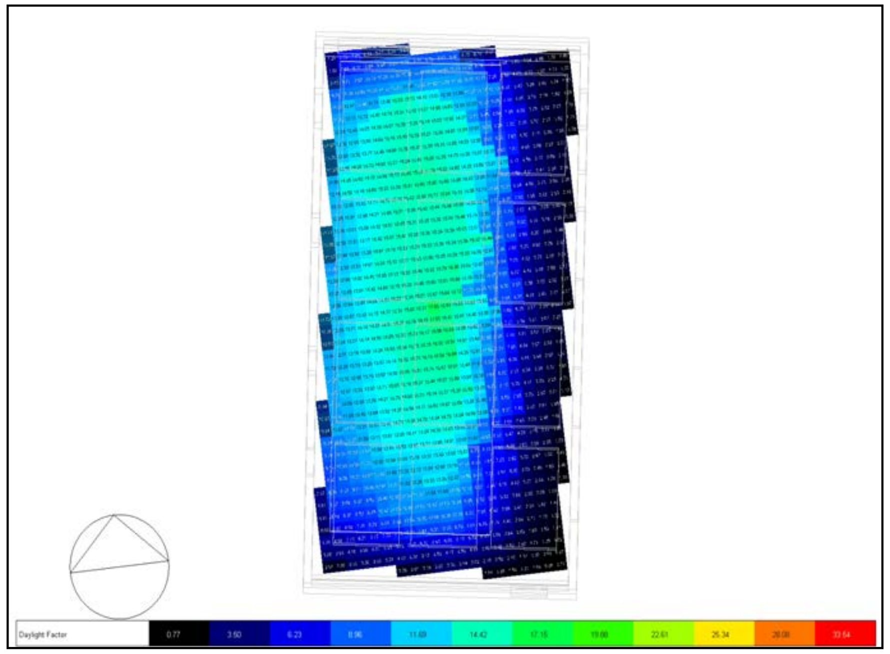
| | Roof window material | | Shading | |
|---|---|---|---|---|
| | material | transmission (SHGC) | type | schedule |
| 1 | BIPV windows | 0.691 | Drape - close weave dark | solar irradiance >200 W/m2 |
| 2 | Triple glazing, clear , 1m louvre - triple LoE film (33) Clear 6mm/3mm Air | 0.31 | Medium reflectance-low transmittence shading - midpane | solar irradiance >200 W/m2 |
| 3 | Triple glazing, clear , 1m louvre - triple LoE film (33) Bronze 6mm/3mm Air | 0.17 | Medium reflectance-low transmittence shading - midpane | solar irradiance >200 W/m2 |
| 4 | Triple glazing, clear , 1m louvre - triple LoE film (33) Bronze 6mm/3mm Air | 0.17 | Blind with highly reflectivity slats | solar irradiance >200 W/m2 |



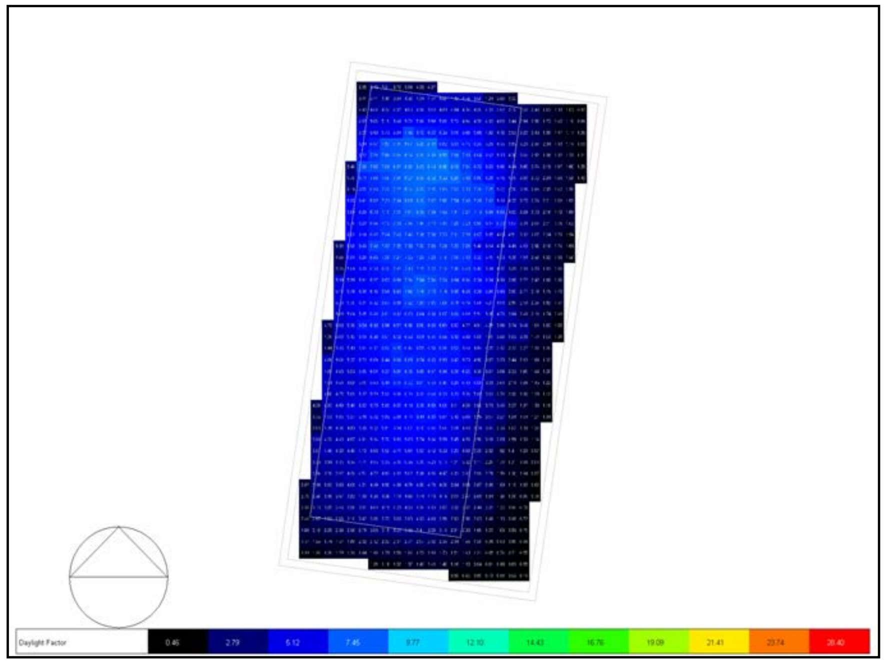
Model 1: single zone gallery space with two long roof windows



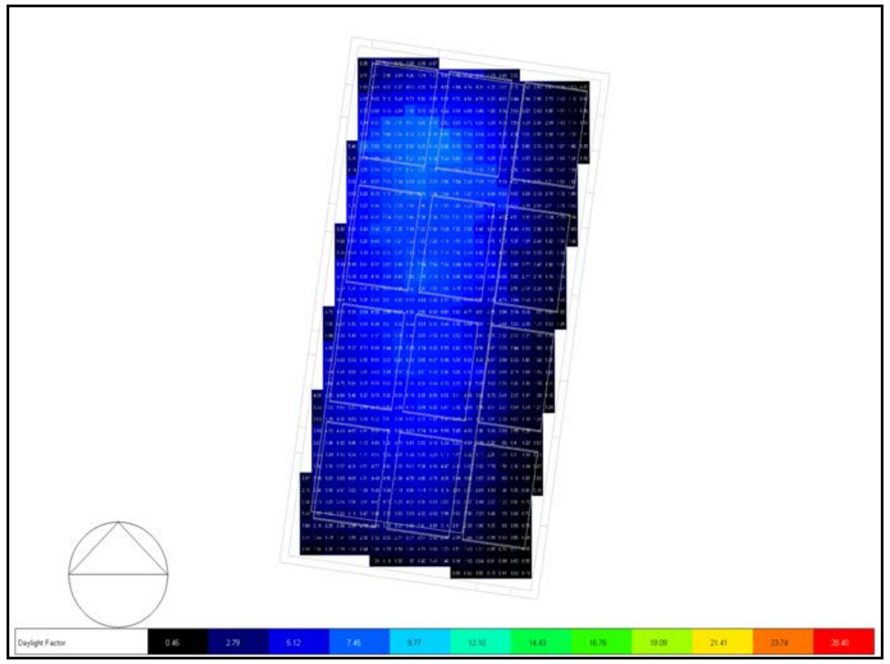
Case 1. An exploration into BIPV materials shows that even when shading is provided, the high SHGC value of BIPV will make the DF too large. Other materials of glazings should be used.



Case 2. A clear LoE film integrated in the glazing can significantly bring down DF values, but they are still above 3.5%. Other glazing materials and shading strategies should be explored.



Case 3. A bronze LoE film, instead of a clear one, has a much smaller SHGC value and bring down DF values to an average of 6%. Other shading strategies should be explored.



Case 4. Another shading material, blinds with highly reflectiveitu slats, result in similar DF outcomes as Case 3.

Conclusion: to maintain the daylight fator of the main exhibition space to minimum 2% and average 3.5%, the roof glazing should have a SHGC value of about 0.17, and shading must be intergrated. Given the glazing ratio of skylight, this is difficult to achieve, which will result in high DF values, risks of glares, and high thermal gain even when shading is provided. What's more, the heat loss through the glazings will be significant, and thus the benefits of a large skylight ratio cannot outweigh the problems it creates. Therefore, large roof windows as modelled in Model 1 are not appropriate, both in terms of daylight provision and thermal performance.

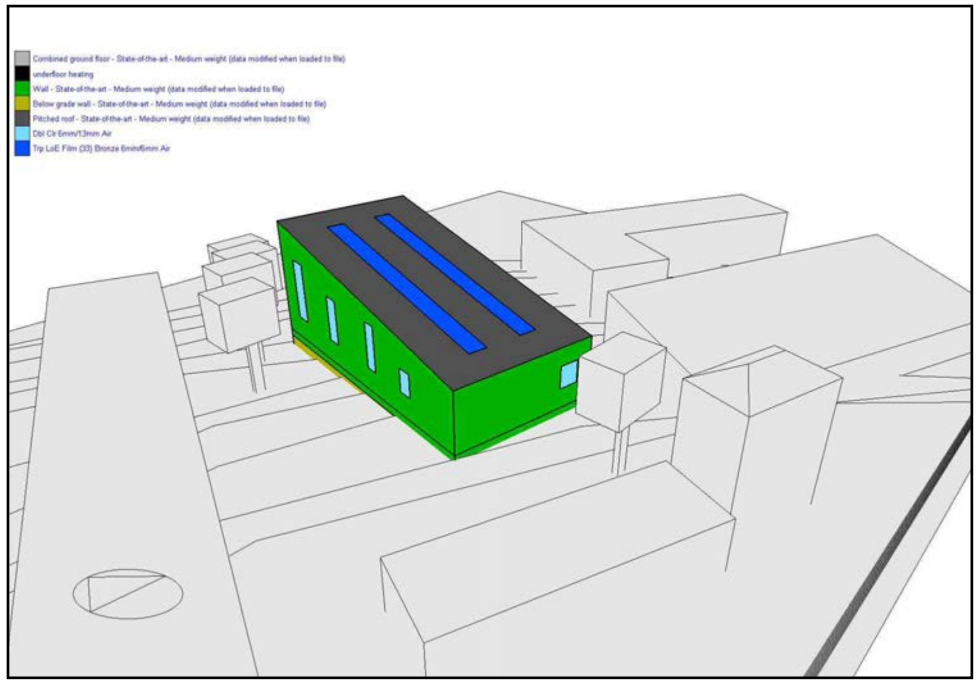
# Designbuilder DF analysis
# - exhibition space

The simulation results of Model 1 all have high DF values. High Daylight factors can result in glares and high thermal gain, and should be avoided. In Model 2, the sizes of roof windows are significantly reduced, to explore whether ideal daylight factors can be maintained. The geometries of the windows are designed to be long and slender, in an attempt to create uniform, diffused and coherent light throughout the exhibition space.

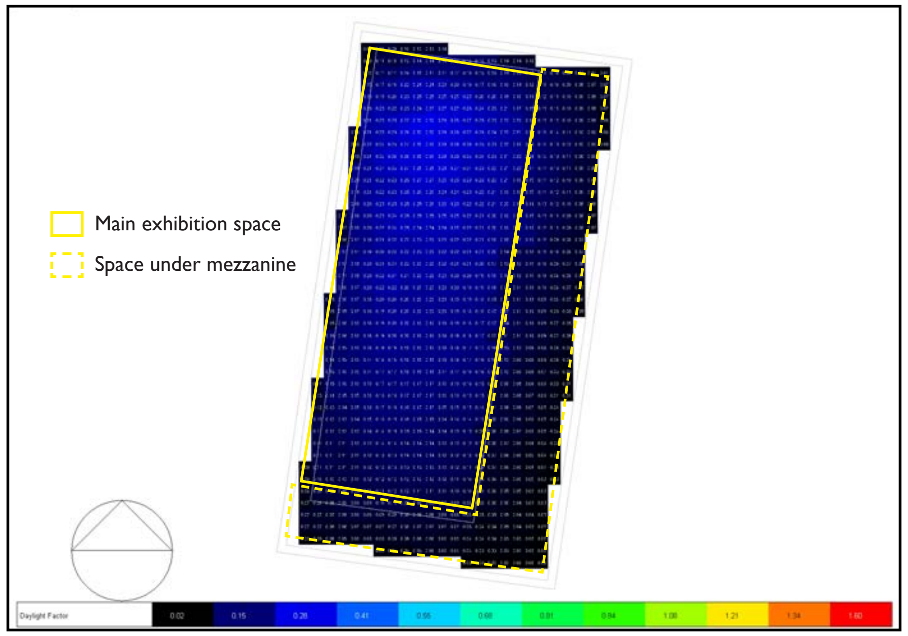
The simulation details are listed below:

- Simulation type: BREEAM Credit HEA 01
- Sky model: standard sky, overcast day (zenith illuminance: 1000lux)

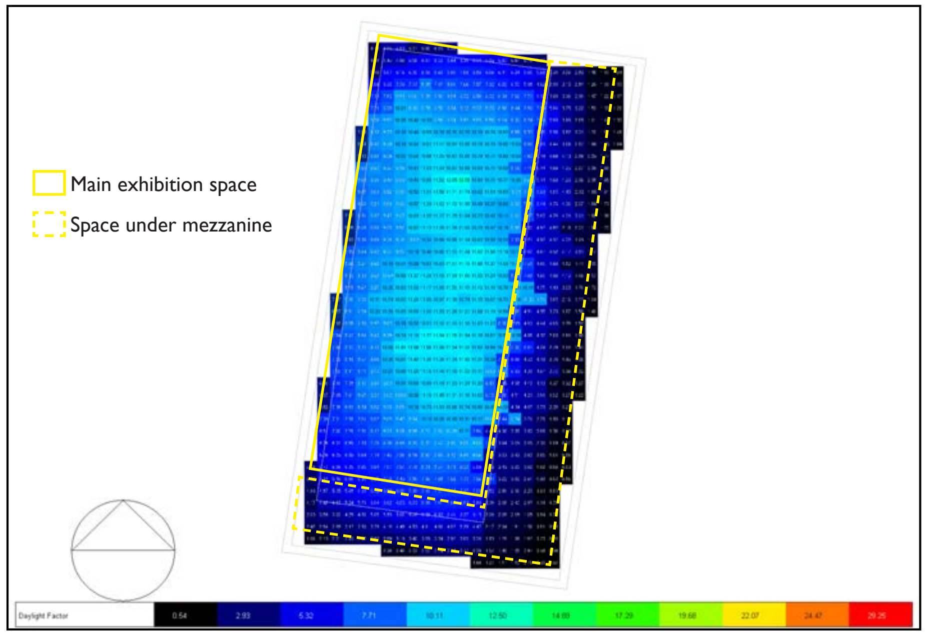
| | Roof window material | | Shading | |
|---|---|---|---|---|
| | material | transmission (SHGC) | type | schedule |
| 1 | Triple glazing, clear , 1m louvre - triple clear 3mm/6mm Air | 0.682 | Medium reflectance-low transmittence shading | solar irradiance >200 W/m2 |
| 2 | Triple glazing, clear , 1m louvre - triple clear 3mm/6mm Air | 0.682 | No shading | / |
| 3 | Triple glazing, clear , 1m louvre - triple clear 3mm/6mm Air | 0.682 | Microlouvre | Outdoor temp>24 & Solar irradiance >200W/m2 |
| 4 | Triple glazing, clear , 1m louvre - triple LoE film (33) Bronze 6mm/3mm Air | 0.17 | Medium reflectance-low transmittence shading - midpane | solar irradiance >200 W/m2 |



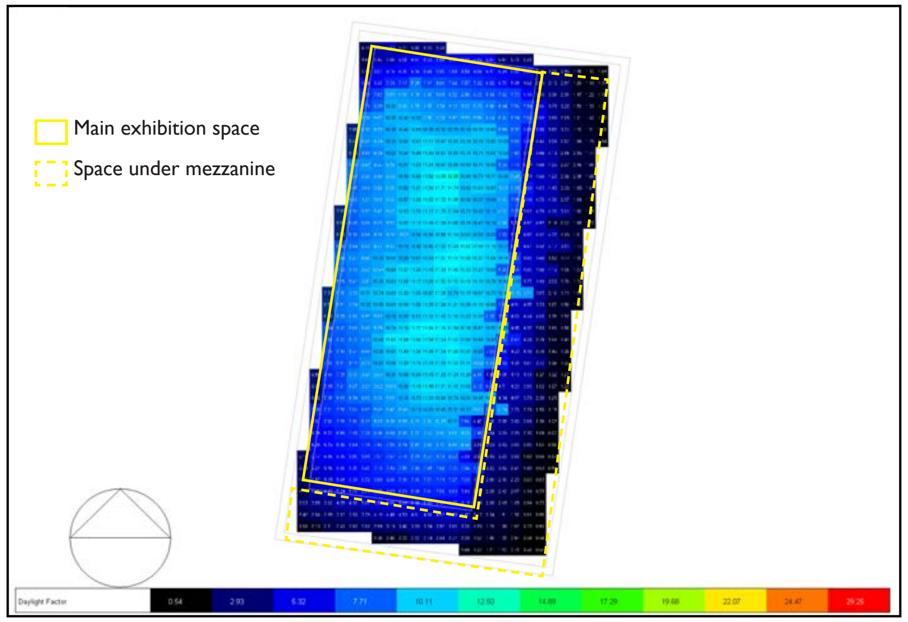
Model 2: single zone gallery space with two long roof windows



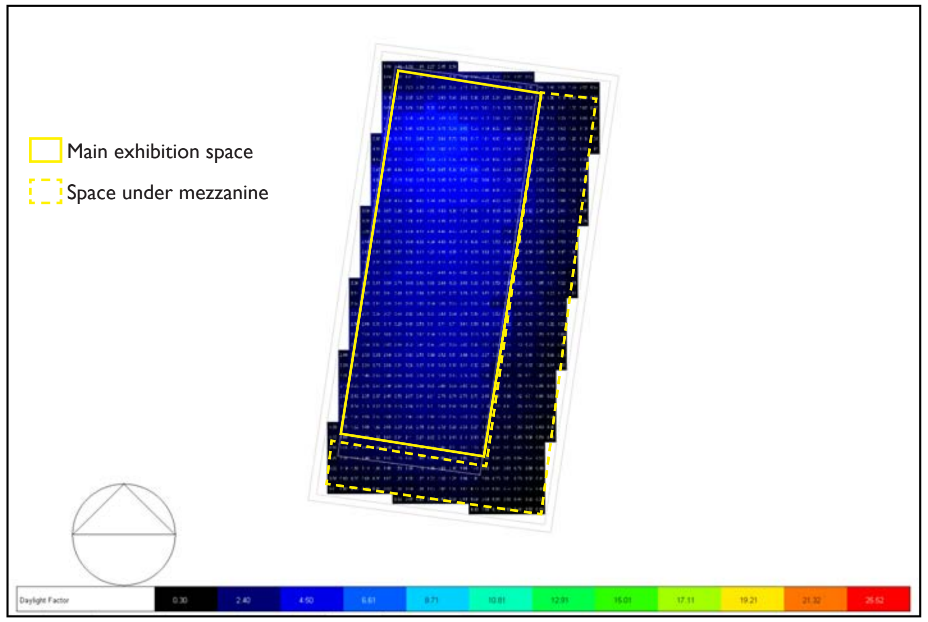

Case 1. Due to the medium reflectance-low transmittence shading, most of the exhibition space is below 0.5, which is too low.




Case 2. When no shading is provided, most spaces have a DF of above 10, which is too high.




Case 3. By changing the shading type to microlouvres, the DF are lower than in Case 2, but are still above 3.5%.




Case 4. By changing the transmittence (SHGC) of windows to a lower value (from 0.68 to 0.17), the daylight factors are significantly reduced, and the values are maintained between 3%-5%, which are appropriate.

Conclusion: to maintain the daylight fator of the main exhibition space beween to minimum 2% and average 3.5%, the roof glazing design plays an important role. A low transmission value (SHGC) can bring down the DFs significantly, as shown in Case 3&4. The shading materials and schedules do not make such differences. A combination of LoE film (bronze) integrated glazing and medium reflectance-low transmittence shading is proved to be the most appropriate strategy, compared with all other combinations that have been explored.

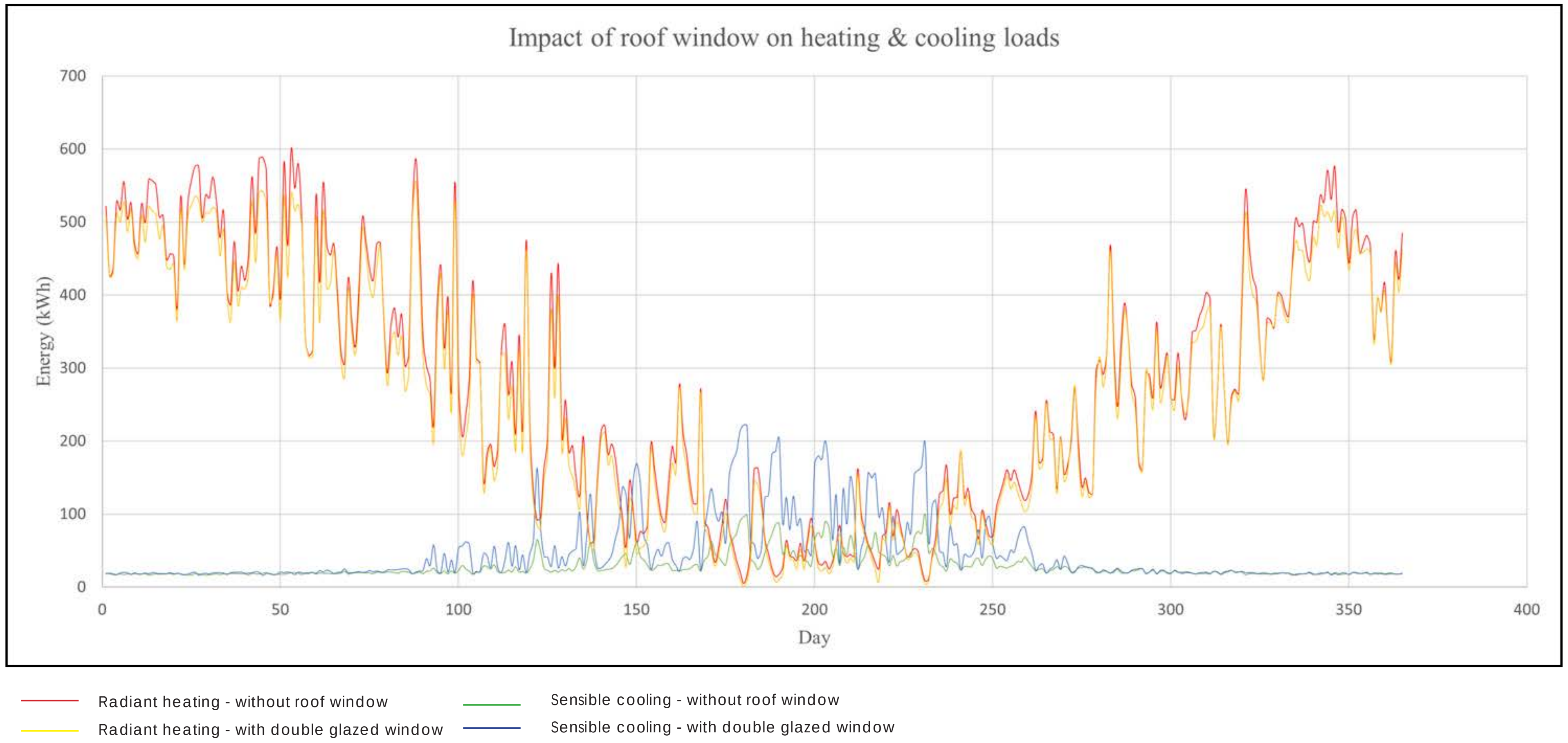
# Daylight and heating/cooling load

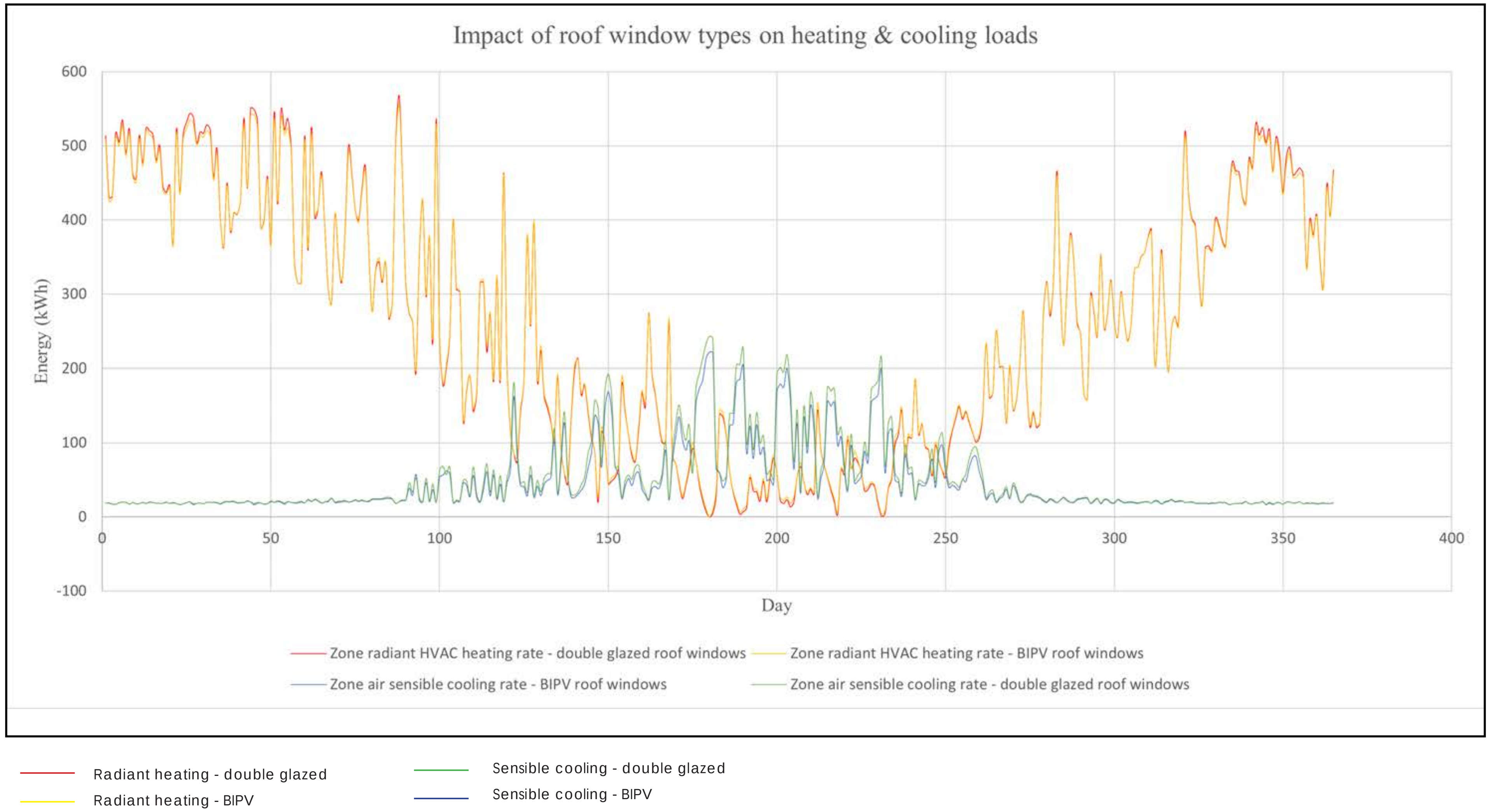
When a roof with 30% glazing ratio is modelled:

- 127% more cooling load compared with no window.
- 24% less heating load compared with no window.

When comparing different materials, BIPV has:

- 0.7% more heating load compared with double glazed window.
- 4.8% less cooling load compared with double glazed window.

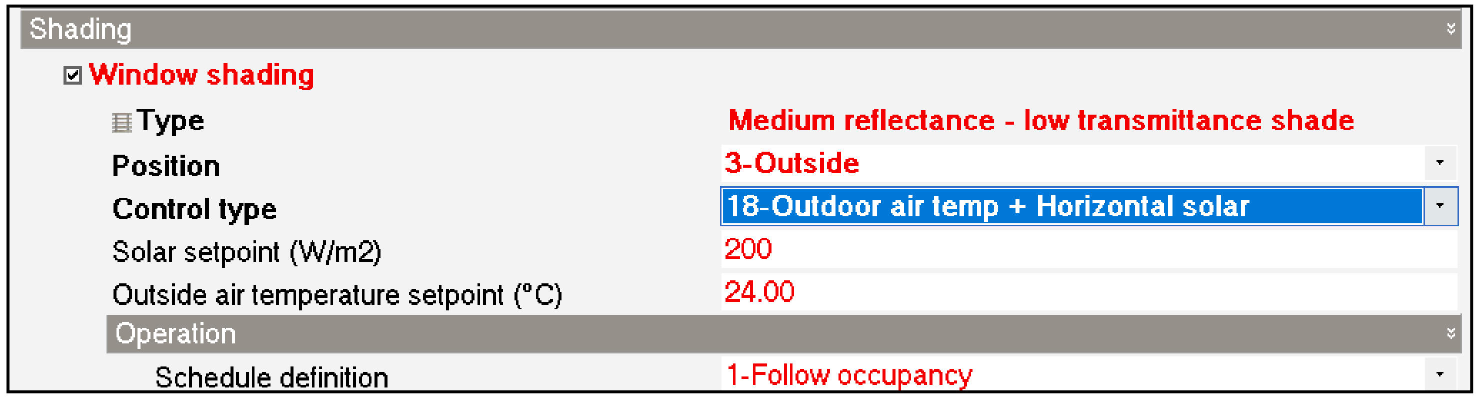


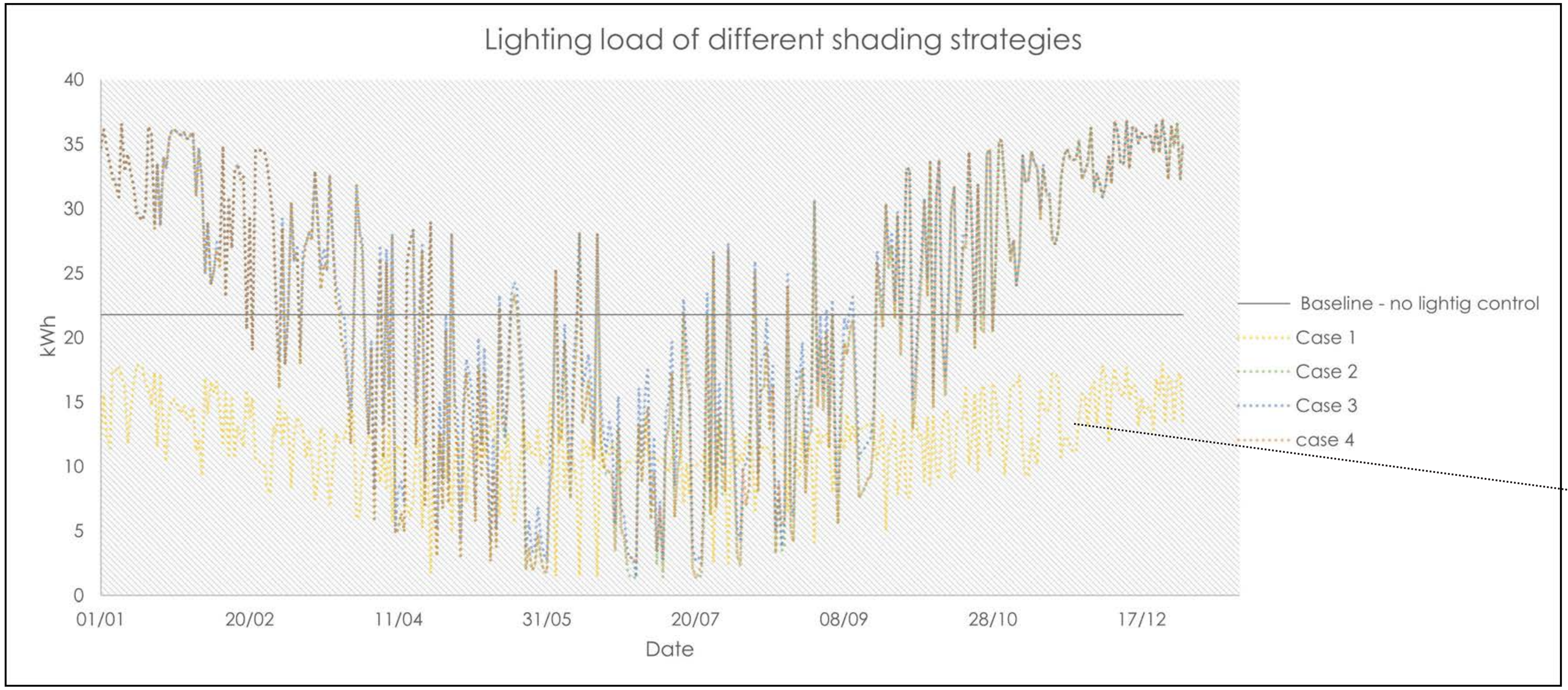



# Shading strategies and lighting load

The introduction of daylight can . In Designbuilder, daylight control can be turned on, which enables the lighting to be automatically operating when the daylight level of space does not receive enough daylight. A well-designed daylight strategy can maintain daylight level to a reasonable range (2% to 5%) and minimise lighting load.

| | Roof window material | | Shading | | lighting control |
|---|---|---|---|---|---|
| | material | transmission (SHGC) | type | schedule | |
| 1 | Triple glazing, clear , 1m louvre - triple LoE film (33) Bronze 6mm/3mm Air | 0.17 | Medium reflectance-low transmittence shading - midpane | solar irradiance on window >200 W/m2 and outside air temp >24 oC | on |
| 2 | | | | Glare | |
| 3 | | | | Daycooling and solar >200 W/m2 | |
| 4 | | | | Horizontal solar irradiance >200 W/m2 and outside air temp >24 | |



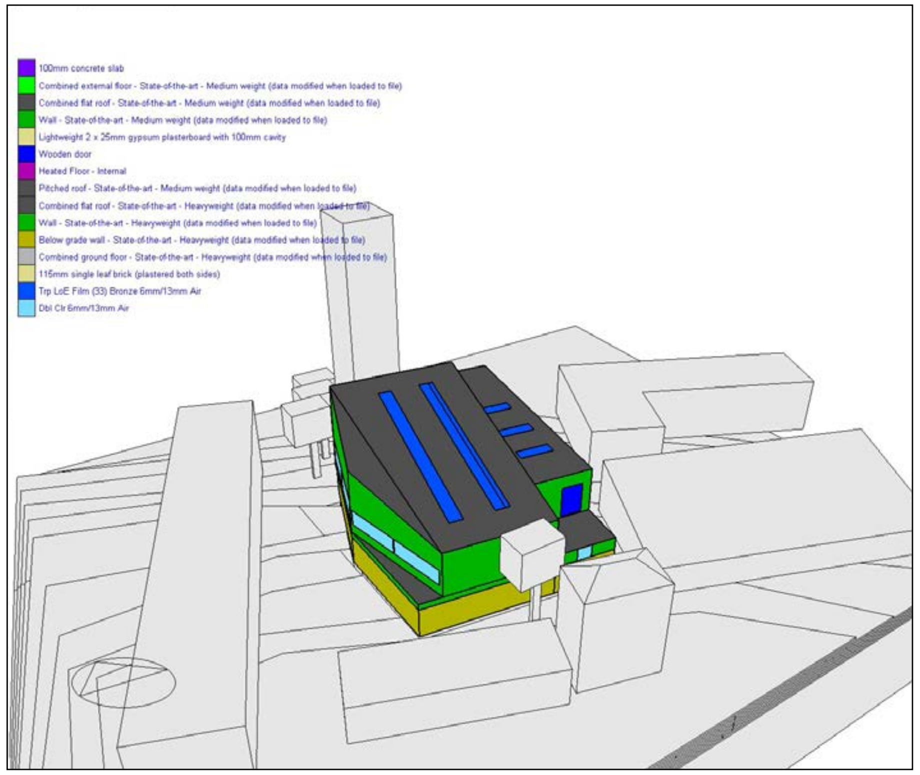




Control case I can effectively reduce lighting load in the exhibition space. Therefore control schedule used for this project is specified as:

*Shading is used when solar irradiance > 200W/m2 and outside air temperature > 24 oC.*

# ASHP simulation iteration 1

Simulation 2 incorporates the roof design resulting from the DF analysis . It also simulates the heat recovery effect of the workshop. Different strategies including heat recovery and air recirculation are explored to minimise energy loads.



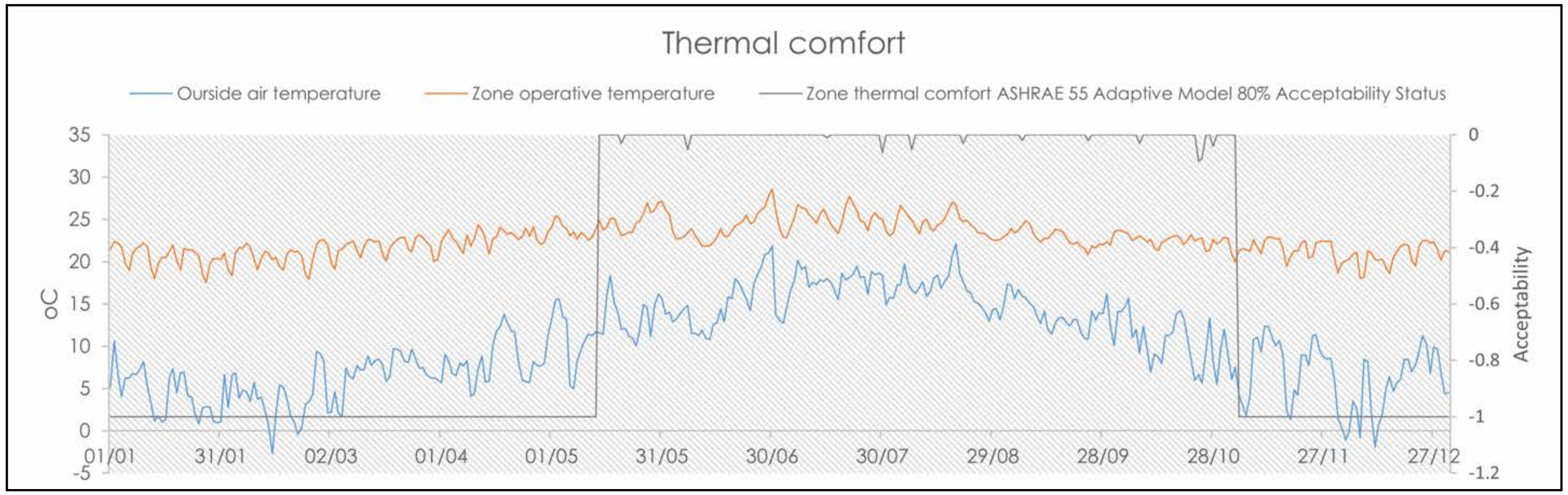
Model layout

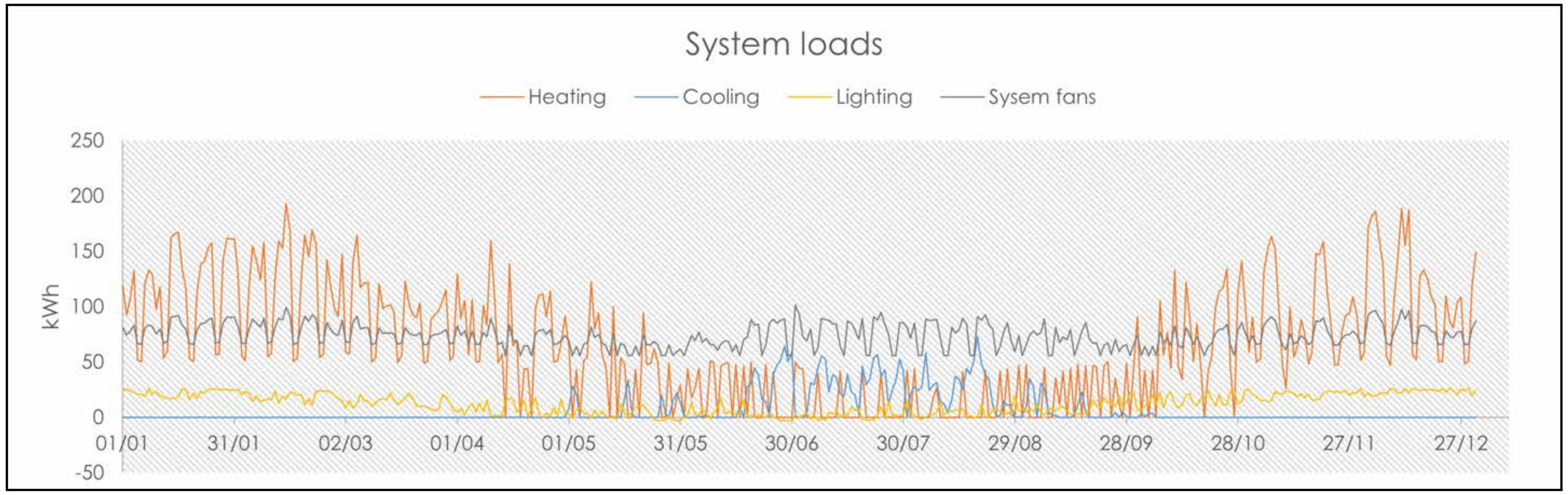
| | Roof window material | | Shading | |
|---|---|---|---|---|
| | material | transmission (SHGC) | type | schedule |
| 1 | Triple glazing, clear , 1m louvre - triple clear 3mm/6mm Air | 0.682 | Medium reflectance-low transmittence shading | solar irradiance >200 W/m2 |
| 2 | Triple glazing, clear , 1m louvre - triple clear 3mm/6mm Air | 0.682 | No shading | / |
| 3 | Triple glazing, clear , 1m louvre - triple clear 3mm/6mm Air | 0.682 | Microlouvre | Outdoor temp>24 & Solar irradiance >200W/m2 |
| 4 | Triple glazing, clear , 1m louvre - triple LoE film (33) Bronze 6mm/3mm Air | 0.17 | Medium reflectance-low transmittence shading - midpane | solar irradiance >200 W/m2 |

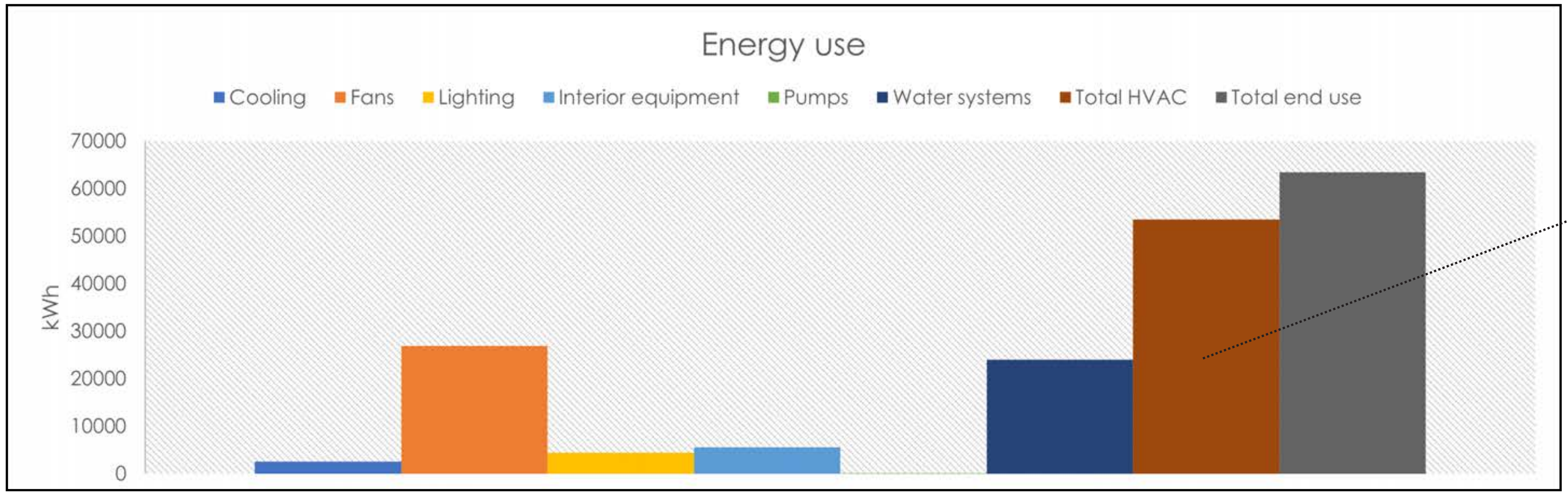
| | Roof window material | | Shading | | lighting control |
|---|---|---|---|---|---|
| | material | transmission (SHGC) | type | schedule | |
| 1 | | | | solar irradiance on window >200 W/m2 and outside air temp >24 oC | |
| 2 | Triple glazing, clear , 1m louvre - triple LoE film (33) Bronze 6mm/3mm Air | 0.17 | Medium reflectance-low transmittence shading - midpane | Glare | on |
| 3 | | | | Daycooling and solar >200 W/m2 | |
| 4 | | | | Horizontal solar irradiance >200 W/m2 and outside air temp >24 | |

| | |
|---|---|
| **Glazing Template** | |
| **Template** | **Triple glazing, clear, LoE, argon-filled** |
| **Airflow Control Windows** | |
| Airflow control | |
| Source | 1-Indoor air |
| Destination | 2-Outdoor air |
| Max flowrate (m3/s-m) | 0.00800 |
| Schedule definition | 1-Follow occupancy |
| **Sloped Roof Windows/Skylights** | |
| **Glazing type** | **Trp LoE Film (33) Bronze 6mm/13mm Air** |
| **Layout** | **No roof glazing** |
| Dimensions | |
| Frame and Dividers | |
| Shading | |
| **Window shading** | |
| **Type** | **Medium reflectance - low transmittance shade** |
| Position | 1-Inside |
| **Control type** | **17-Outdoor air temp + Solar on window** |
| Solar setpoint (W/m2) | 200 |
| Outside air temperature setpoint (°C) | 24.00 |
| Operation | |
| Schedule definition | 2-Custom schedule |
| Operation schedule | LibMusGall_Lecture_Equip |
| Free Aperture | |
| Doors | |

# ASHP Simulation 1



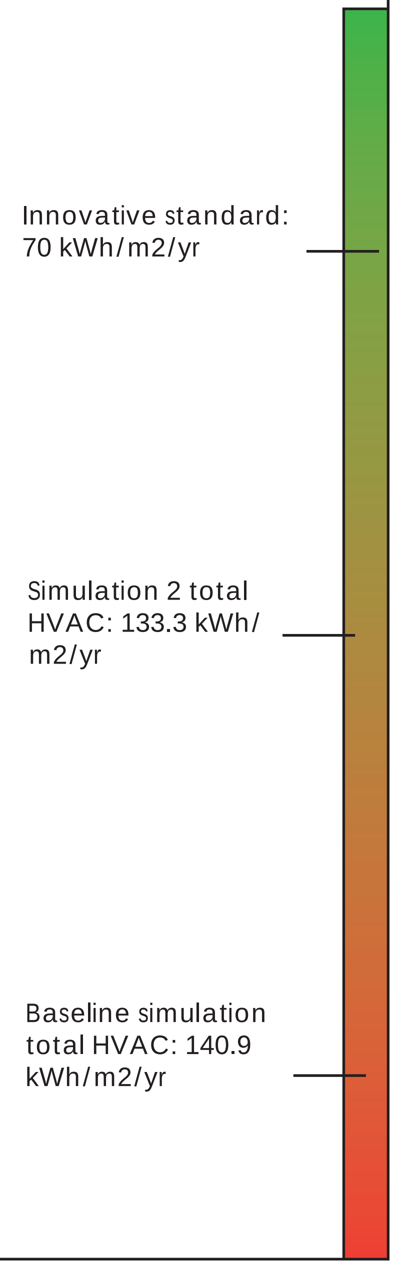




Change summary:

1. Glazing ratio is reduced according to DF analysis.
2. Shading schedule is changed to '*Shading is used when solar irradiance > 200W/m2 and outside air temperature > 24 oC*'.
3. Glazing material is changed to *triple LoE bronze (33) film, 6mm/3mm air*
4. Shading material is changed to *medium reflectance and low transmittance*

Total HVAC consumption: 133.3 kWh/m2/yr

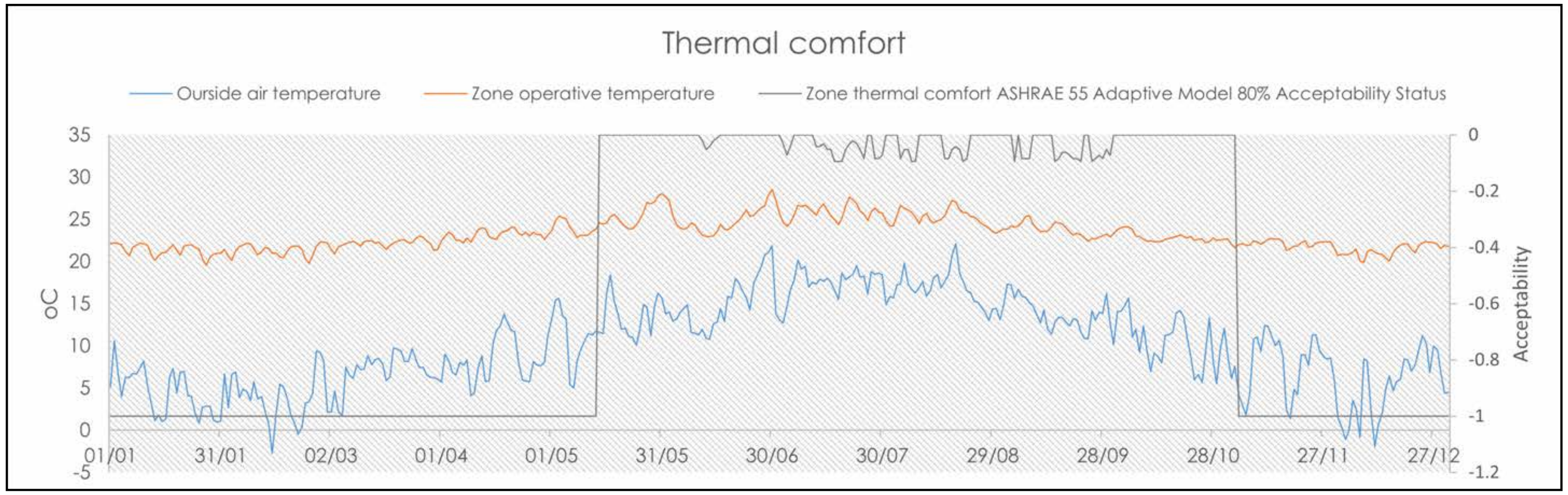


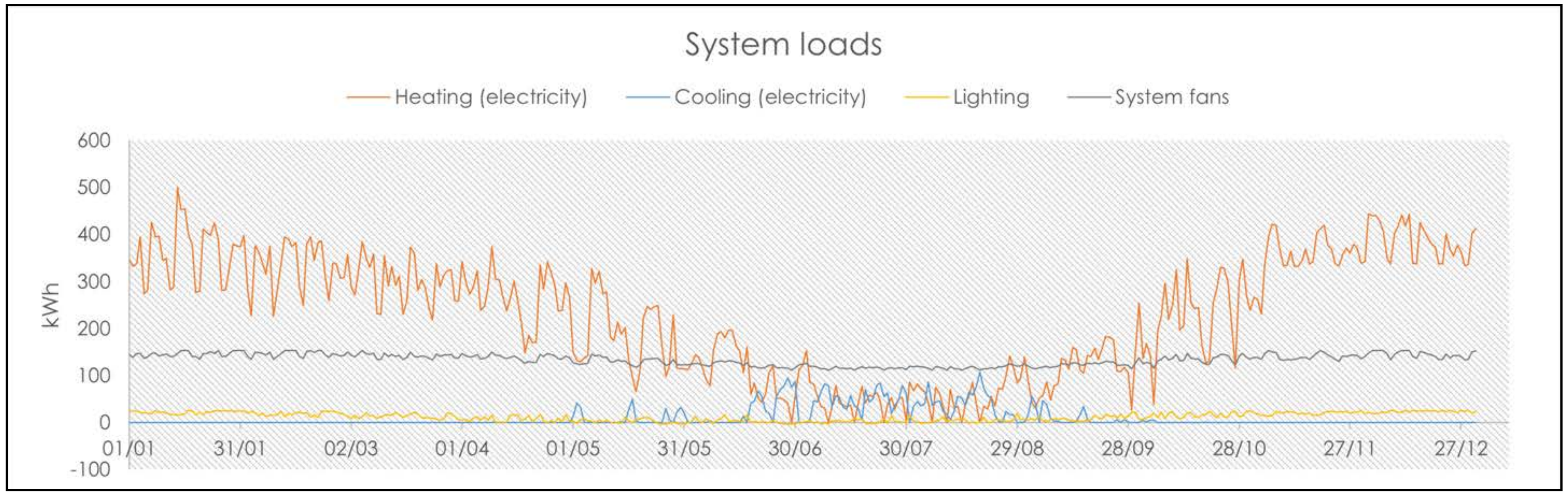
# ASHP Simulation 2

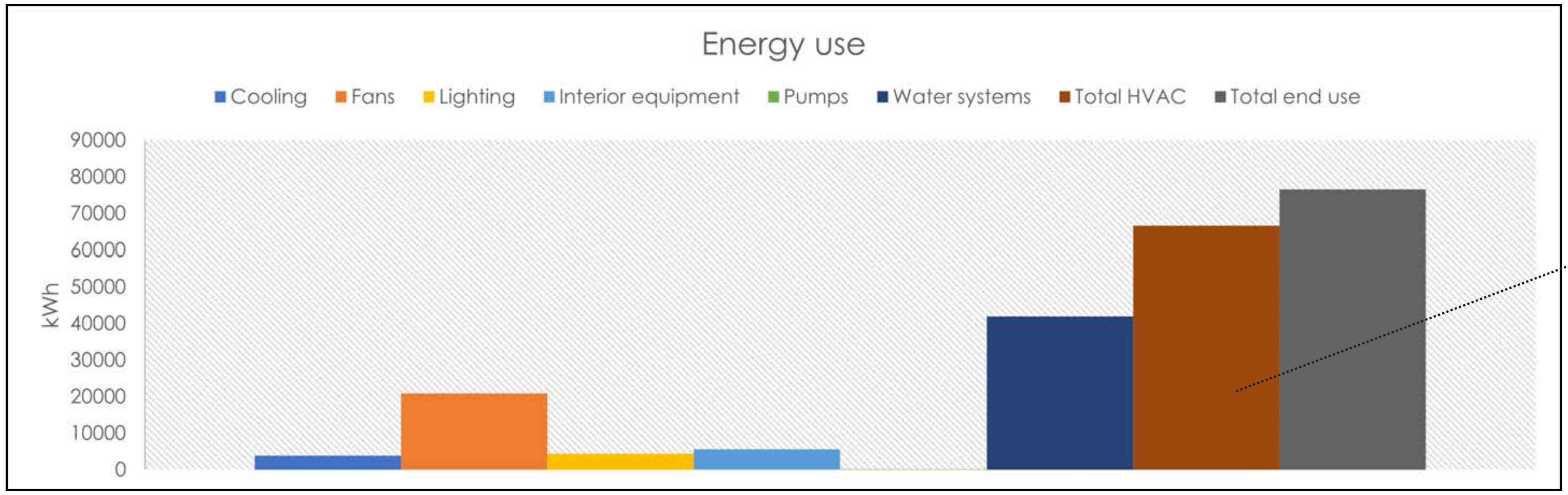
Change summary:

1. U values of walls, roofs and floors are all reduced to levels of Max Fordham Innovative standard.

2. A CAV air loop is replaced by a VAV air loop.



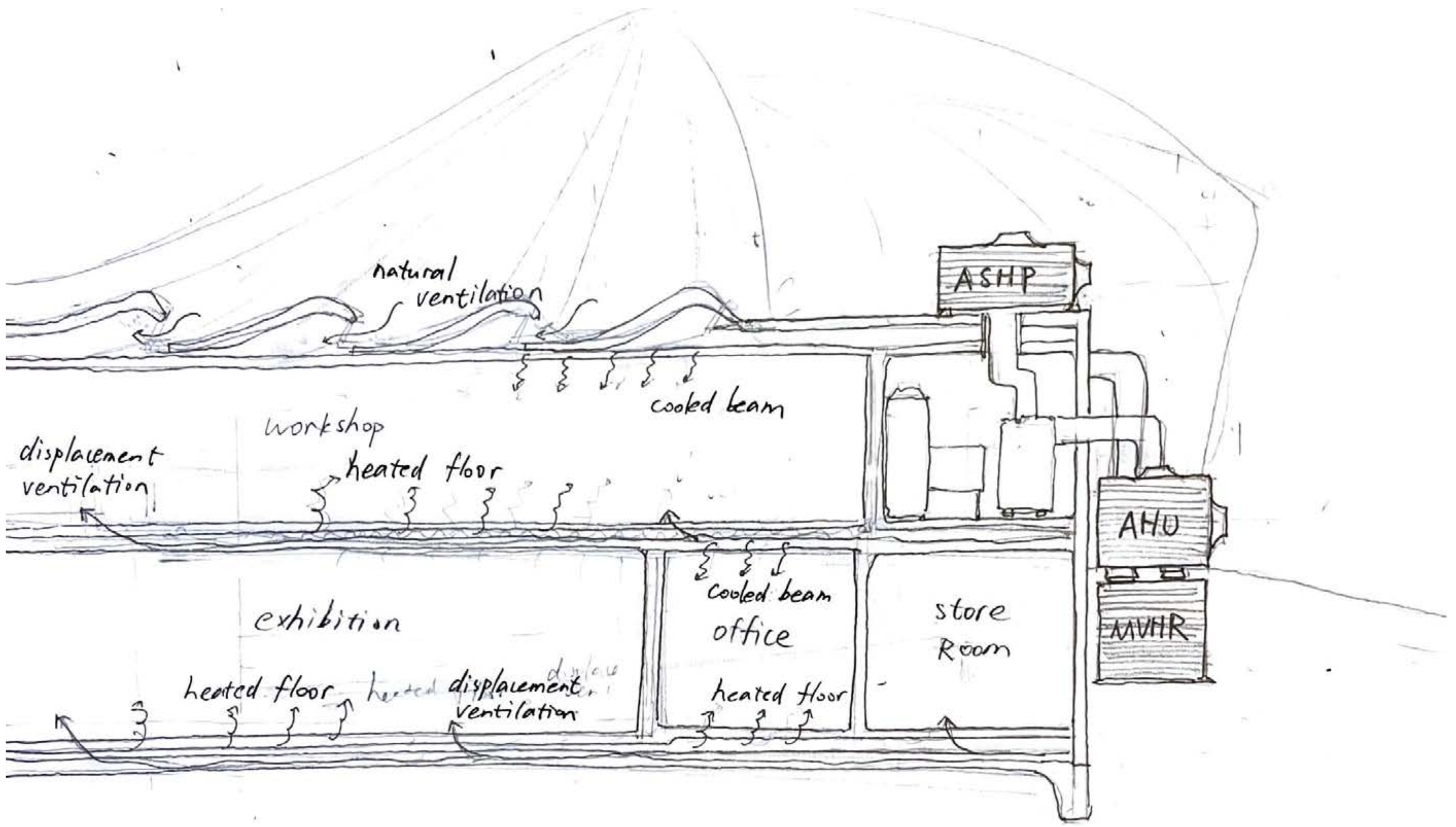




Total HVAC consumption: 106.9 kWh/m2/yr

Innovative standard: 70 kWh/m2/yr

Simulation 2 total HVAC: 106.9 kWh/m2/yr

Baseline simulation total HVAC: 175.4 kWh/m2/yr








# ASHP + MVHR

There are also a series of constraints in the design:

1. ASHPs have more constraints of minimum distance from other buildings, which needs careful design in such a crowded site.

2. ASHPs are noisier to operate compared with GSHPs, which will potentially cause more disturbance to surrounding residents and thus noise mitigation measures will be required.

3. ASHPs have limited power of raising temperature below certain temperatures, and can be ineffective in extreme weathers.

Therefore, an MVHR system can be incorporated to assist the heating capacity of the HVAC system. MVHRs work well with ASHPs and are very suitable for this project, because the eccessive heat generated in the workshop space can be efficiently redistributed to other zones.

N

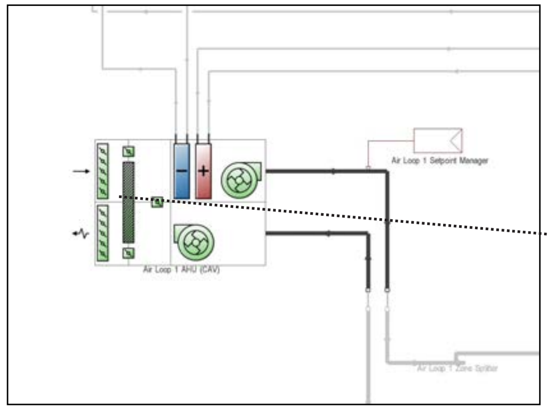
# Heat recovery with summer bypass

A workshop space is integrated into the model with the power density of 10W/m2 (heavy machine area). It is compared how much energy heat recovery can save annually. The settings and configurations are listed below.

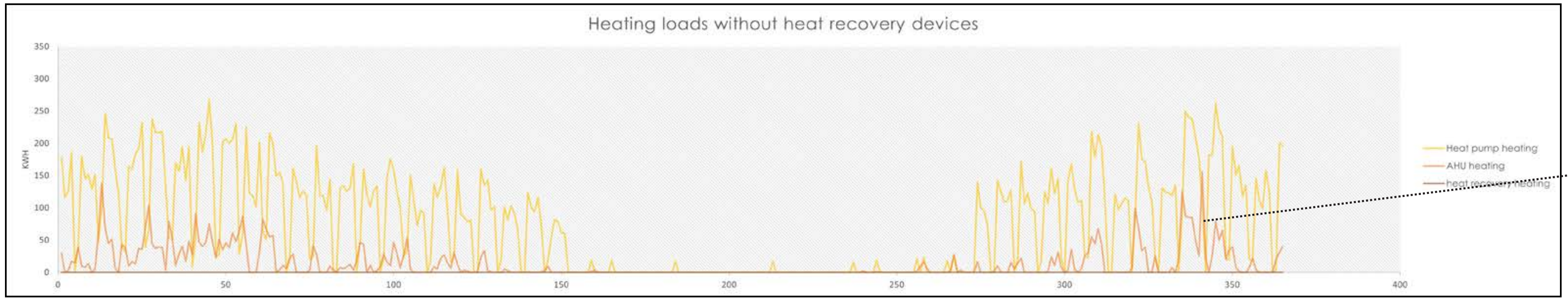
**ASHP**: cooling system seasonal CoP: 1.67; Displacement air distribution system

**Heat recovery**: Type: Enthalpy (recovers both sensible and latent heat); Sensible heat effectiveness: default 0.7; Latent heat effectiveness: default 0.65; No economiser; Heat recovery schedule: 1- heat recovery is available; 0- it is not available and the bypass is opened (summer bypass); Heat recovery will operate when the following three conditions are all satisfied:

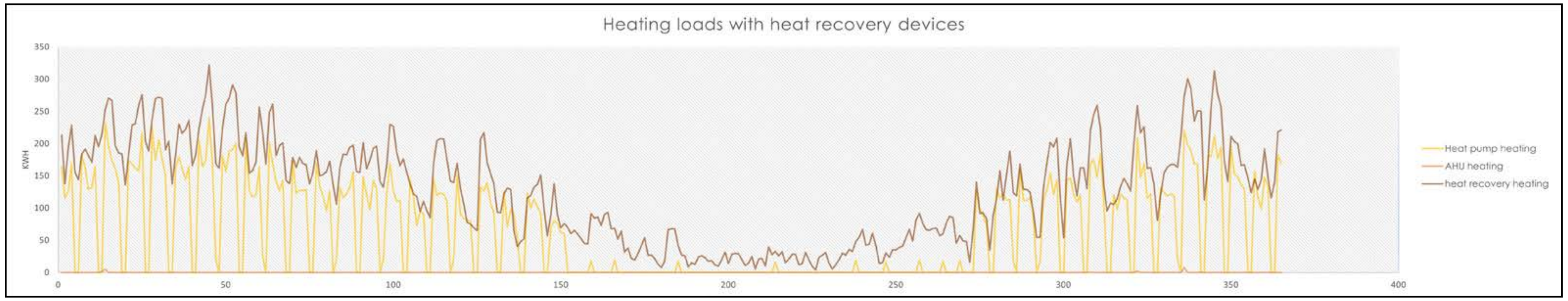
1. Heat recovery is switched on at the building level for VAV and unitary multizone systems and at zone level for Unitary single zone systems AND
2. The heat recovery schedule has a value of 1 AND
3. When economiser operation is off.



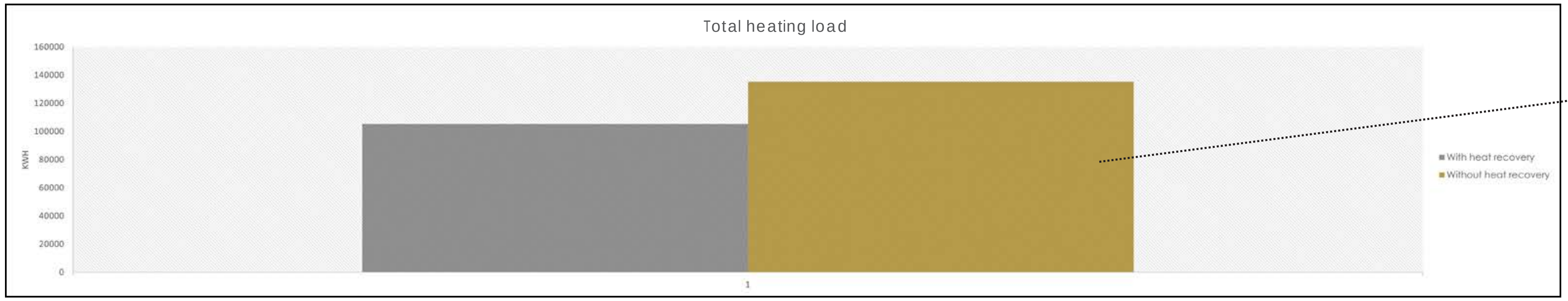
Heat recovery is turned on in the central AHU




When no heat is recovered from the zones, the heating coil in the AHU which uses heated water from the ASHP consumes more electricity.




The recovered heat offsets the heating load of AHU, and the heating load of ASHP is slightly reduced.

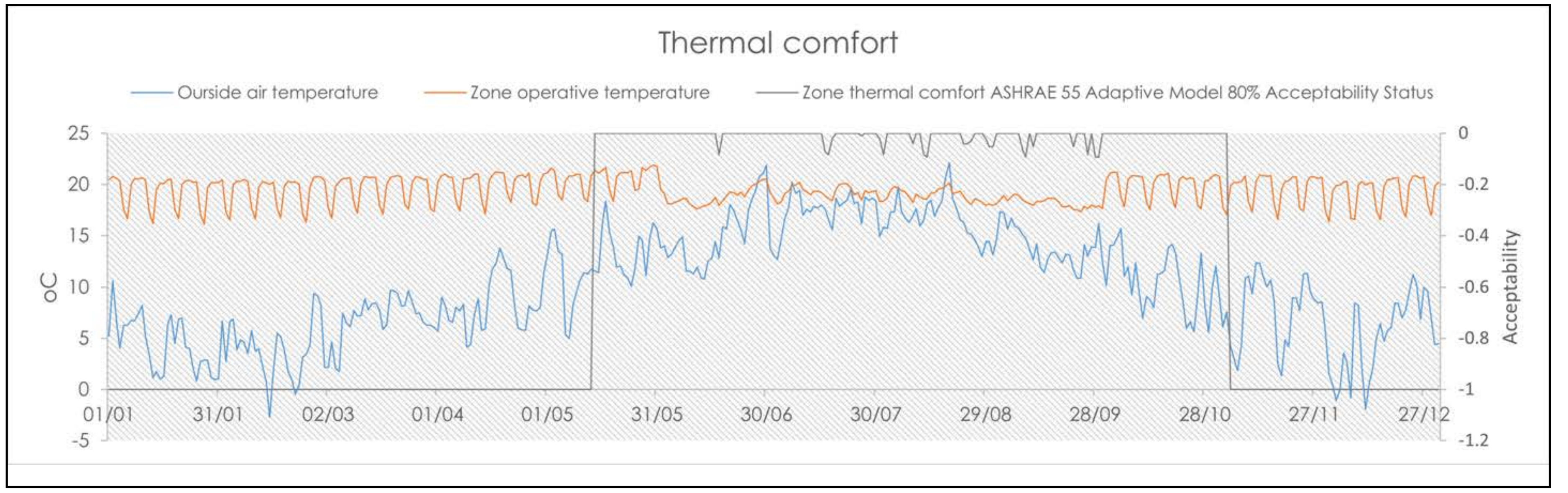


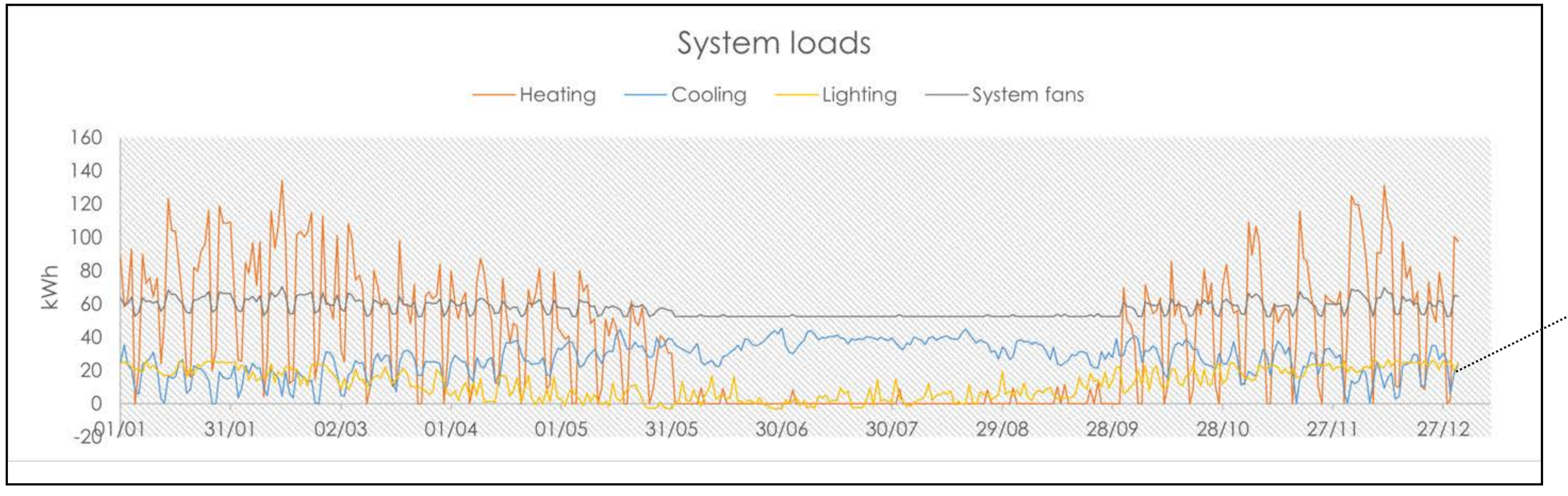

Heat recovery devices can save up to 22.3% of annual energy.

# ASHP Simulation 3

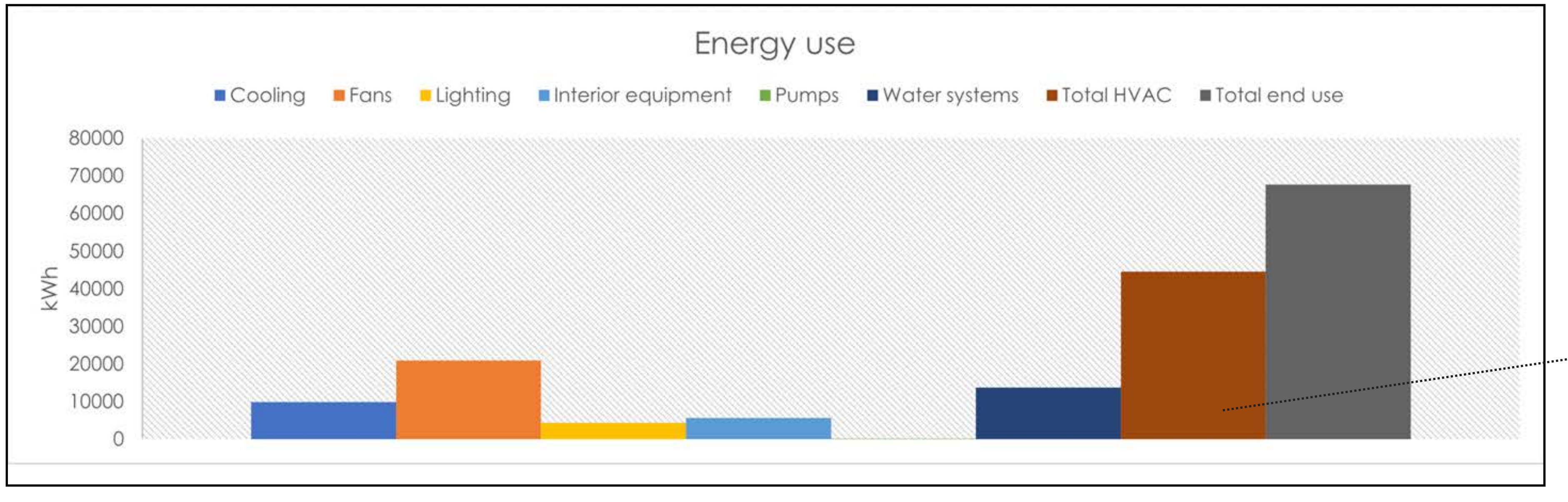
Change summary:

A heat recovery component is integrated into the central AHU system.




Although heating load is reduced by around 25% compared with simulation 2 annually, cooling load and fan power have both increased, probably because summer bypass is not properly set.




Total HVAC: 105.7 kWh/m2/yr.

Innovative standard: 70 kWh/m2/yr

Simulation 3 total HVAC: 105.7 kWh/m2/yr

Simulation 2 total HVAC: 106.9 kWh/m2/yr

Baseline simulation total HVAC: 175.4 kWh/m2/yr

# Avoid overheating:

## CIBSE TM52 Thermal comfort analysis

The risk of overheating in buildings is becoming more prevalent as changing climates and global energy insecurity make the control of indoor climate increasingly problematic. Overheating occurs in a building either through inappropriate design, poor management or inadequate services. Features of a design that support lower winter heating demand (such as large areas of south facing windows, high levels of insulation, low air permeability rates and low thermal mass) can result in excessively high internal temperatures during summer months.

In response to this increasing level of risk, CIBSE have developed an adaptive methodology to assess the predicted level of thermal comfort within a building. This assessment can be carried out at the detailed design stage by way of Dynamic Simulation Model. CIBSE TM52 sets three criteria for compliance. A building that fails two or more of the criteria is deemed to be at unacceptable risk of overheating:

**Criterion 1**: Hours of Exceedance

**Criterion 2**: Daily Weighted Exceedance

**Criterion 3**: Upper Limit Temperature

The number of hours ($H_e$) during which ΔT is greater than or equal to one degree (K) during the period May to September inclusive shall not be more than 3% of occupied hours.
If data are not available for the whole period (or if occupancy is only for a part of the period) then 3% of available hours should be used.

**Criterion 1**: Hours of Exceedance

To allow for the severity of overheating the weighted Exceedence ($W_e$) shall be less than or equal to 6 in any one day.
Where
$W_e = \Sigma he \times wf = (h_{e0} \times 0) + (h_{e1} \times 1) + (h_{e2} \times 2) + (h_{e3} \times 3)$

the weighting factor wf = 0 if $\Delta T \leq 0$, otherwise wf = ΔT, and $h_{ey}$ = time in hours when wf = y

**Criterion 2**: Daily Weighted Exceedance

To sets an absolute maximum value for the indoor operative temperature the value of ΔT shall not exceed 4K.

**Criterion 3**: Upper Limit Temperature

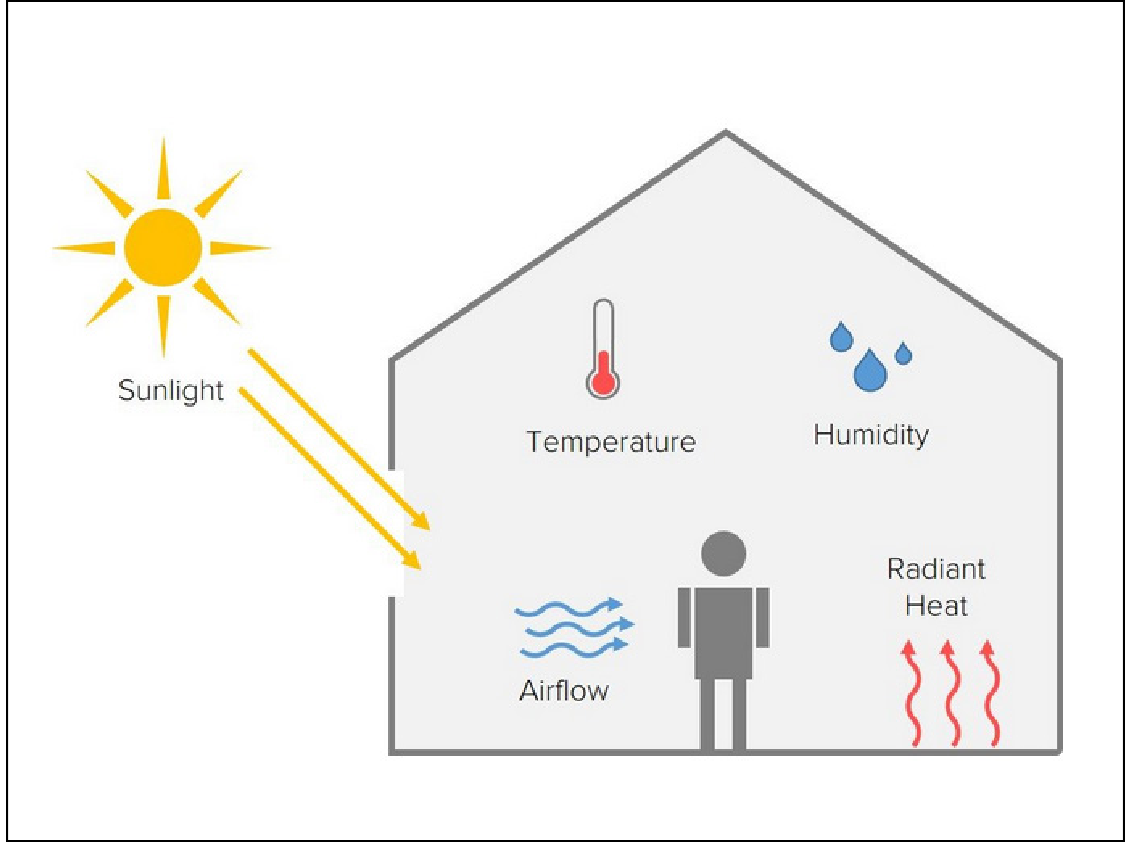




# TM52 The limits of thermal comfort: Avoiding overheating in European buildings

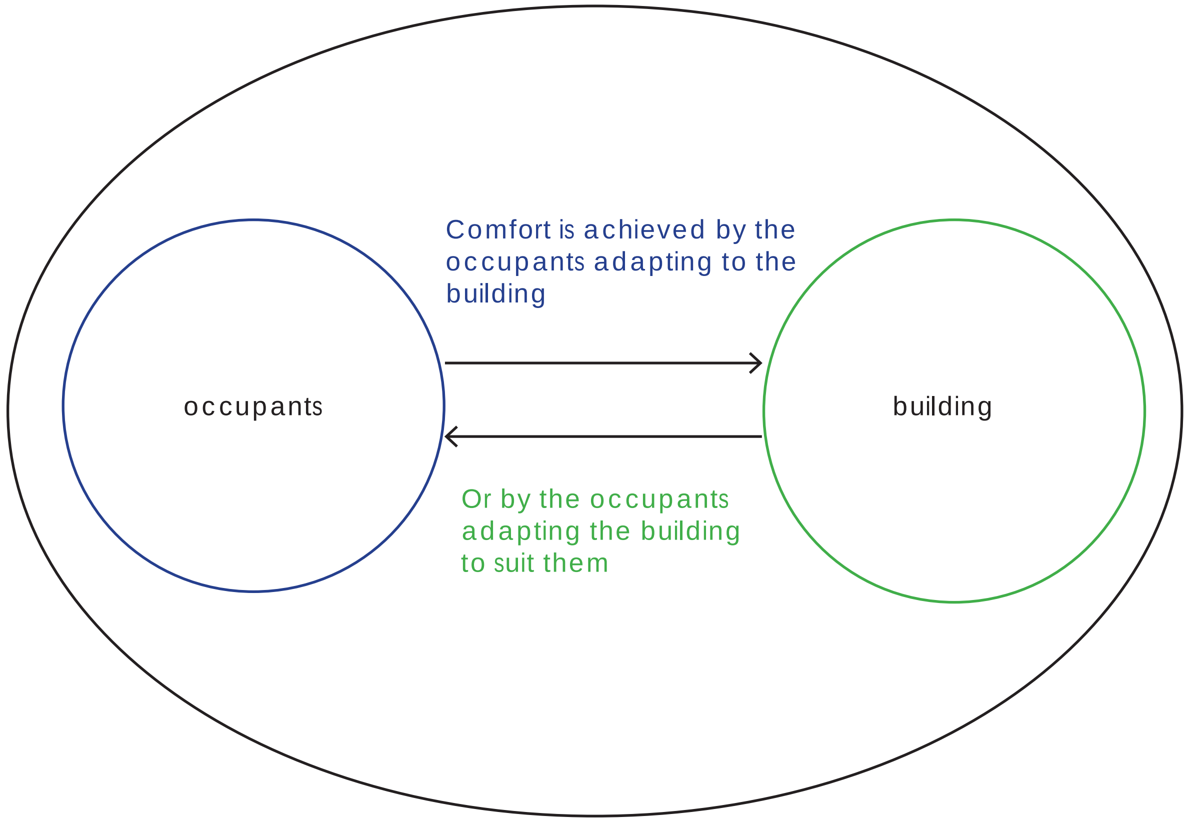
Overheating has become a key problem for building design. The need to reduce energy consumption whilst dealing with global climate change has reduced the options available for building comfortable, low-energy buildings. Research has been directed towards methods for increasing indoor winter temperatures but this can lead to lightweight, highly insulated buildings that respond poorly in the summer. CIBSE has responded by forming the CIBSE Overheating Task Force.

CIBSE TM 52 (https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q20000008I7f5AAC)




Overheating issues. (https://ggbec.co.uk/quick-guide-overheating-thermal-comfort/)

# Adapting the building to occupants




## Maximum acceptable temperature

For buildings specified in EN15251, the maximum acceptable temperature (Tmax) can be calculated from the running mean of the outdoor temperature (Trm) using the formula:

$$T_{max} = 0.33T_{rm} + 21.8\ (°C)$$

The average outdoor drybulb temperature is: 10.23 oC. Therefore the maximum acceptable temperature for this project is:

$$T\ max = 0.33*10.23+21.8=25.17\ oC$$





# Buildings with mechanical cooling

Maximum temperatures for different types of indoor space. Clothing is assumed to be 1.0 clo in winter and 0.5 clo in summer (after BSI, 2007)

| Type and use of space | Assumed met | Winter (clo = 1.0) | Summer (clo = 0.5) |
|---|---|---|---|
| | pmv> | +0.5 | +0.5 |
| Residential (sedentary) | 1.2 | 25.0 | 26.0 |
| Residential (active) | 1.5 | 25.0 | |
| Offices | 1.2 | 24.0 | 26.0 |
| Public spaces (auditoria, cafe etc) | ~1.2 | 24.0 | 26.0 |
| Classrooms | 1.2 | 24.0 | 26.0 |
| Kindergarten | 1.4 | 22.5 | 25.5 |
| Shops | 1.6 | 22.0 | 25.0 |

Although heating load is reduced by around 25% compared with simulation 2 annually, cooling load and fan power have both increased, probably because summer bypass is not properly set.

# European Standard EN 15251

This standard entitled 'indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics' was designed to set limits for indoor conditions to ensure that the energy performance of buildings directive did not compromise the comfort of occupants in the pursuit of energy reduction.

| Category | Applicability/level of expectancy | PMV range in mechanically cooled buildings |
|---|---|---|
| I | High: Buildings with high expectancy for sensitive occupants | ± 0.2 |
| II | Normal: New buildings | ± 0.5 |
| III | Acceptable: Existing buildings | ± 0.7 |
| IV | Low expectancy only for short periods | > 0.7 |

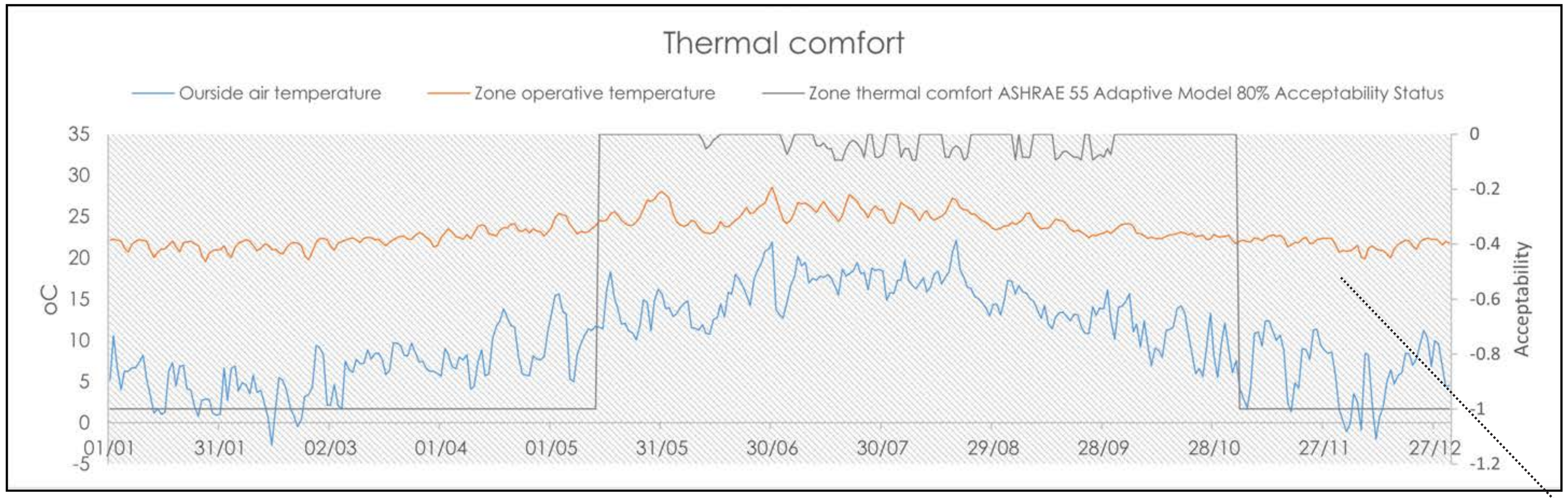
# ASHP Simulation 4

Change summary:

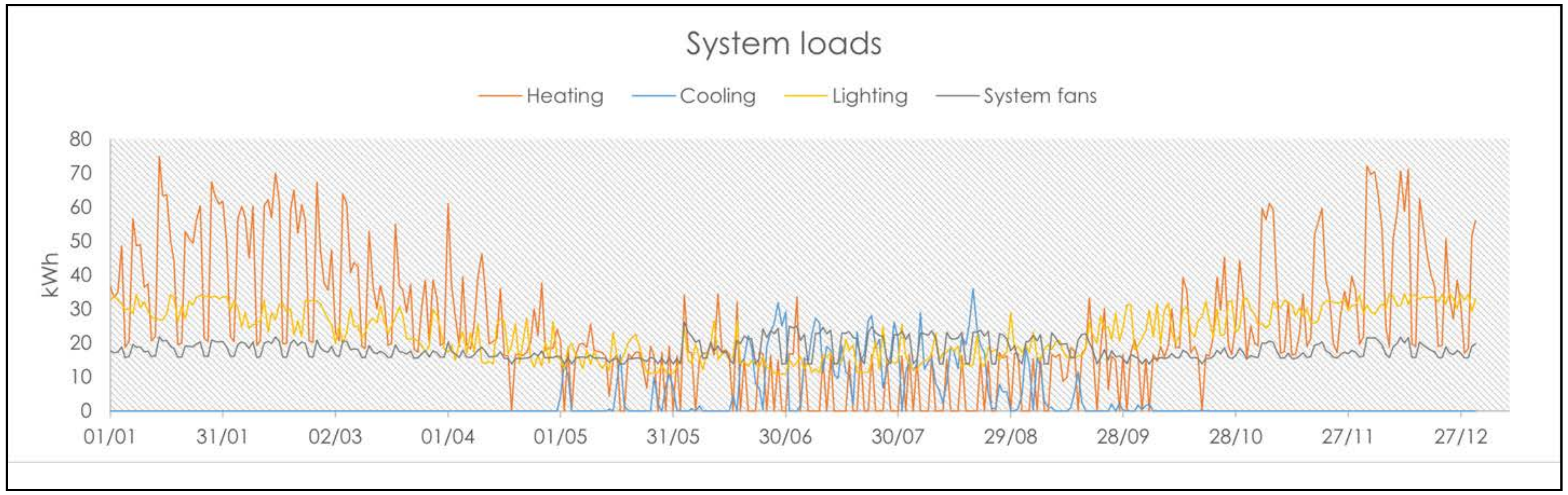
1. Changed Heat Recovery Operation Availability Schedule to simulate the effect of summer bypass.

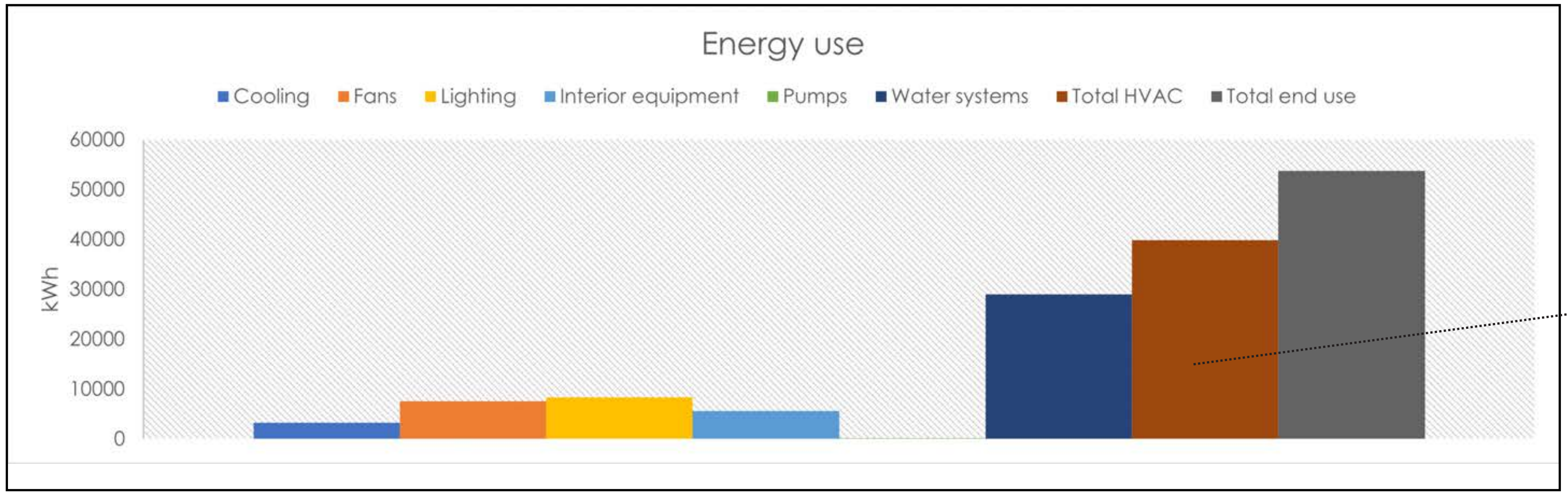
2. Changed PMV setpoint temperature to widen the comfort range and allow for some outliar temperatures.

3. Improved natural ventilation schedule in summer to reduce cooling load.

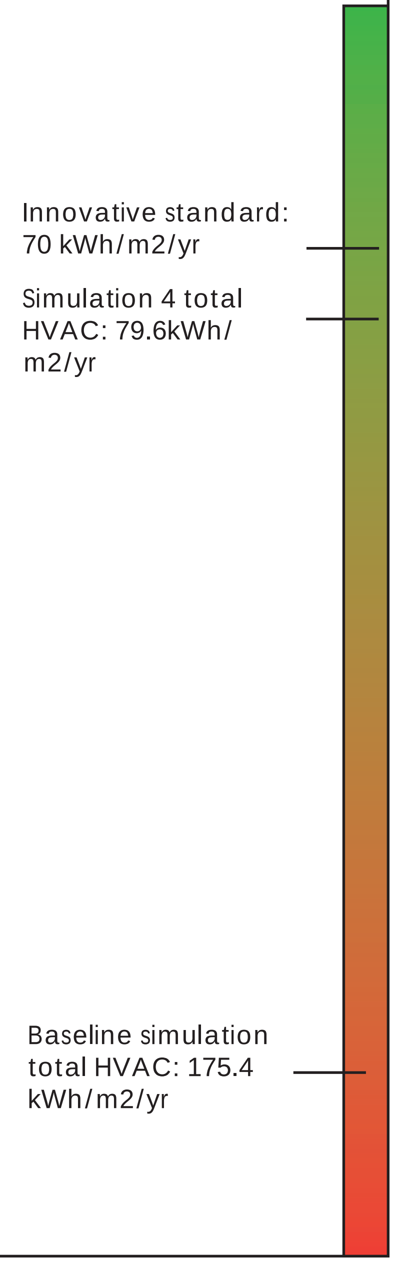



According to the hourly data, the total time of temperature exceeding 25.17 oC (the maximum acceptable temperature) between May and September during occupancy time is 2.1%, which is below the value (3%) of criteria 1, TM52.



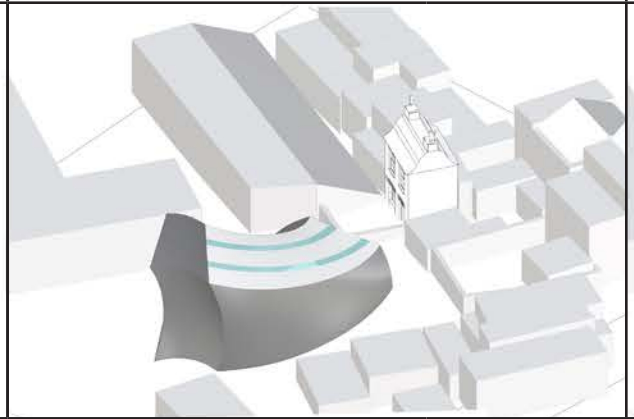
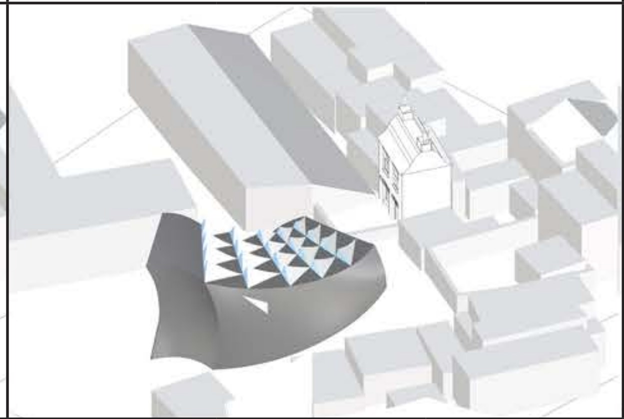
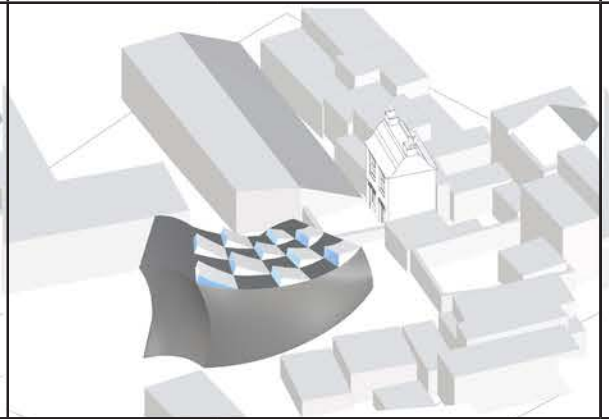
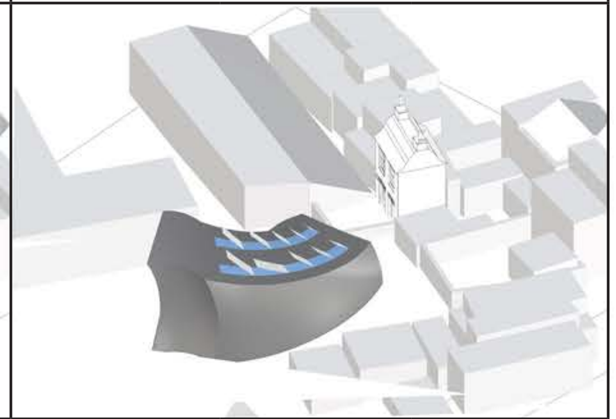
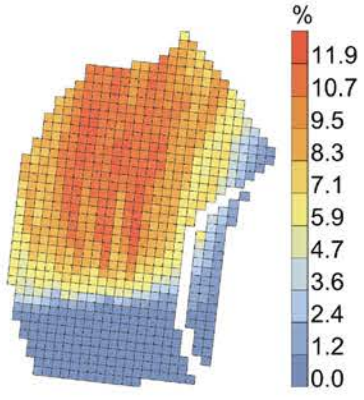
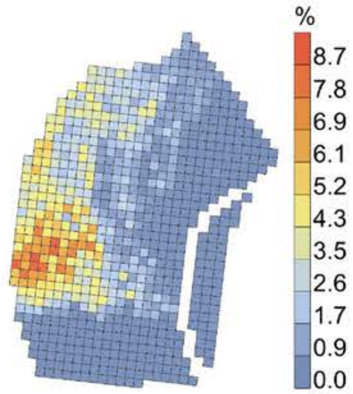
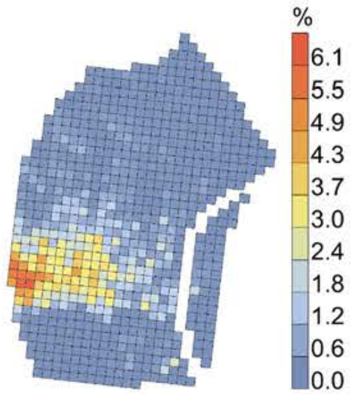
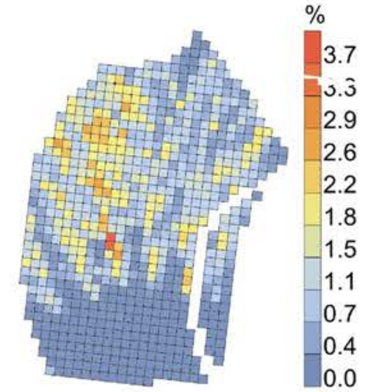
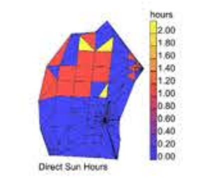
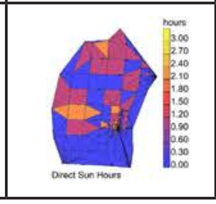
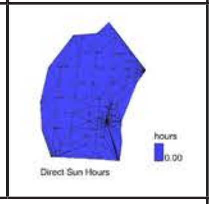
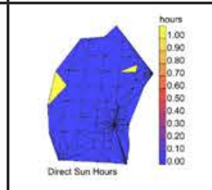
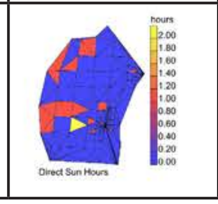
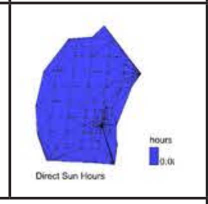
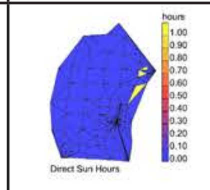
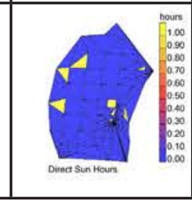
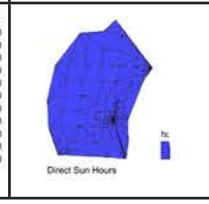
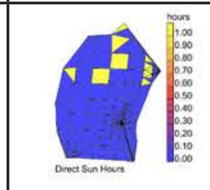
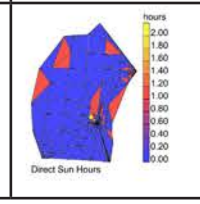
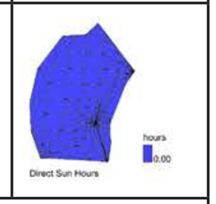

Total HVAC load: 79.6 kWh/m2/yr



# Shading strategies - Sawtooth roof or flat roof

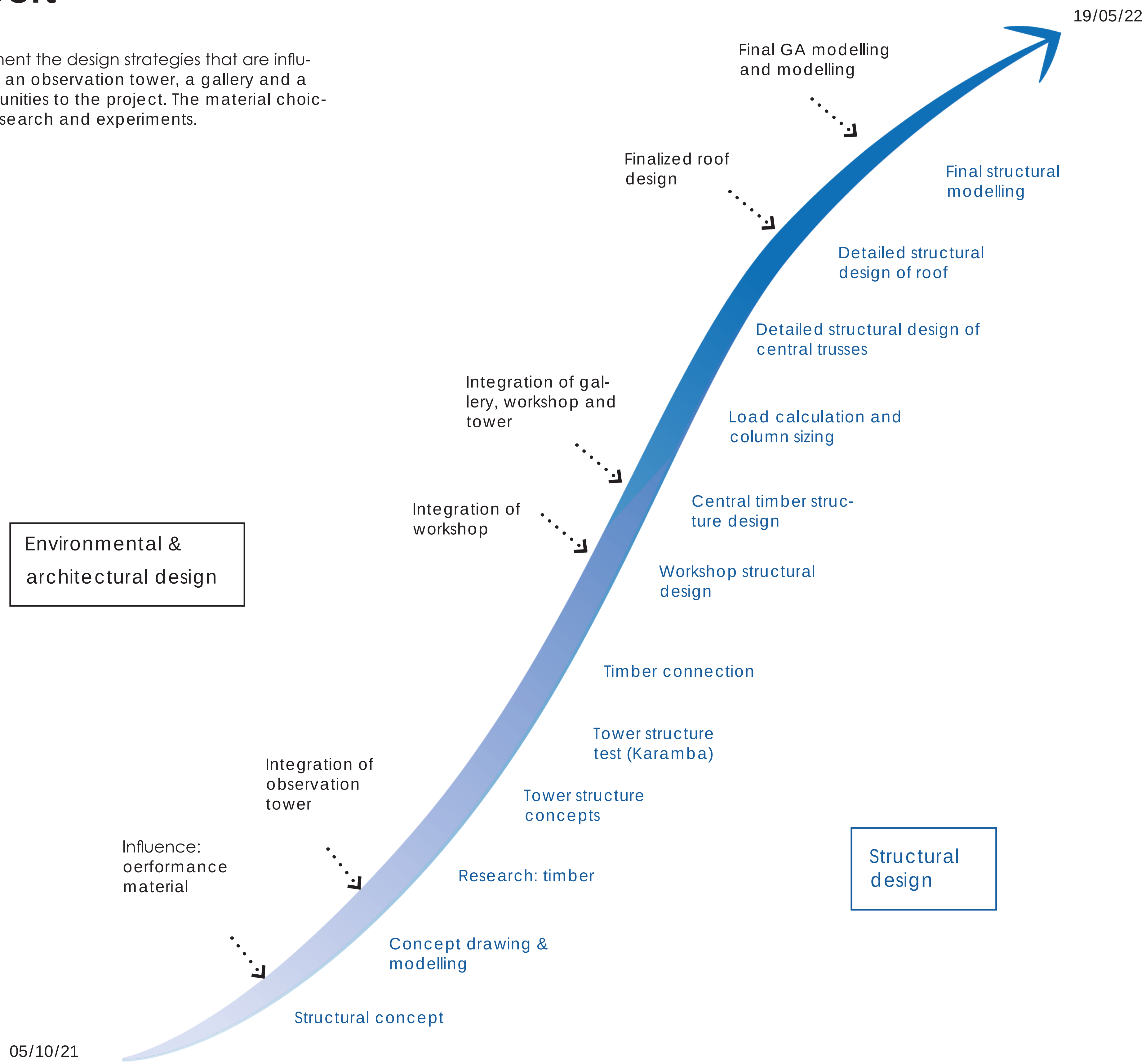
It has been concluded from previous simulations that the glazing ratios of skylight should be smaller or equal to the glazing ratio in Model 2. North-facing saw-toothing shading could perform well in terms of daylight factor, but might cause more heat loss. Shadings such as flat roof and external motorised shading might be less effective in providing diffused light but better in reducing heat loss.

- Shading strategy
- Heat loss (glazing ratio)
- Daylight factor
- Sun access time

| | **Flat room glazing - no shading**<br>Roof glazing ratio: 20.4 % | **Saw-tooth glazing - North-East**<br>Roof glazing ratio: 21.7% | **Saw-tooth glazing - North**<br>Roof glazing ratio: 9.9% | **Flat glazing - south shading**<br>Roof glazing ratio: 20.4 % |
|---|---|---|---|---|
| Roof shading strategies represent ...<br>N |  |  |  |  |
| Annual daylight factors of the basement space<br>N |  |  |  |  |
| Sunlight access hours on design days | Mar 21 <br>June 22 <br>Dec 21  | Mar 21 <br>June 22 <br>Dec 21  | Mar 21 <br>June 22 <br>Dec 21  | Mar 21 <br>June 22 <br>Dec 21  |
| Conclusions | The daylight factors of the space are above 10% , and may cause glare and excessive thermal gain. The direct sunlight hours on a typical day (Mar 21) can reach 1.5 hours, which is also too high. This means shading must be provided even the transmittance of glazing is low (0.17). | The daylight factors are within reasonable range and the sun access hour on June 22 is acceptable. However, the roof glazing ratio can be large due to the glazing ratio of 21.7%. | The saw-tooth glazing on the north side of the building roof receives very little daylight, due to the curved geometry. This results in low daylight factors in the areas under these parts of the roof. However, it manages to avoid sunlight penetration and the low glazing ratios means the heat loss can be very small. | The daylight factors are below an average of 3.5%, but are more evenly distributed compared with previous strategies. The daylight factors can be improved by adjusting shading angles. |

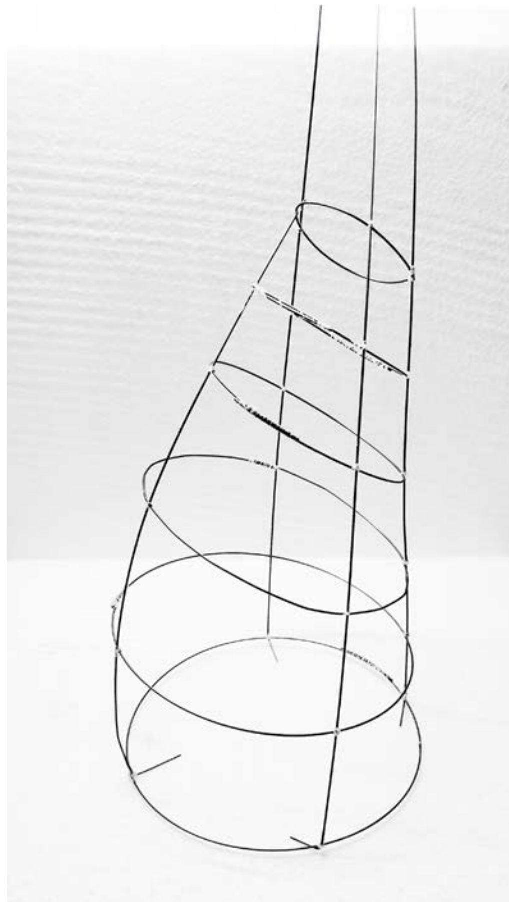
# Structural Report

The primary aim of the structural report is to organise and document the design strategies that are influenced by structural research and design. The project consists of an observation tower, a gallery and a workshop. The sloped site poses interesting challenges and opportunities to the project. The material choices and structural concepts are developed from research and experiments.




## Structural concept

The observation tower poses potenials for interesting structural concepts. Several concepts are explored during early stages of the design, including a sculptural combination of gallery and tower spaces, a structure balanced by opposing supports inspired by Noguchi, and a leaning wire model made possible by the bespoke curvatures of vertical supporting wires. These early inspirations have all influenced later designs in some ways.



# Research: material

This project primarily uses timber as its material, for the following considerations:

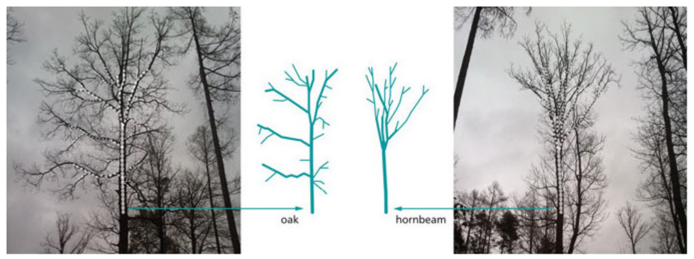
- The environmental parameter of this project is daylight: its versatility and change. The natural complexity of timber by wood's heterogeneous properties and dentriform shape can be activated and expoited to achieve ideal daylight effects.

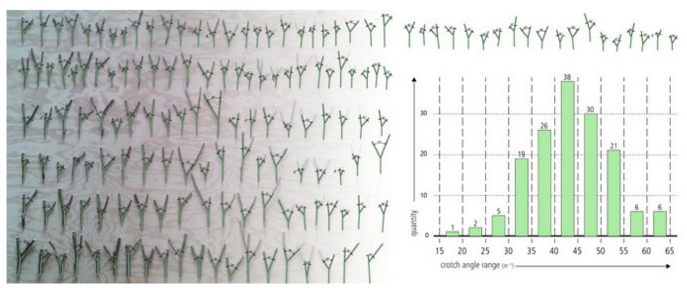
- The site is surrounded by heavy-weight buildings constructed with brick and concrete. A sense of contrast, lightweightness and youth is desired for this project, and timber is ideal for these purposes.

- Timber can merge harmoniously with the trees on the site.

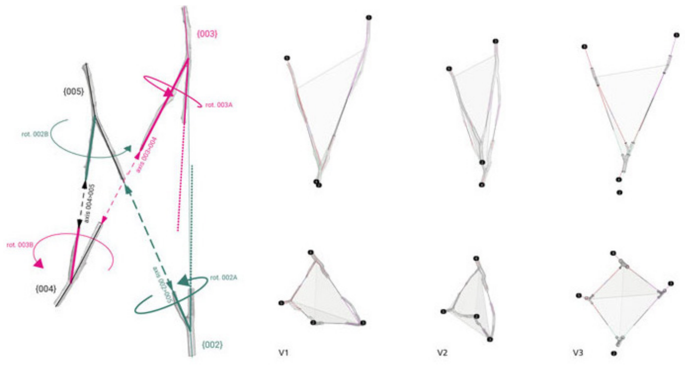
- Timber has been heavily researched as a promising material in the future that help achieve the sustainability and carbon neutral goals. It is of personal interest to explore the potential and performance of this material.

The main research applied in this project is '*Natural Complexity. An Introduction to Structural Design with Tree Forks*' by Lukas Allner and Daniela Kroehnert from Univerity of Applied Arts Vienna. The paper has provided innovative framework and workflow of wood design, and explores the possibility of using dentriform shapes in structures.

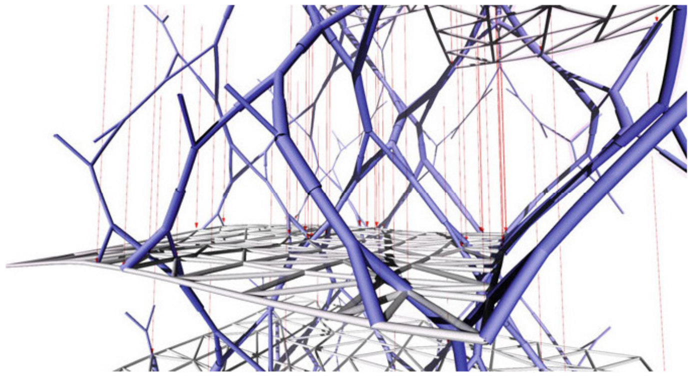


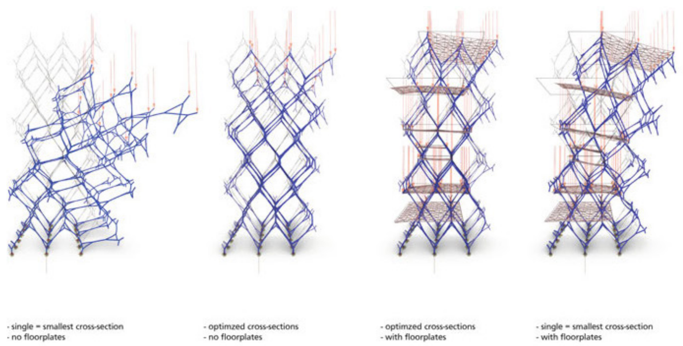




The research starts by looking into a specific species of trees, Hornbeam, which is characterised by a high rigidity and a tendency to extensive branching. The crotch angle ranges of it are recorded.




The geometries are abstracted into nodes and axes, and elements of branches are connected together.





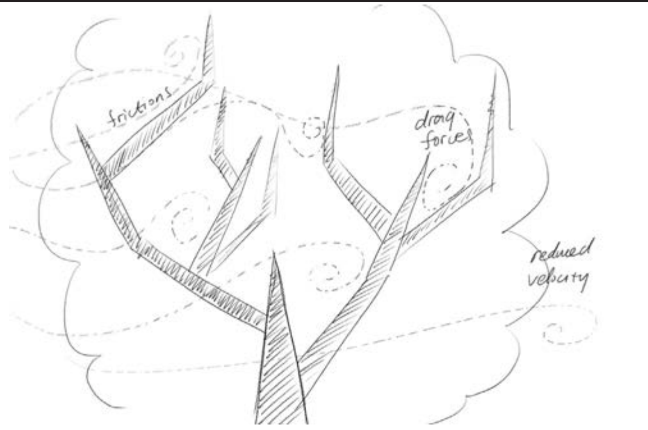
Y-shaped elements are connected into tetrahedron modules, and tetrahedron and octahedron frameworks can be formed.

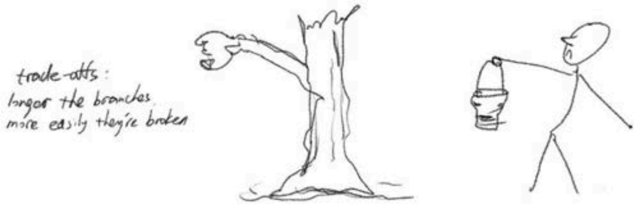


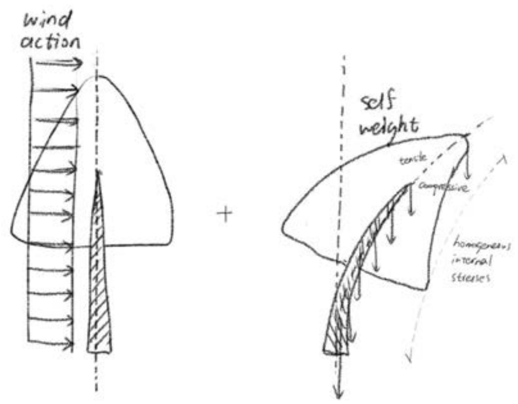


# Research: dentriform shape

One of the biggest challenges of tower design is how the structure resists wind load. Tree chunks and branches are excellent in this aspect. Trees have evloped to configure their own shape so that they can withstand against strong wind force and tackle resultant bending moments. Axial compression due to their weight is another load that is carried by tree stems and trunk. In bending condition, when the tree is exposed to wind, the stresses change from tensile at the convex side to compressive at the concave side of a component. On the other hand, internal shear stresses prevent component parts from slipping on shear-loaded interfaces. Structurally, for a good performance, these internal stresses must be homogeneous for distributing the loads evenly. Trees have optimized their shape to follow this structural demand.

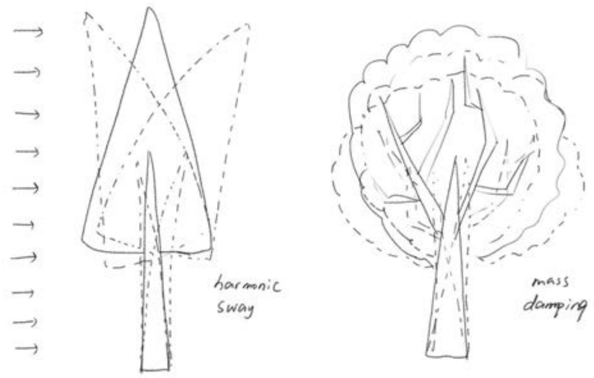


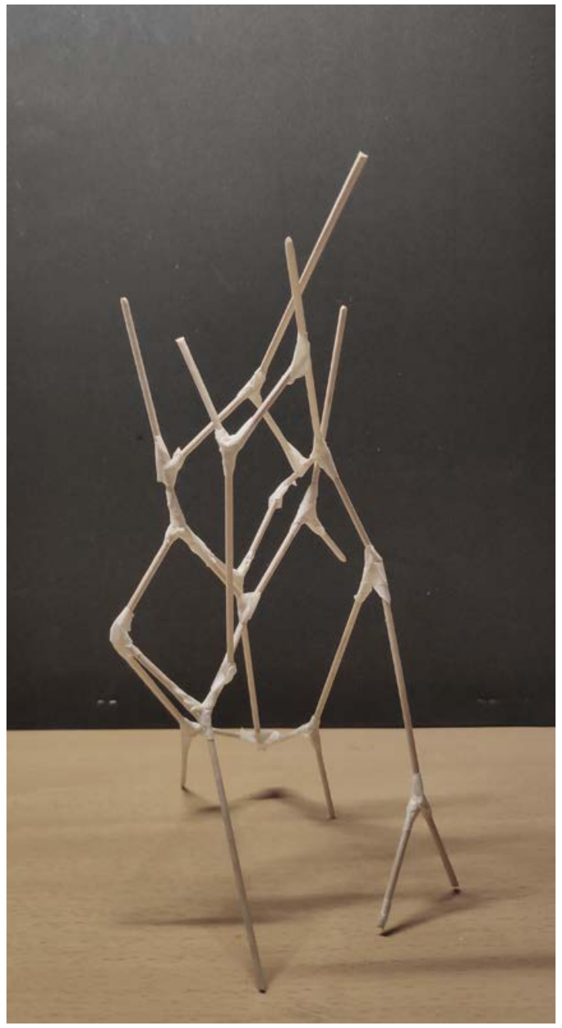





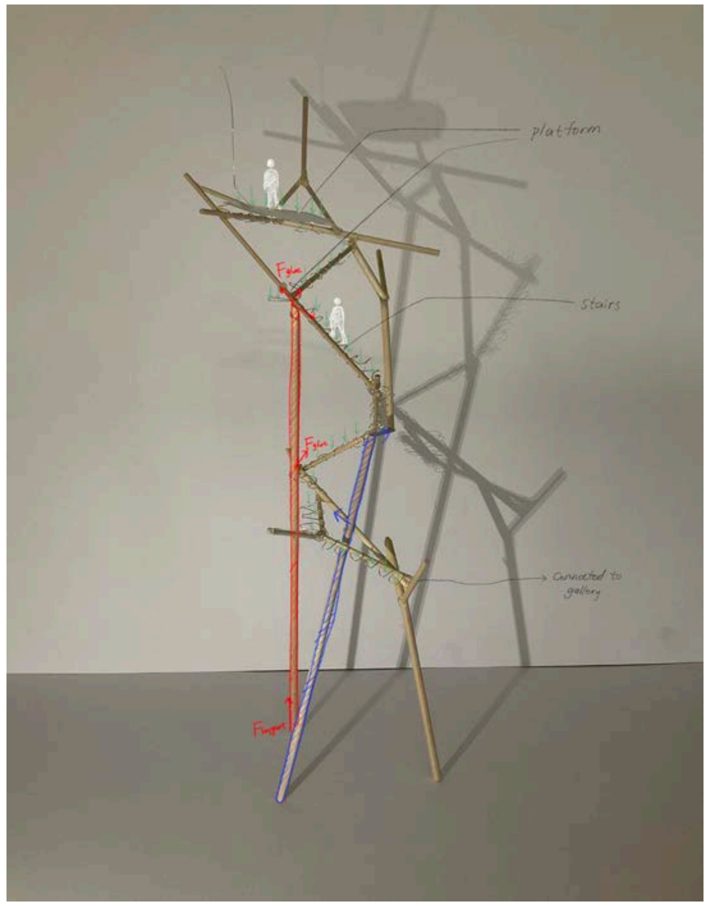
Under the wind loading forces, the group of complex patterned branches as a mass contributes a dynamic damping, known as mass damping, which acts to reduce dangerous harmonic sway motion of the trunk and so minimizes loads and increases the mechanical stability of the tree.




The fractal skeleton of a tree diverges the heavy wind to lower the impact on its tree-body. Besides, higher fractal dimension of branches helps to increase the drag forces and frictions in trees, thus lessens the wind velocity on its path especially during storms.



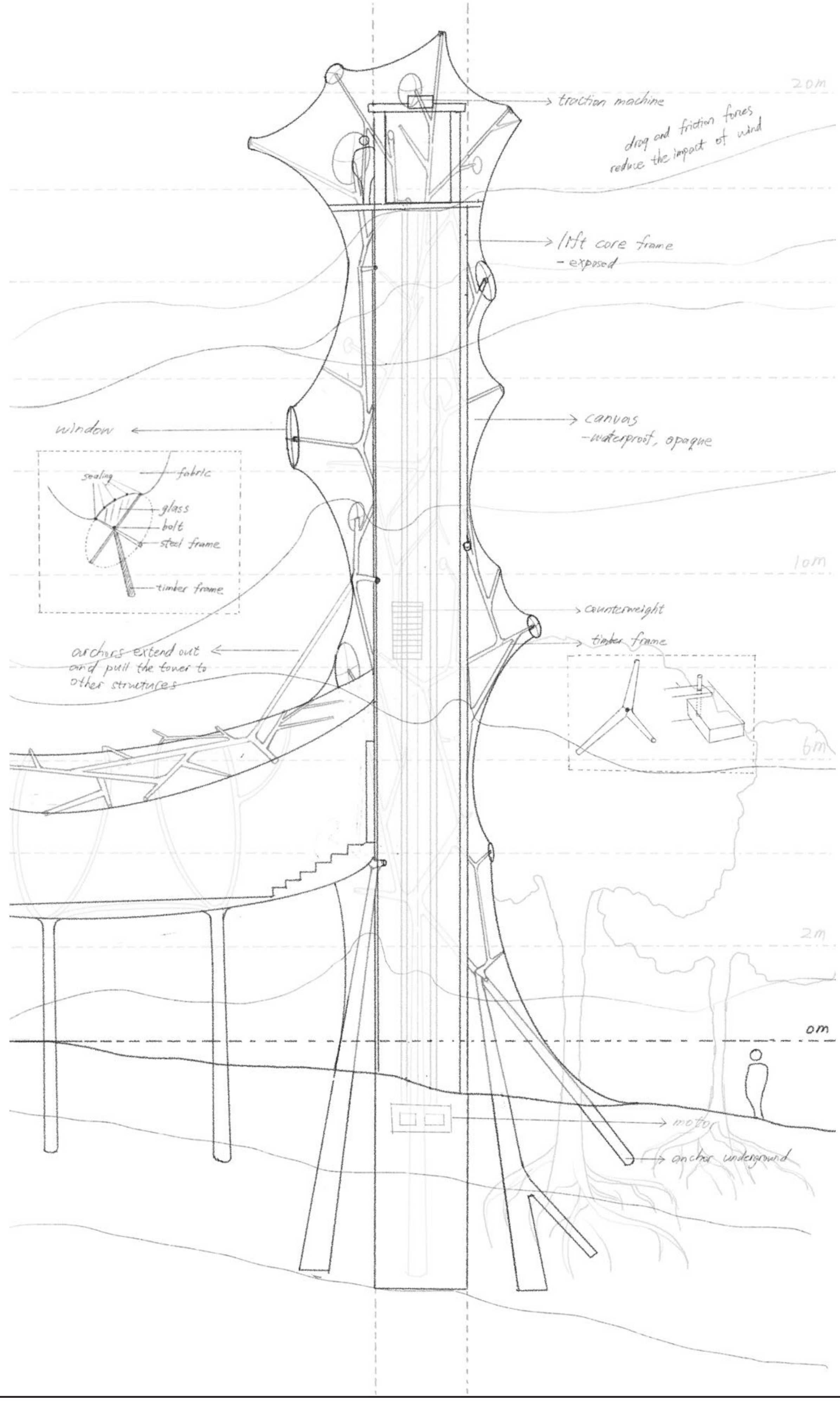
Procedural assembly parts are put together in iterative steps. Instead of a global logic controlling the formation, local parameters define the aggregation in every step. The form of aggregation is found in the process of making. Self organised structures can be adapted to local conditions by maintaining an overall systematic coherence dependent of the respective ruleset.




Preliminary force analysis of structural members of the tower. Because of the eccentricity of angles and configurations, the identification of compressive and tensile forces is difficult. Karamba 3D is later applied to analyze and optimise the structure.

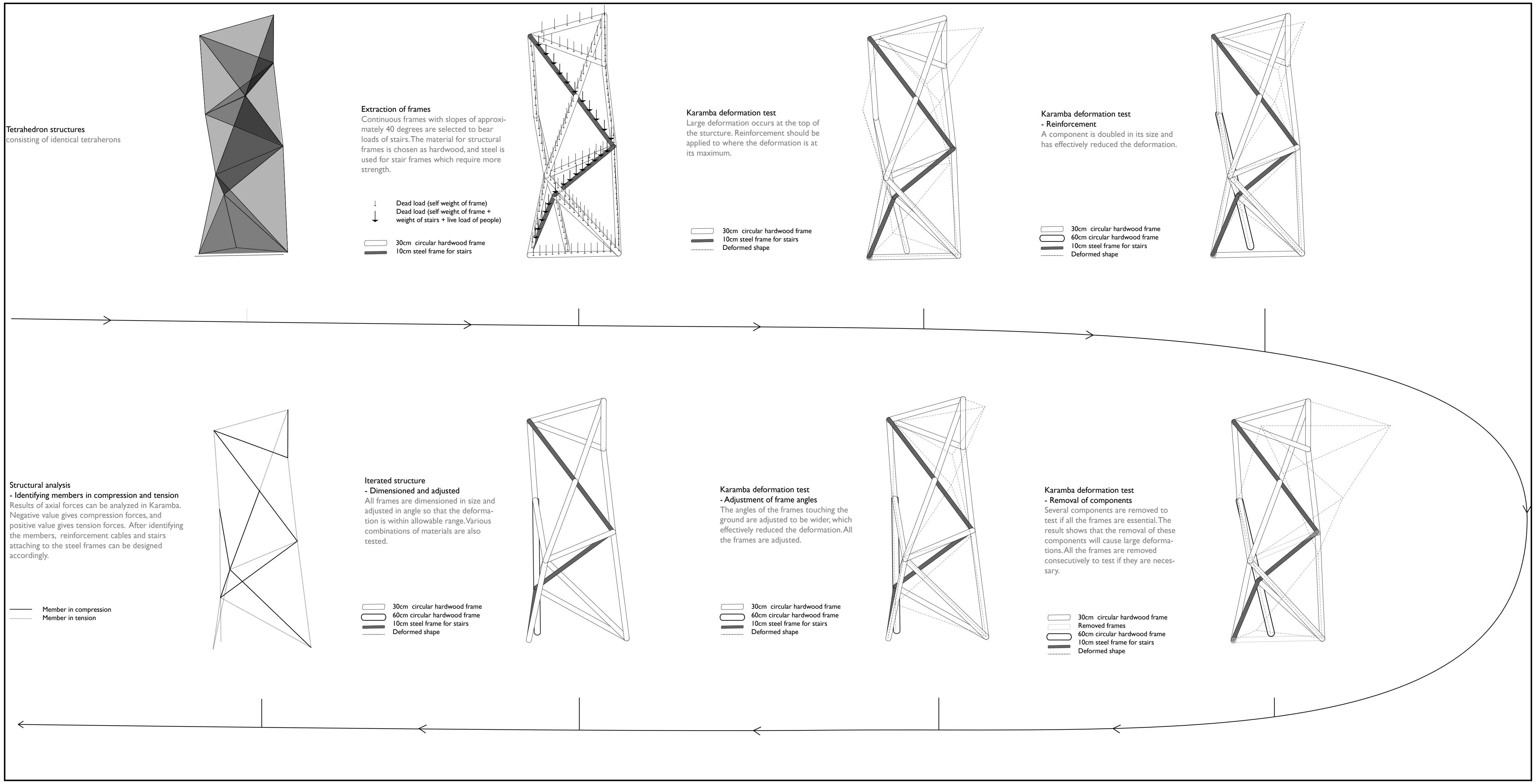
# Tower

The observation tower poses the greatest engineering challenge of this project. The tower structure is inspired by the research into dendriform shapes and the natural mechanism of trees, which has the potential of effectively resisting wind loads and transferring loads throughtout the structure. The structure is a rigid and hard, whereas the fabric around it softens the edges and encloses the space where people can look out and down when they walk up towards the top.

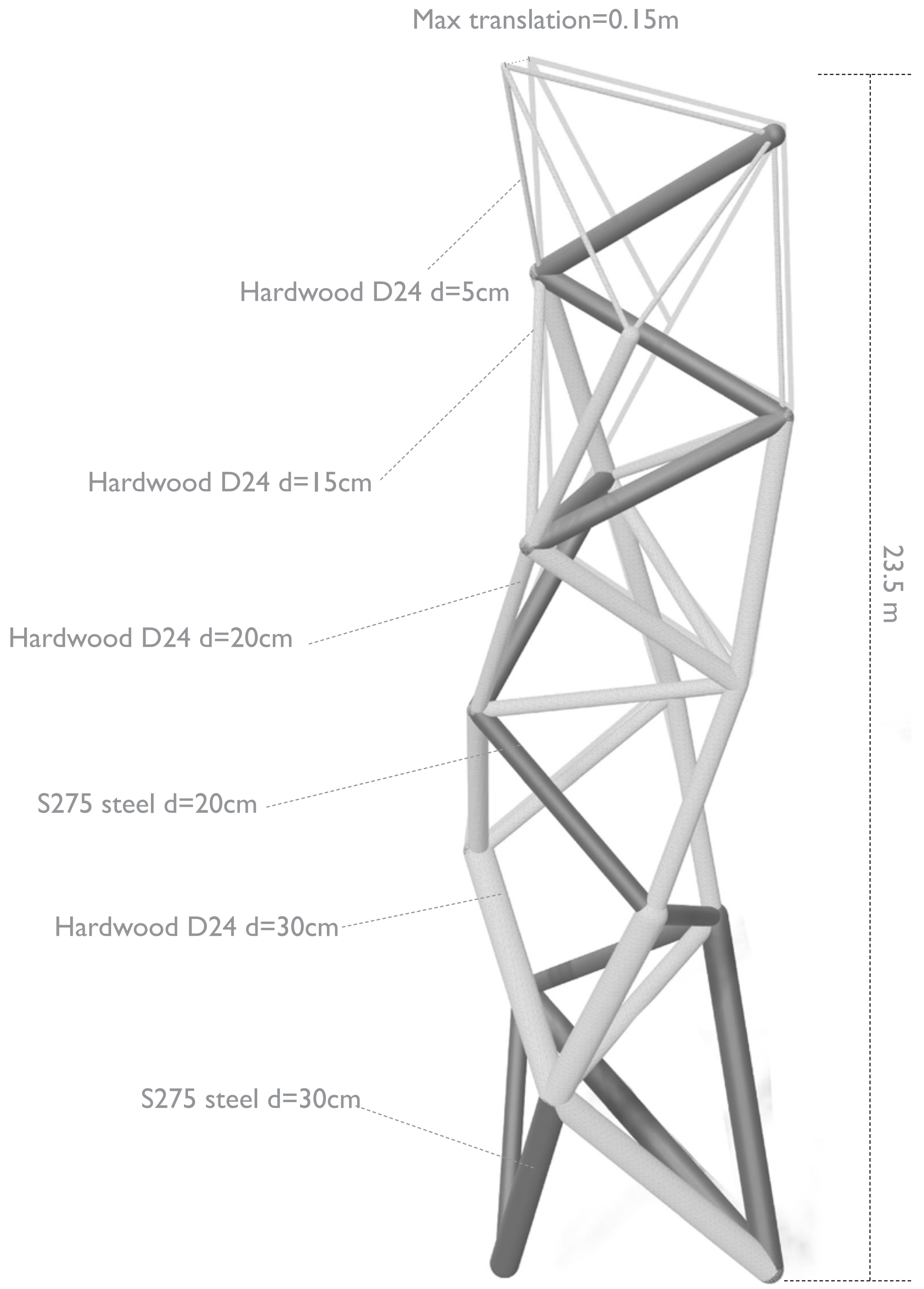



Section drawing

concept of the structure of tower

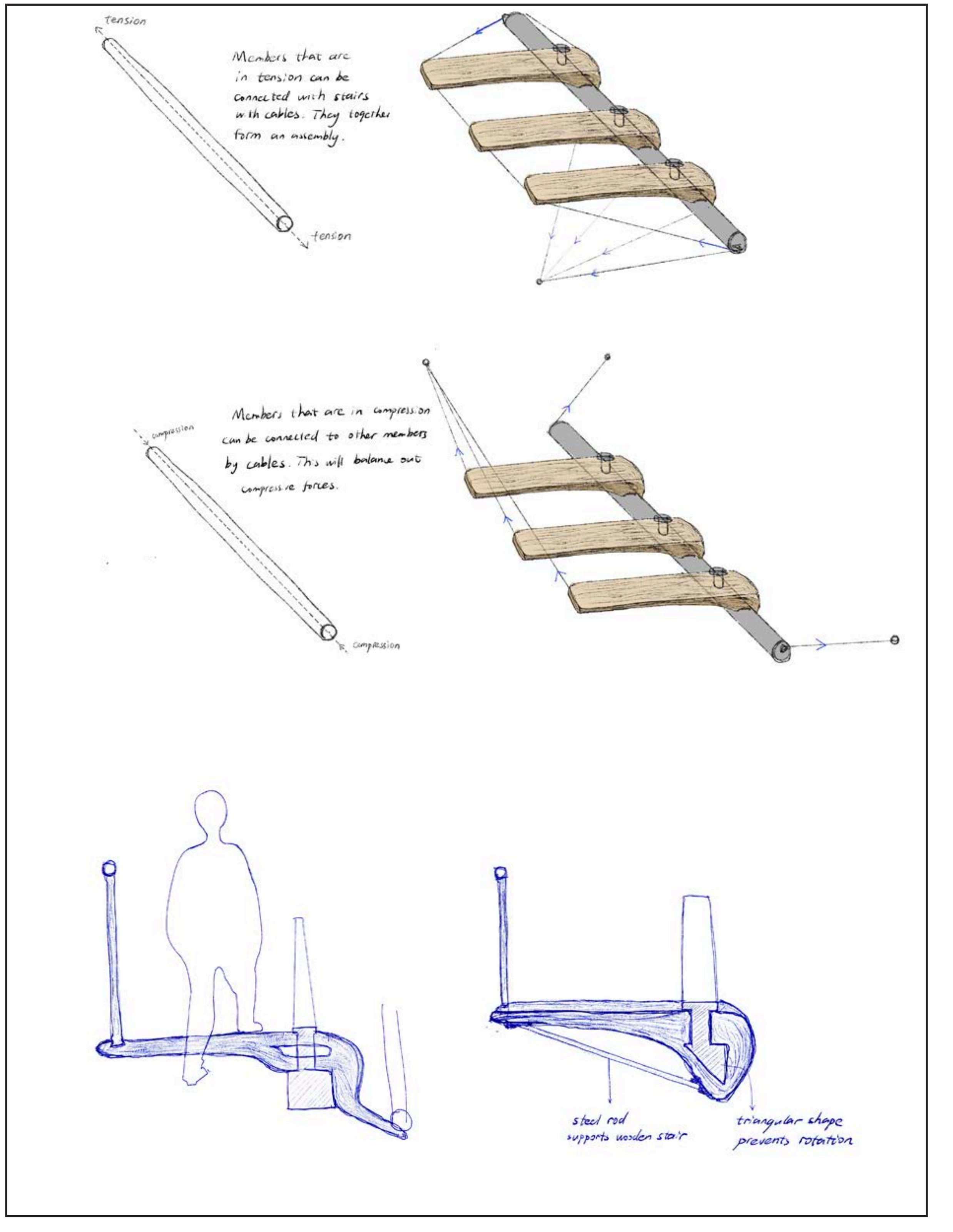



Principles of iterative designs of the observation tower




# Observation tower structural iteration 1

Maximum translation: 0.15m

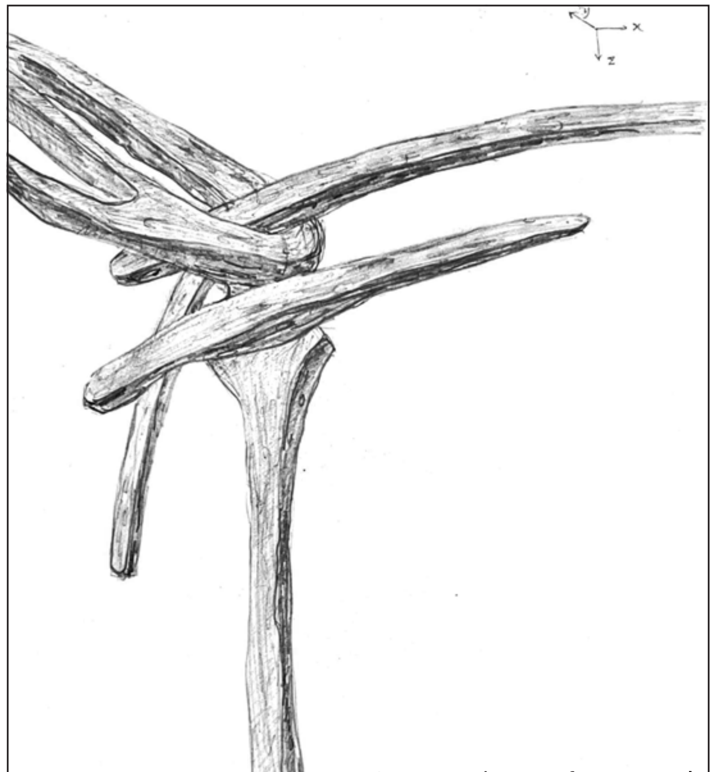



After identifying if the members are in tension or compression, the stairs will be balancing the forces which form an assembly.

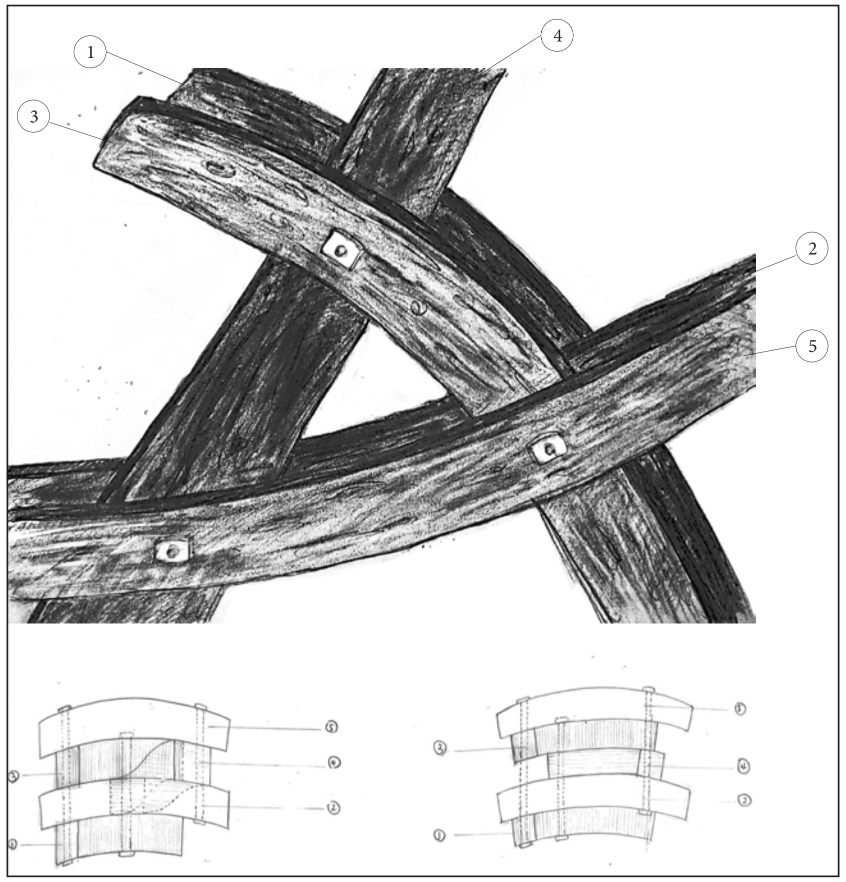
# Connection details

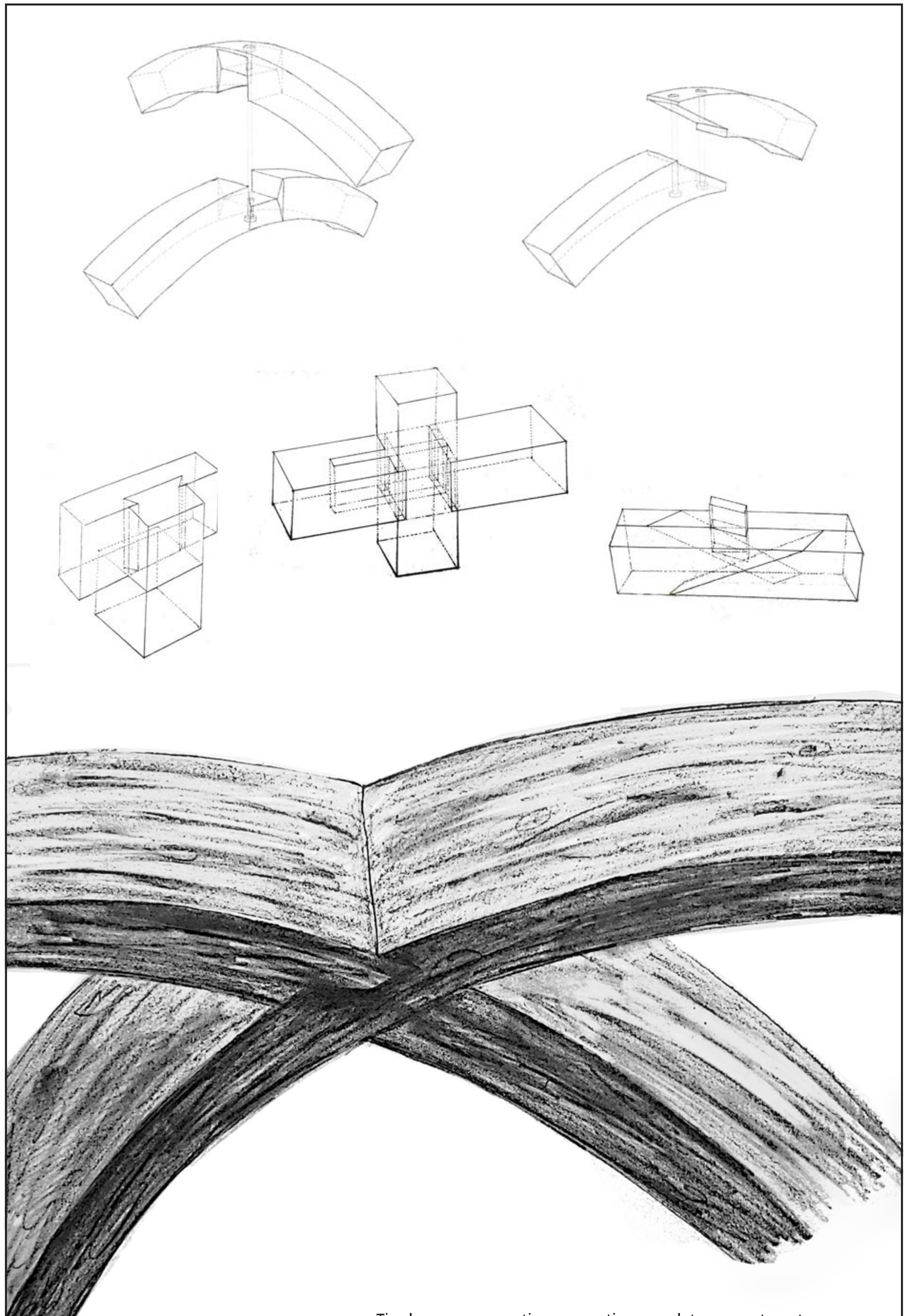
Timber members are connected in various ways, posing a series of structural challenges. Instead of making the connections as invisible as possible, it is proposed that large connections where visitors can appreciate the details of connections can provide interesting experiences. Several connection mechanisms of wooden membes are explored.

Timber-to-steel connection: used where the structure is fragile and timber-to-timber connection is not enough.




Connection of natural timber using the nratudal geometry to balance

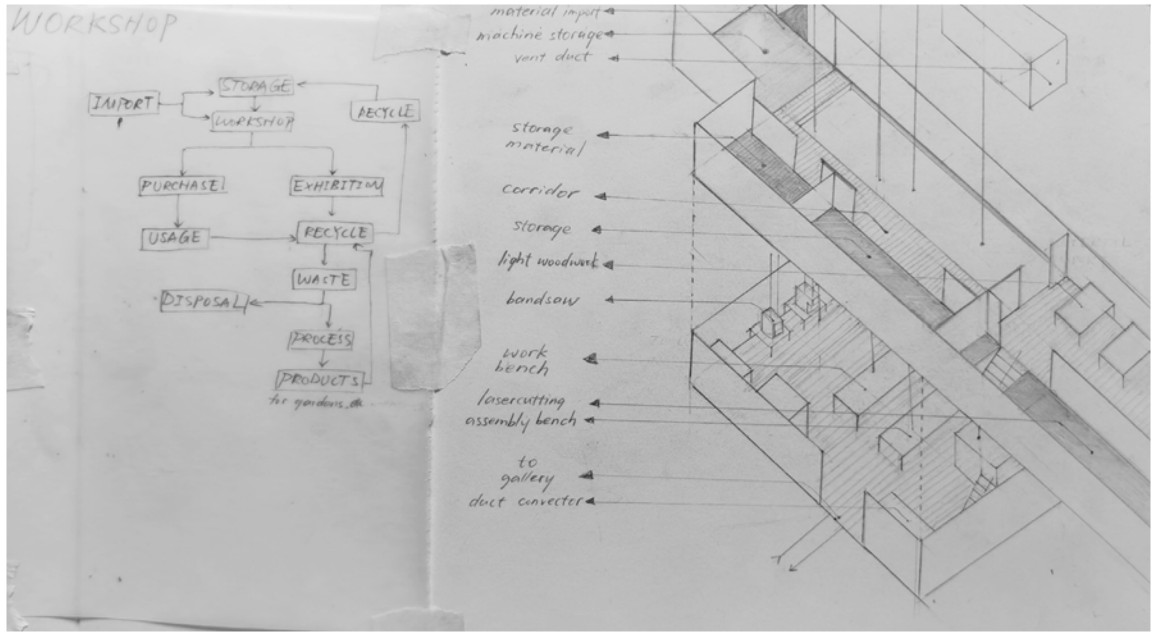


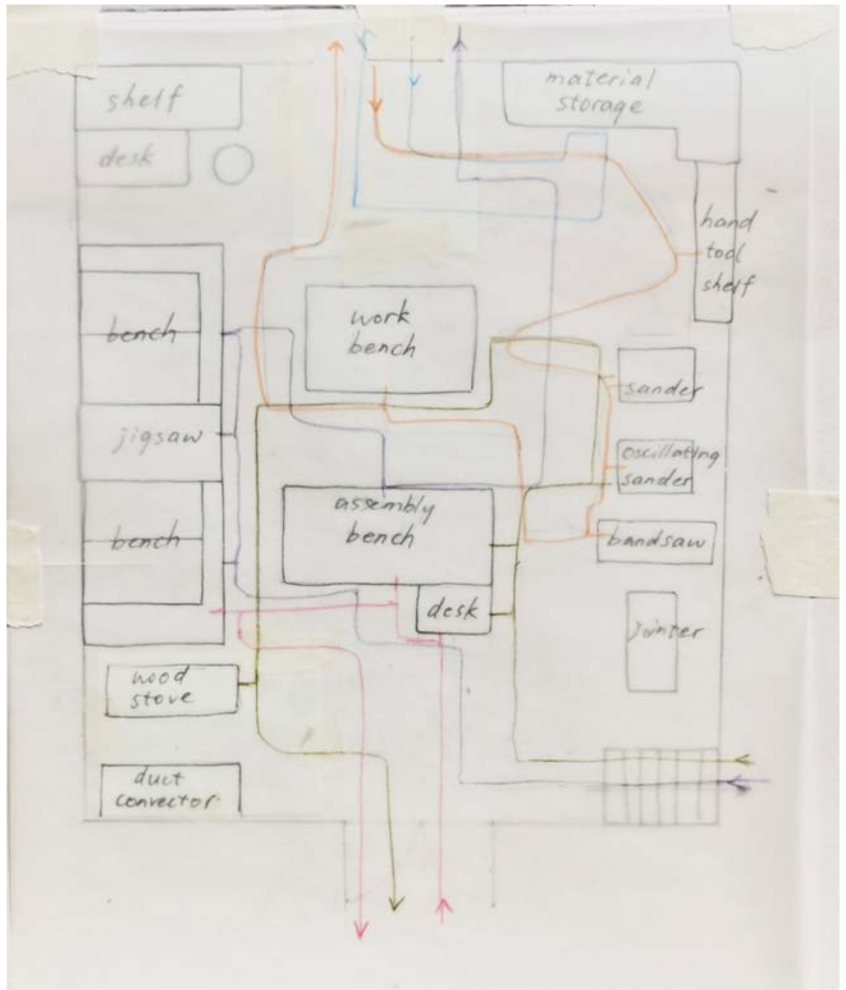
Timber connection: mortise-and-tenon structures

## Workshop

A workshop space is designed to enable visitors to enjoy and appreciate the craftsmanship of architecture fragments. It is connected with the main gallery space to form a relationship of watching and being watched. A conveyer belt will circulate the space and convey the exhibits to the gallery space.

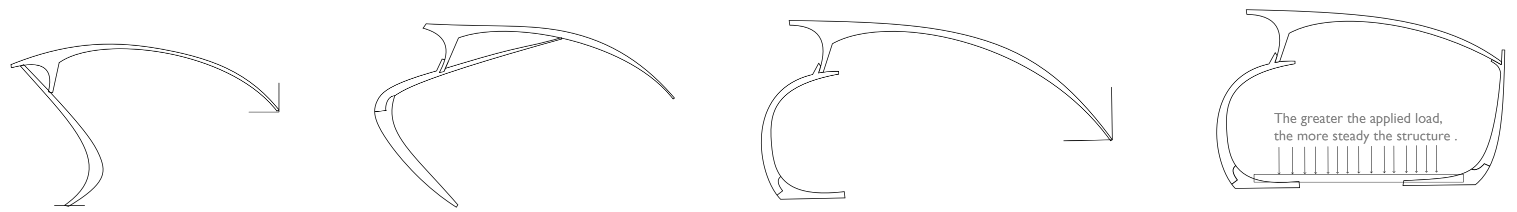



Life circle of materials ; Facilities and arrangement of the workshop

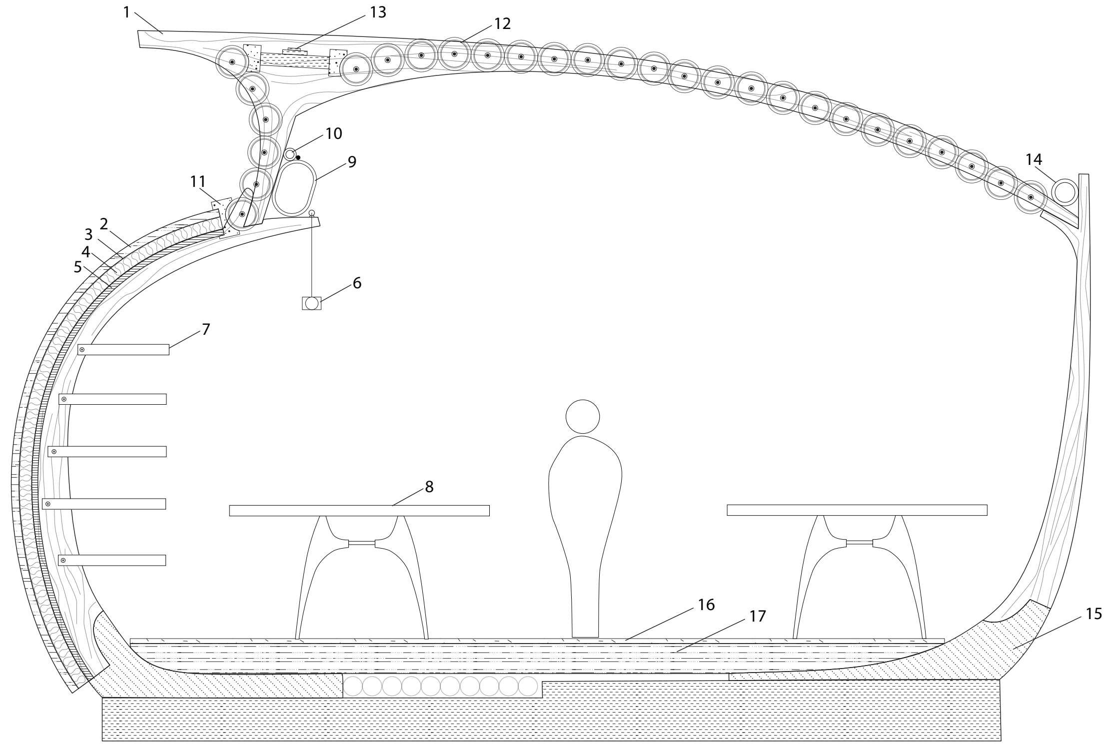



Circulation in the workshop space

Laser-cut models and sketch



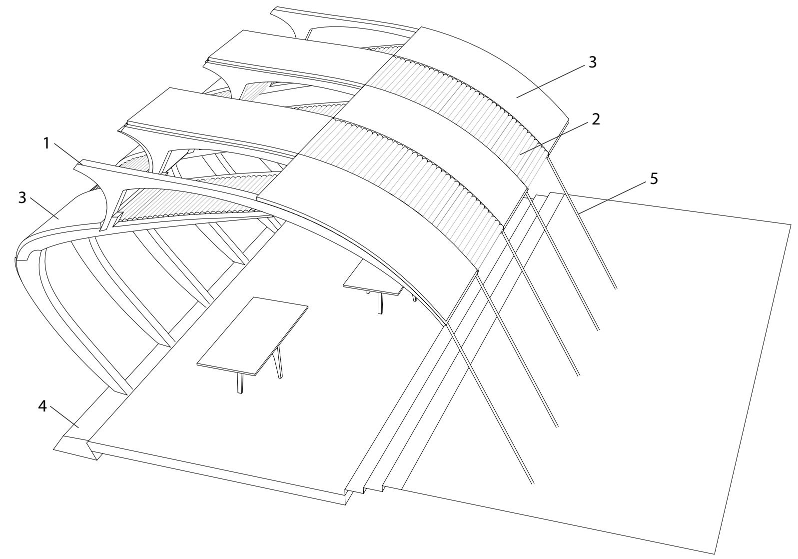

Mechanism of using the tensions of natural wood to create a framed structure.




1. Hard wood - whole pieces
2. 25mm boarding with water-proof coating
3. Bituminous felt
4. Glass wool board 5cm
5. 25mm boarding
6. LED lighting
7. Shelves neiled to frames
8. Workshop tables
9. Ventilation ductwork
10. Pipe works and miscellaneous wires
11. Metal connecter
12. Vacuum glass tubes as glazing and insulation (firmly sealed between tubes)
13. Operable ventilation valve
14. Drainage pipe
15. Metal foundation
16. Floor coating
17. 100mm boarding

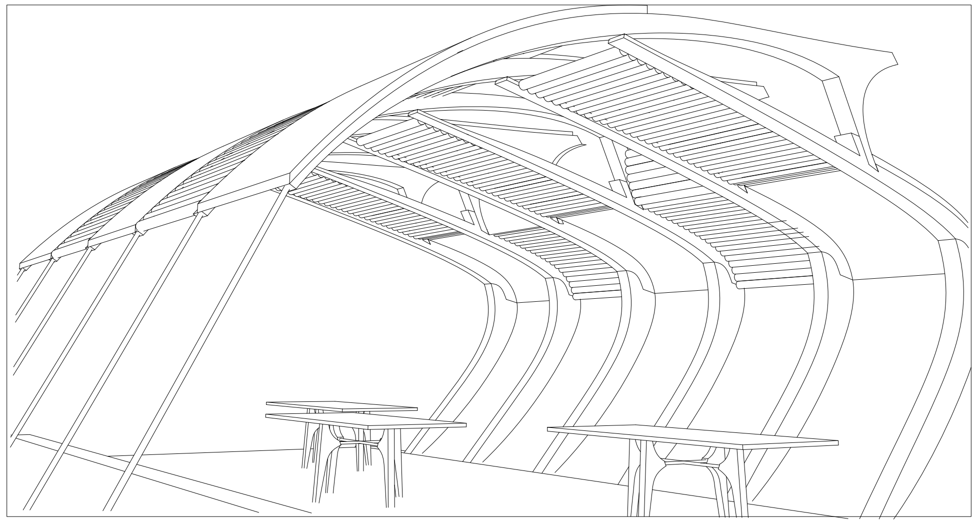
N

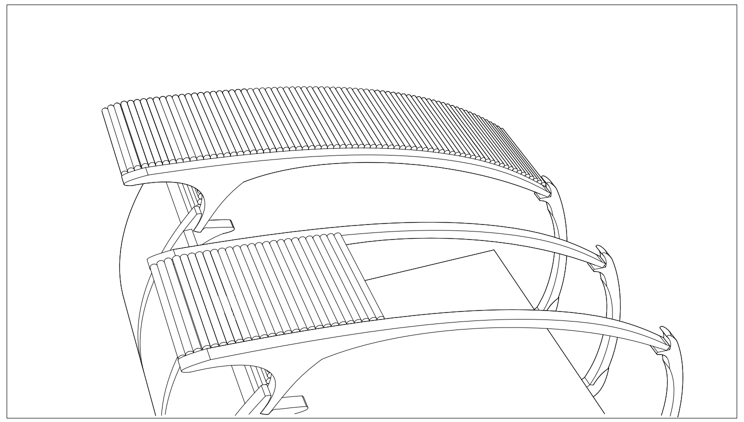
Section of Cafe

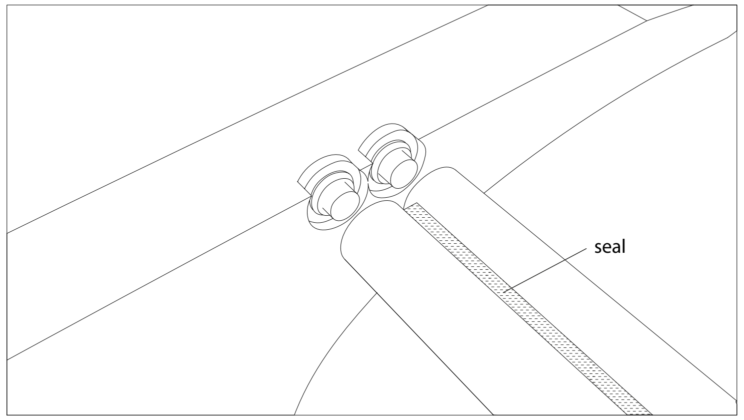


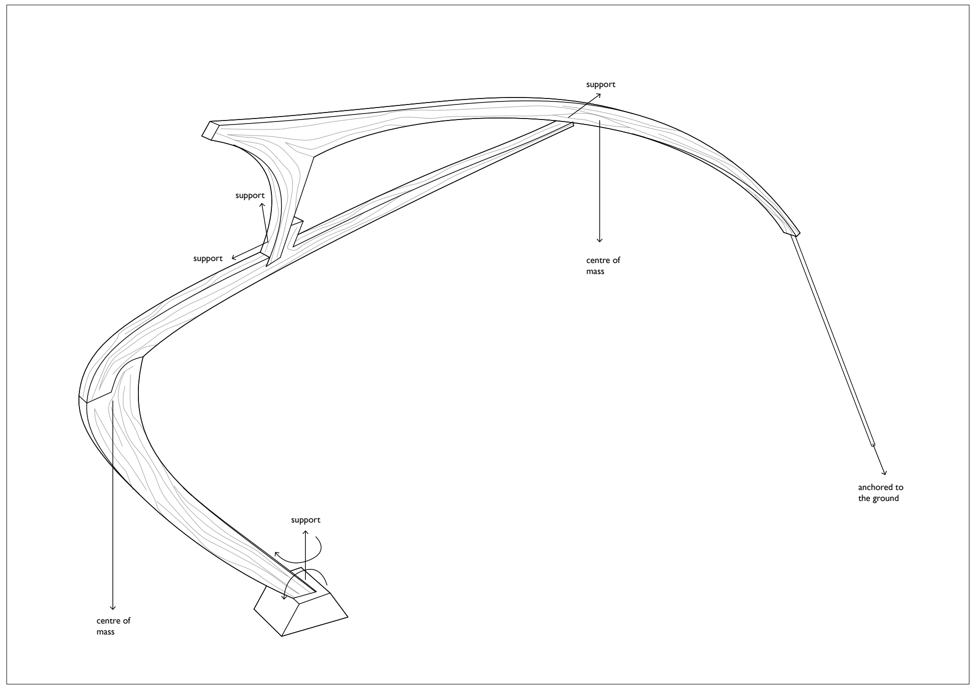

1. Hard wood frames
2. Glass tubes - glazing
3. Aluminium panel
4. Metal base
5. Cable

Workshop iteration 1



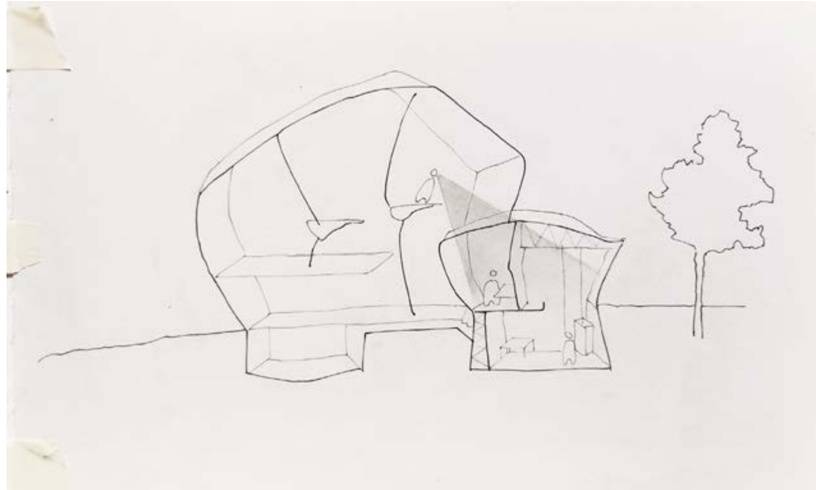




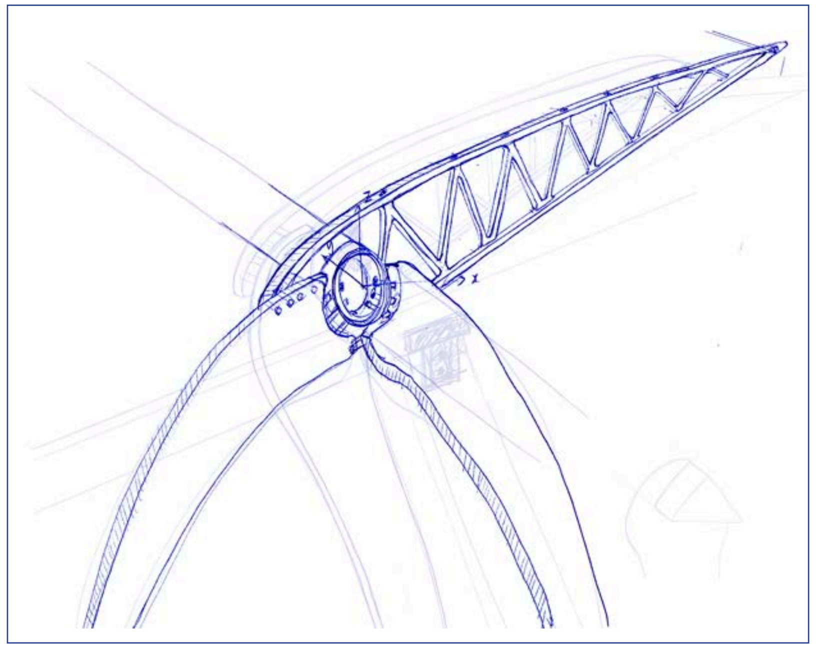
# Gallery

The gallery and workshop spaces are combined, and the structure is designed to integrate the two spaces.

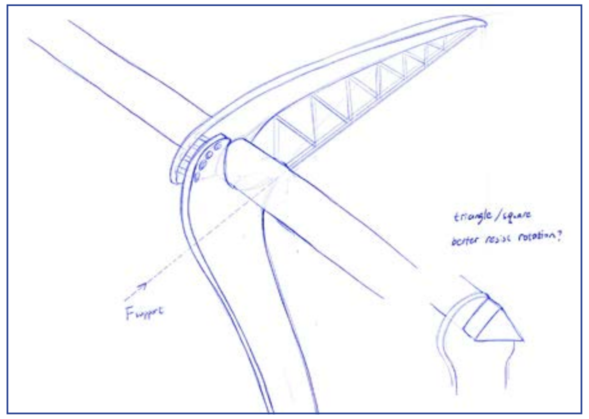


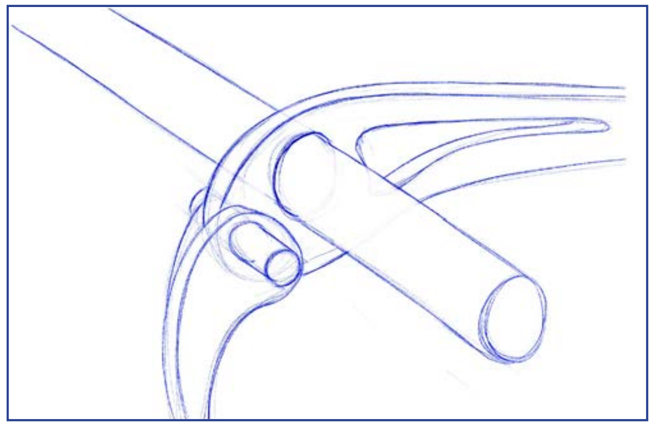
Cross section: visitors in the gallery can observe events in workshop spaces.

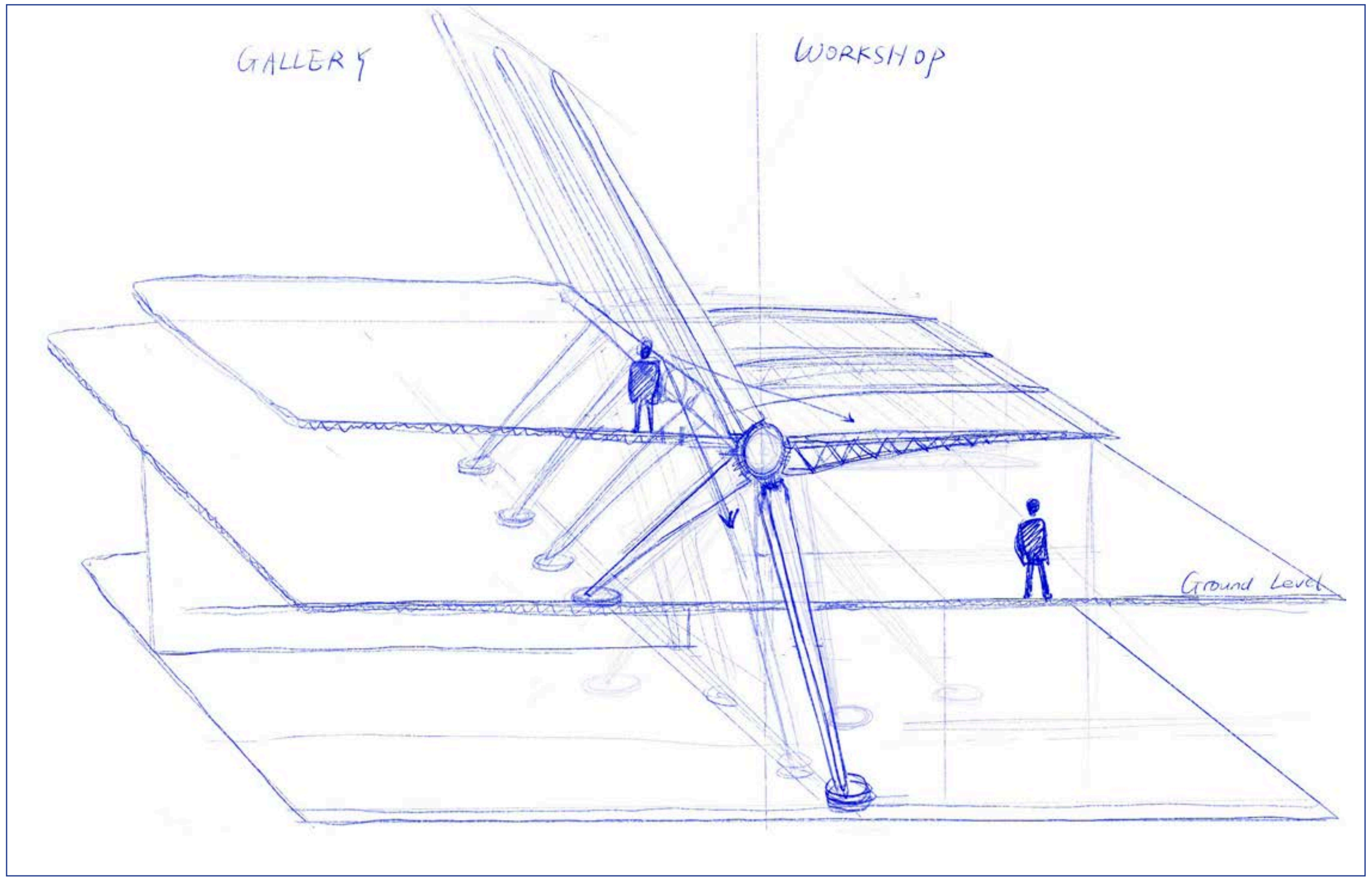
Structural proposal 1: a central beam with connections to 'wings' will run through the structure .

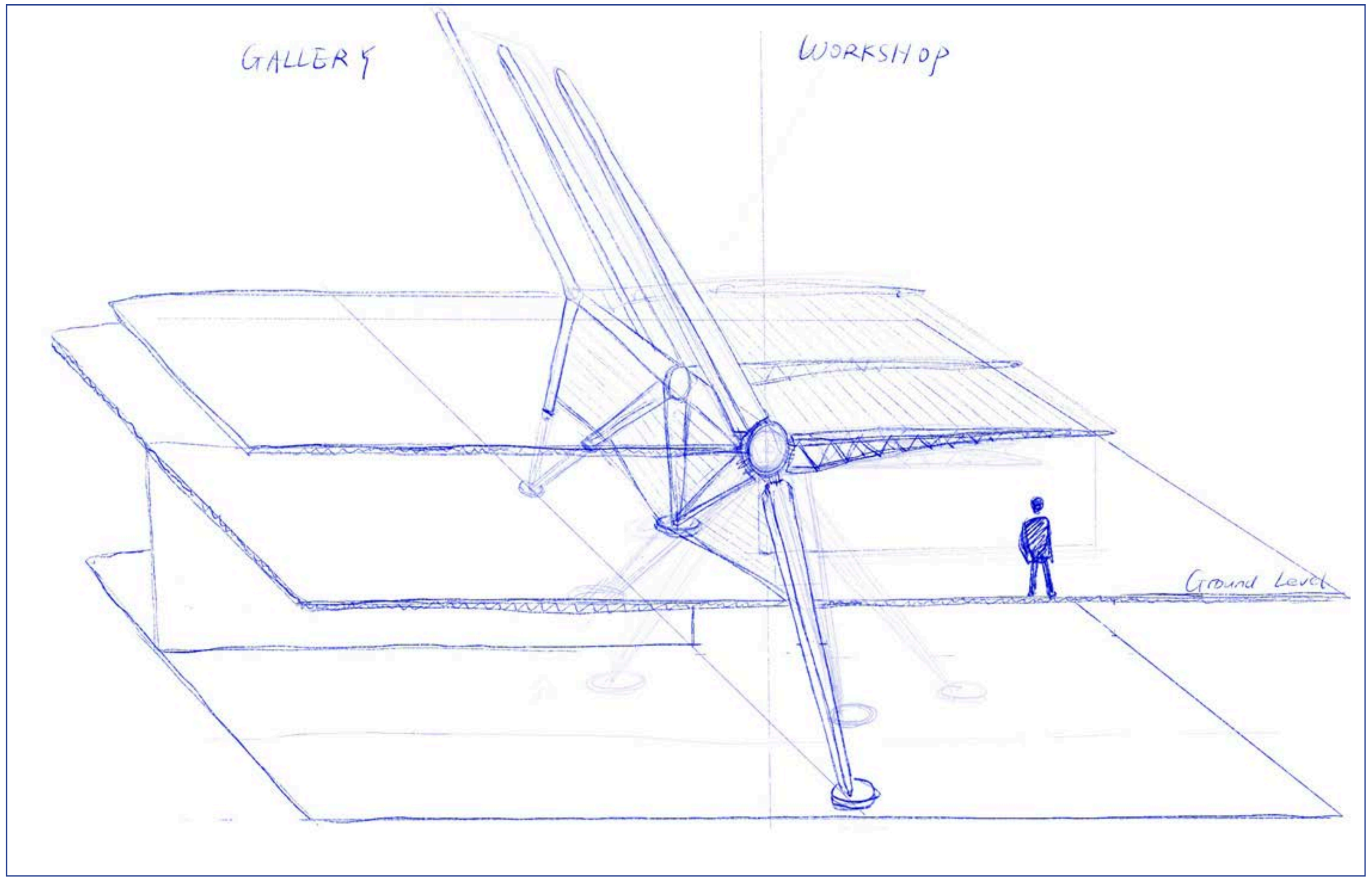


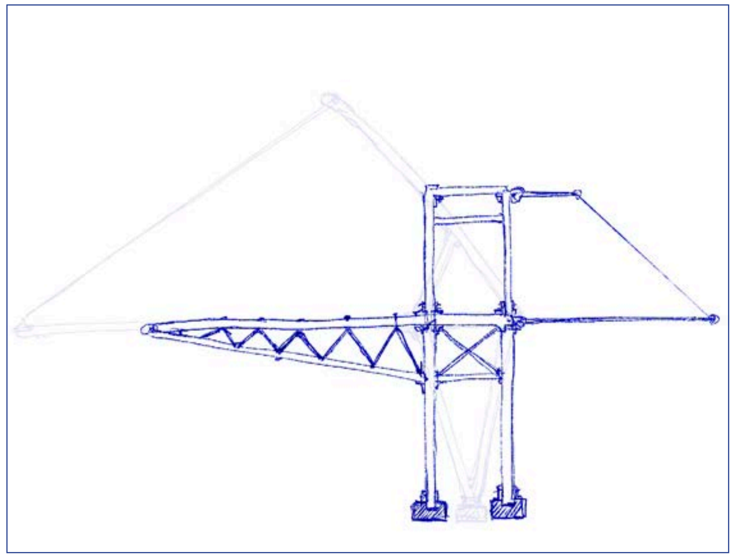
Connection details: the columns and trusses are connected to a central structure , which will take an immensive load.

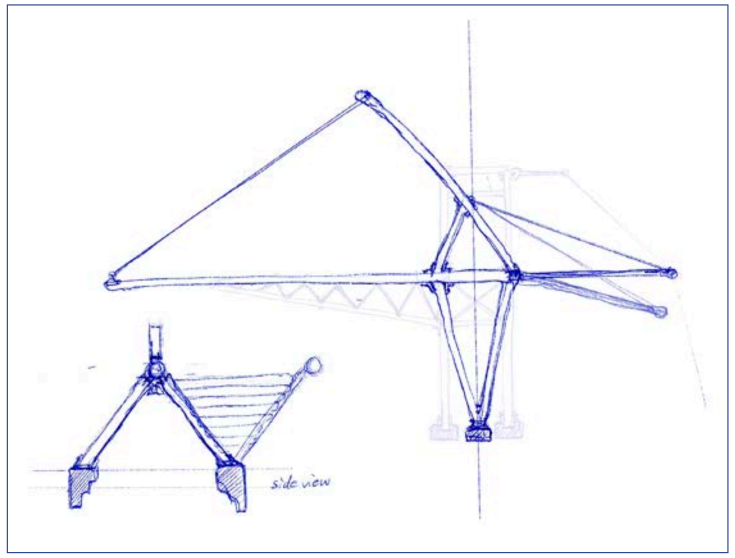


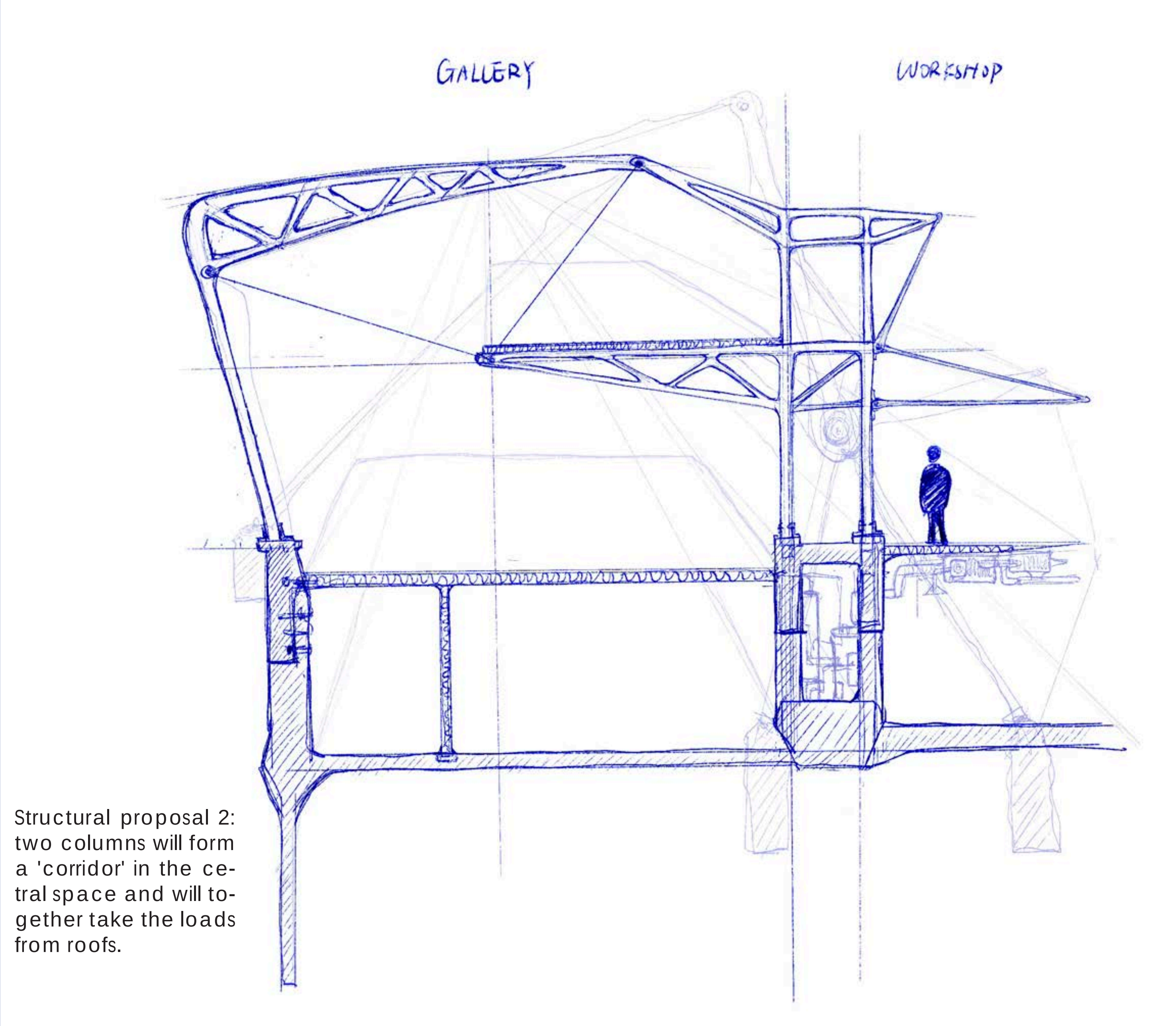




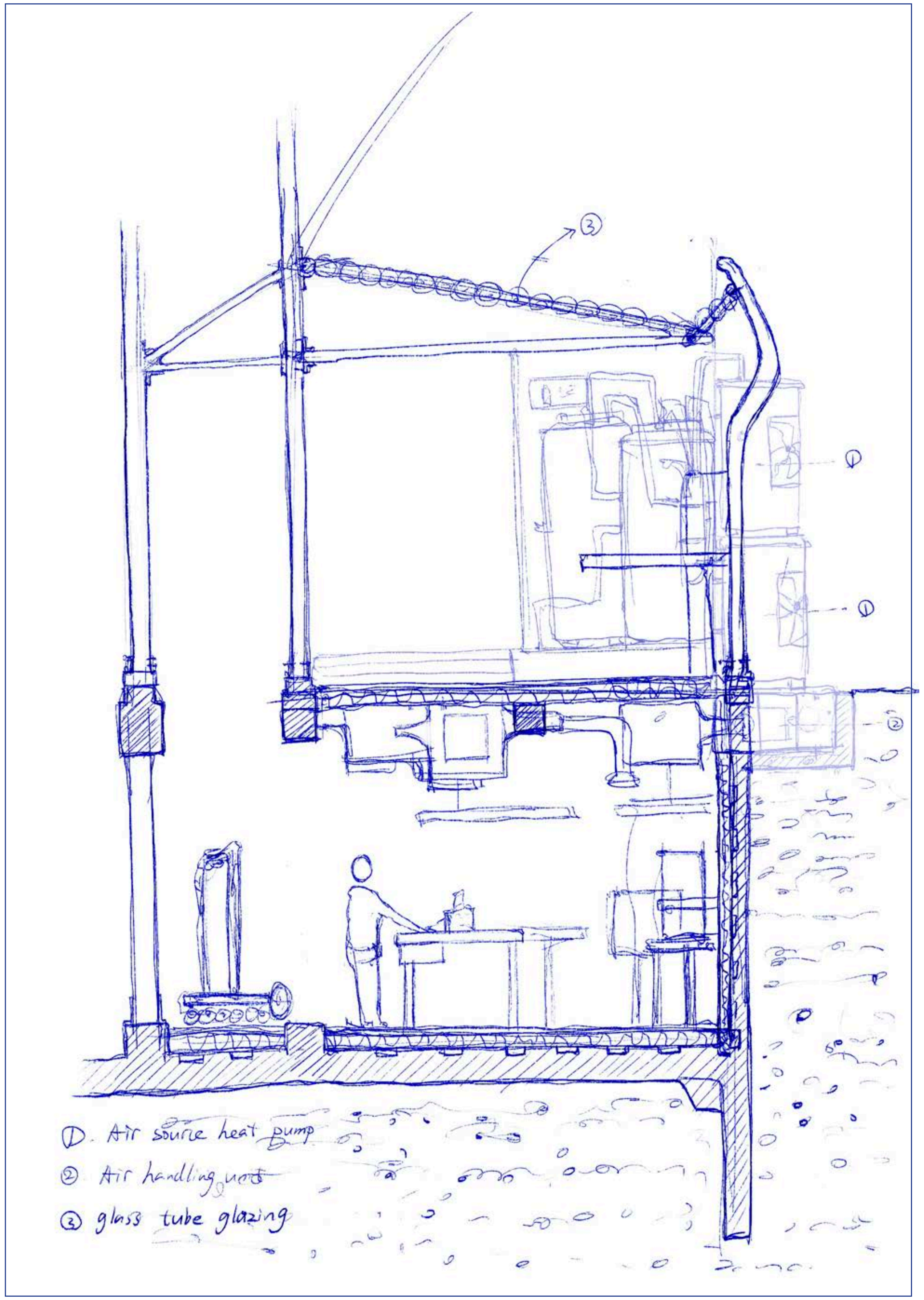







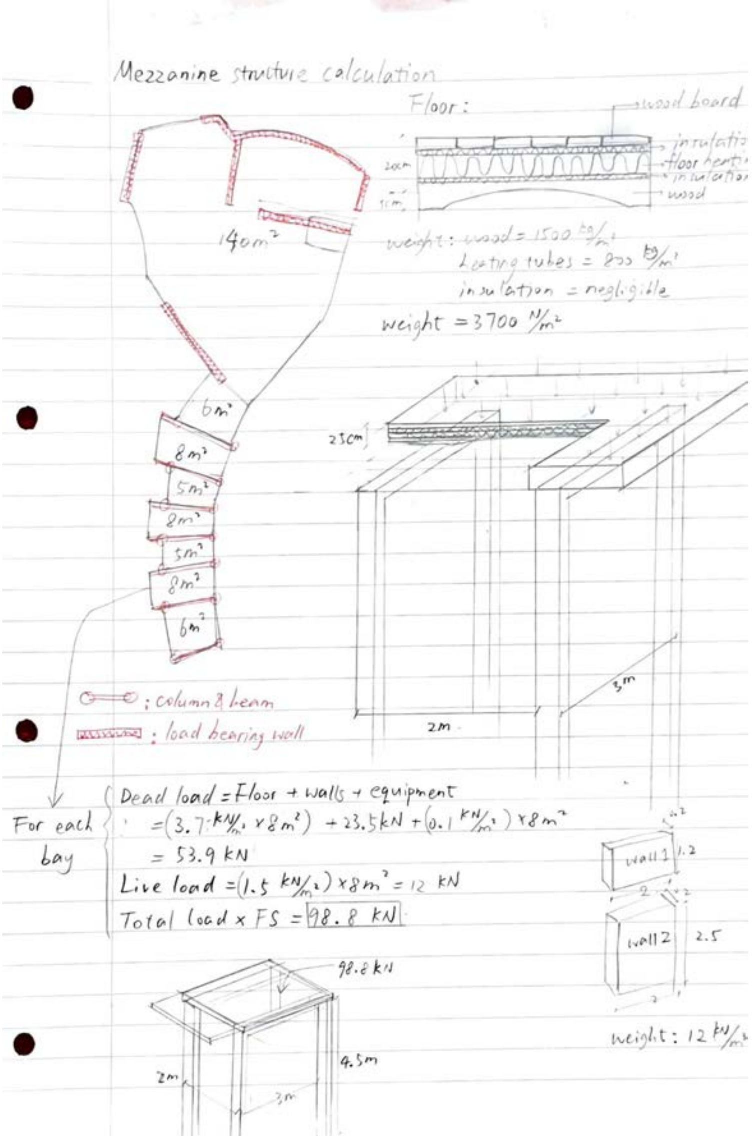



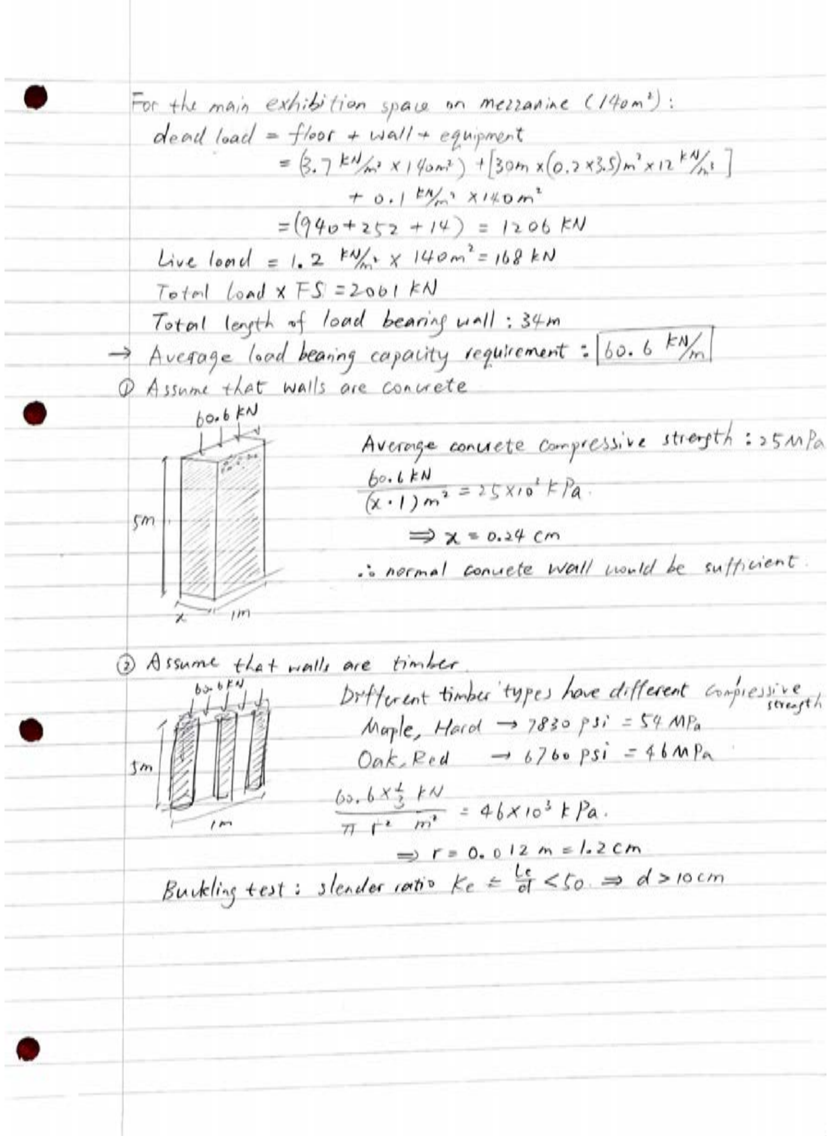

Structural proposal 2: two columns will form a 'corridor' in the cetral space and will together take the loads from roofs.

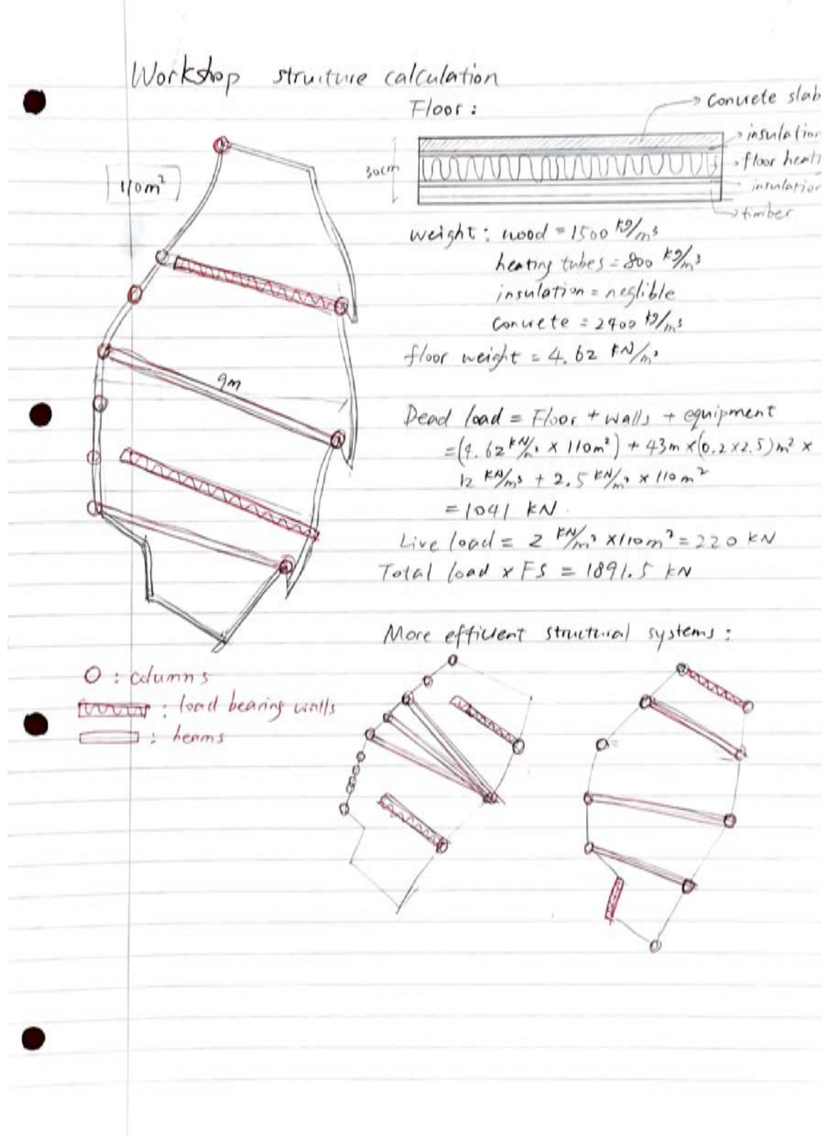



Equipments, layout and circulation in the workshop.

# Load calculation of mezzanine and workshop



# Main structure

-