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OSLO OPERA HOUSE

Targets, solutions and challenges

Norwegian National Opera and Ballet

- 2000-2008
- Location: Oslo, Norway
- Typology: Opera House
- Client: Statsbygg, The Governmental Building Agency
- Size: 38 500 m²

Norwegian National Opera and Ballet

- Design Team:
  - Architect: Snøhetta
  - HVAC: Erichsen & Horgen AS
  - Energy: Erichsen & Horgen AS
  - Environment: Erichsen & Horgen AS
  - Electric & Instrumentation: Ing Per Rasmussen AS
  - Construction design: Reinertsen

Types of areas

Types of areas

- Three theatres
- Orchestra rehearsal
- Ballet and opera rehearsal
- Tailor, carpenter and painter workshops
- Offices
- Restaurants

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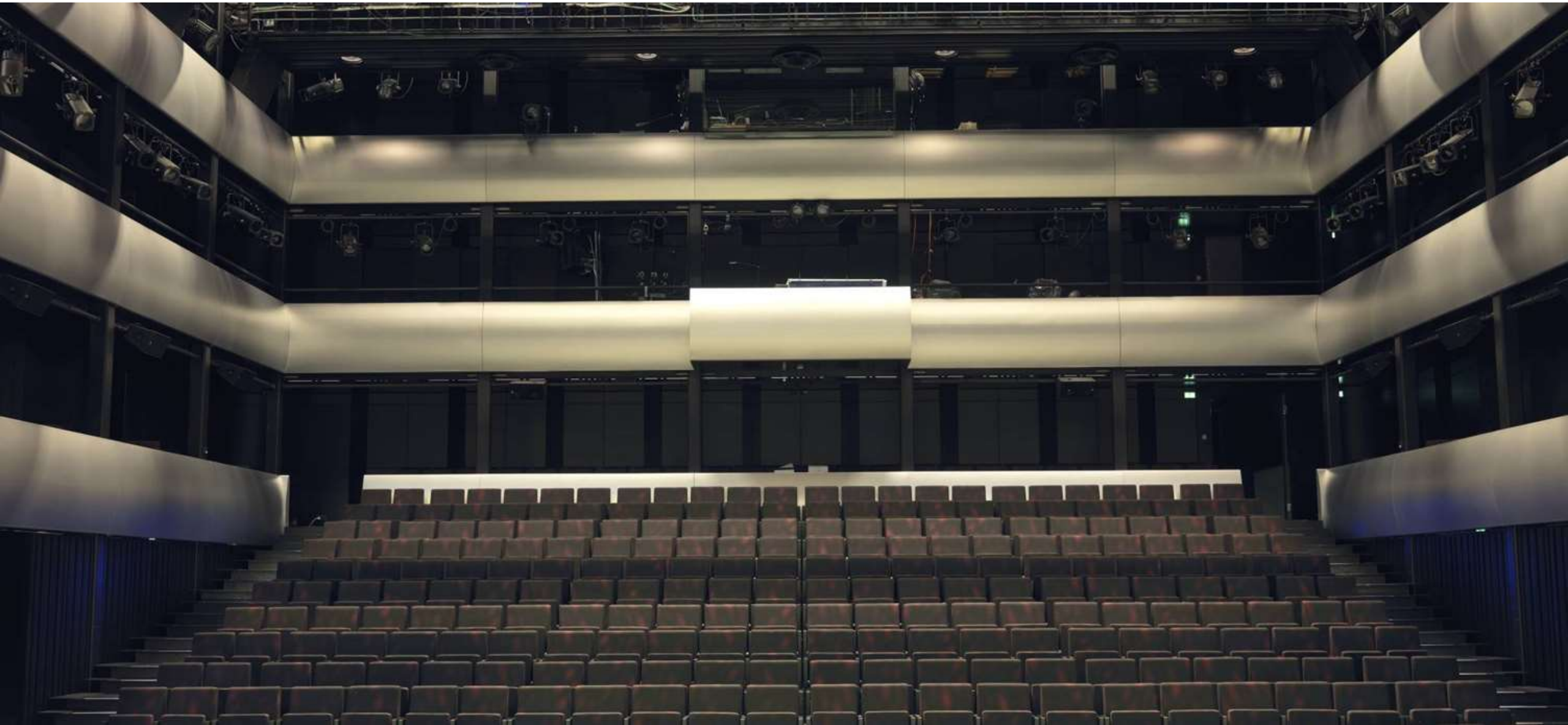

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Requirements

REQUIREMENT I

- ACOUSTICS HAS HIGHEST PRIORITY
  - Max 17 dBA from ventilation system

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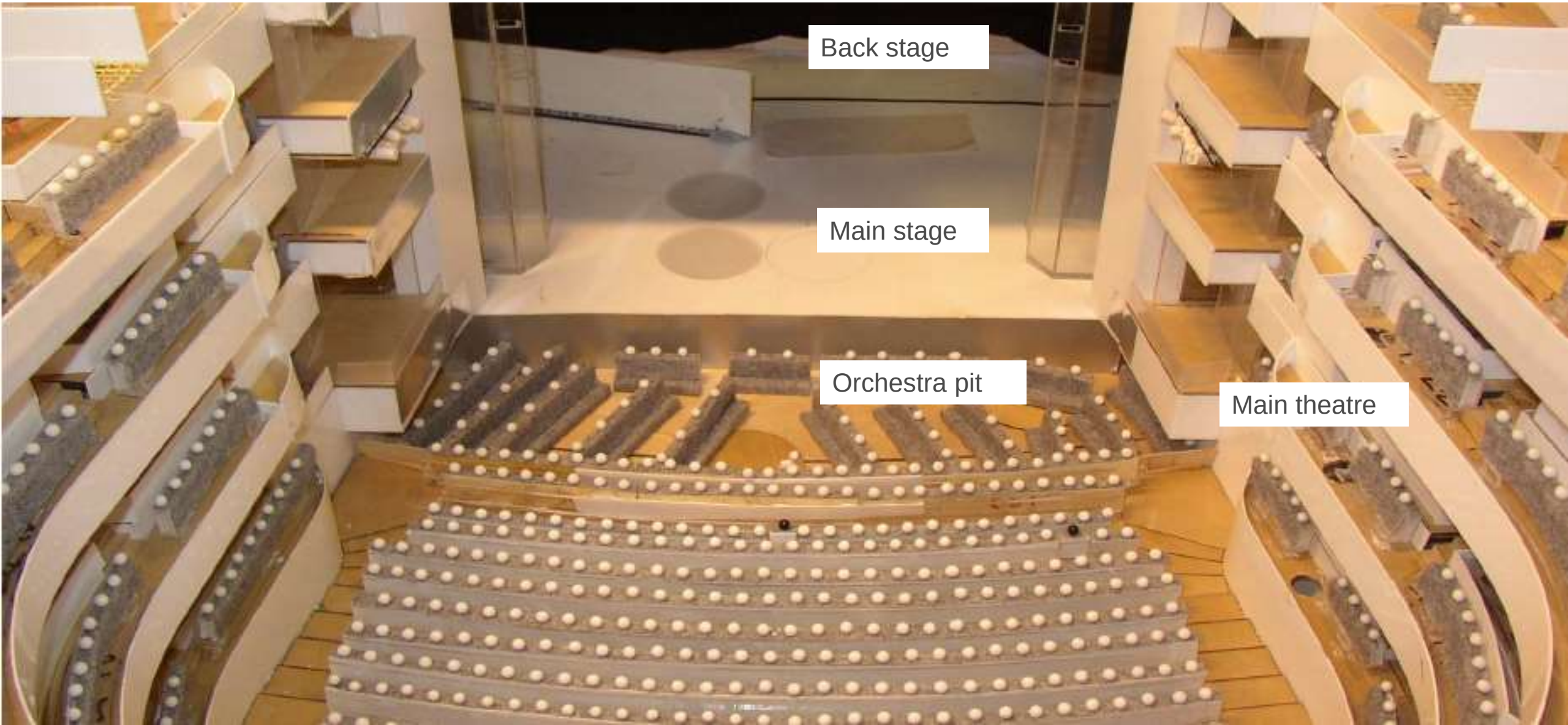

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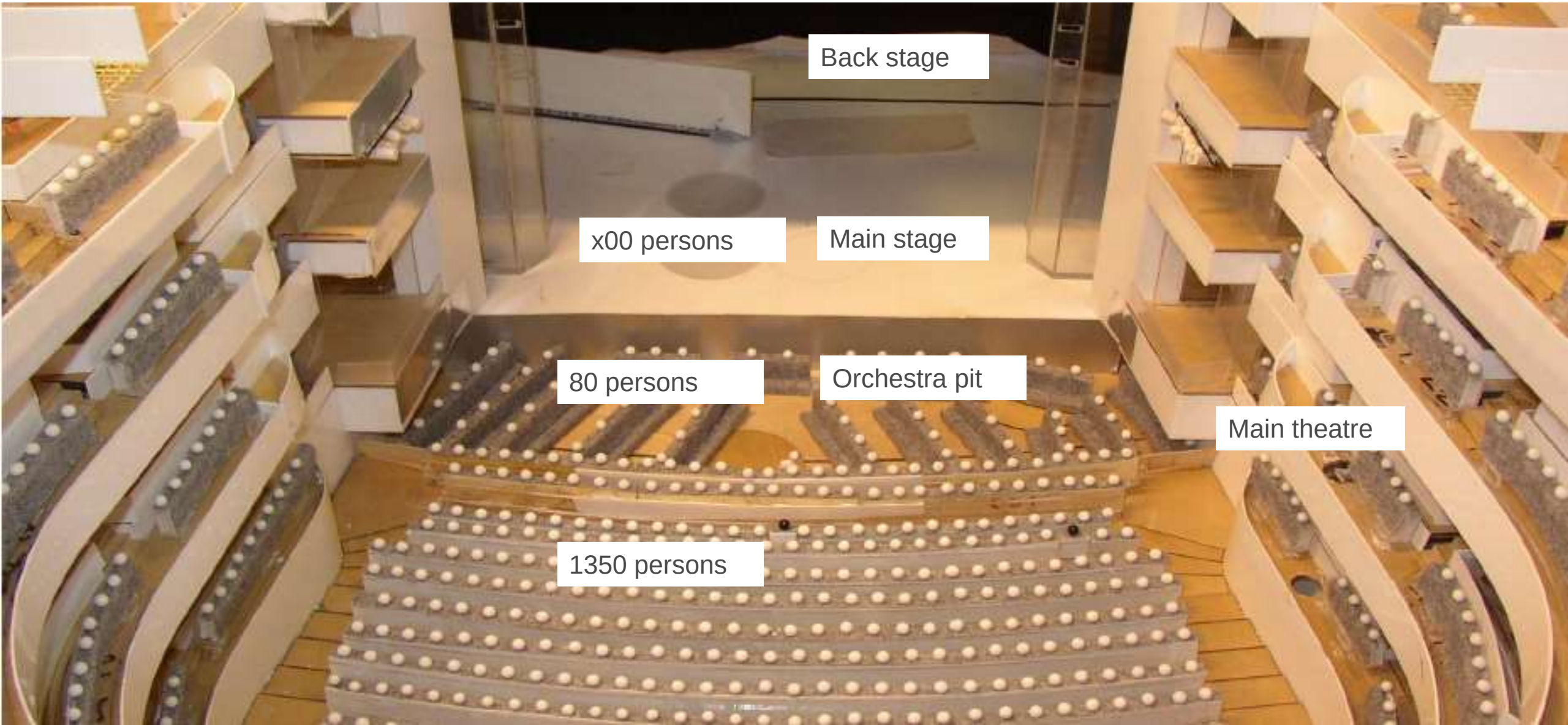

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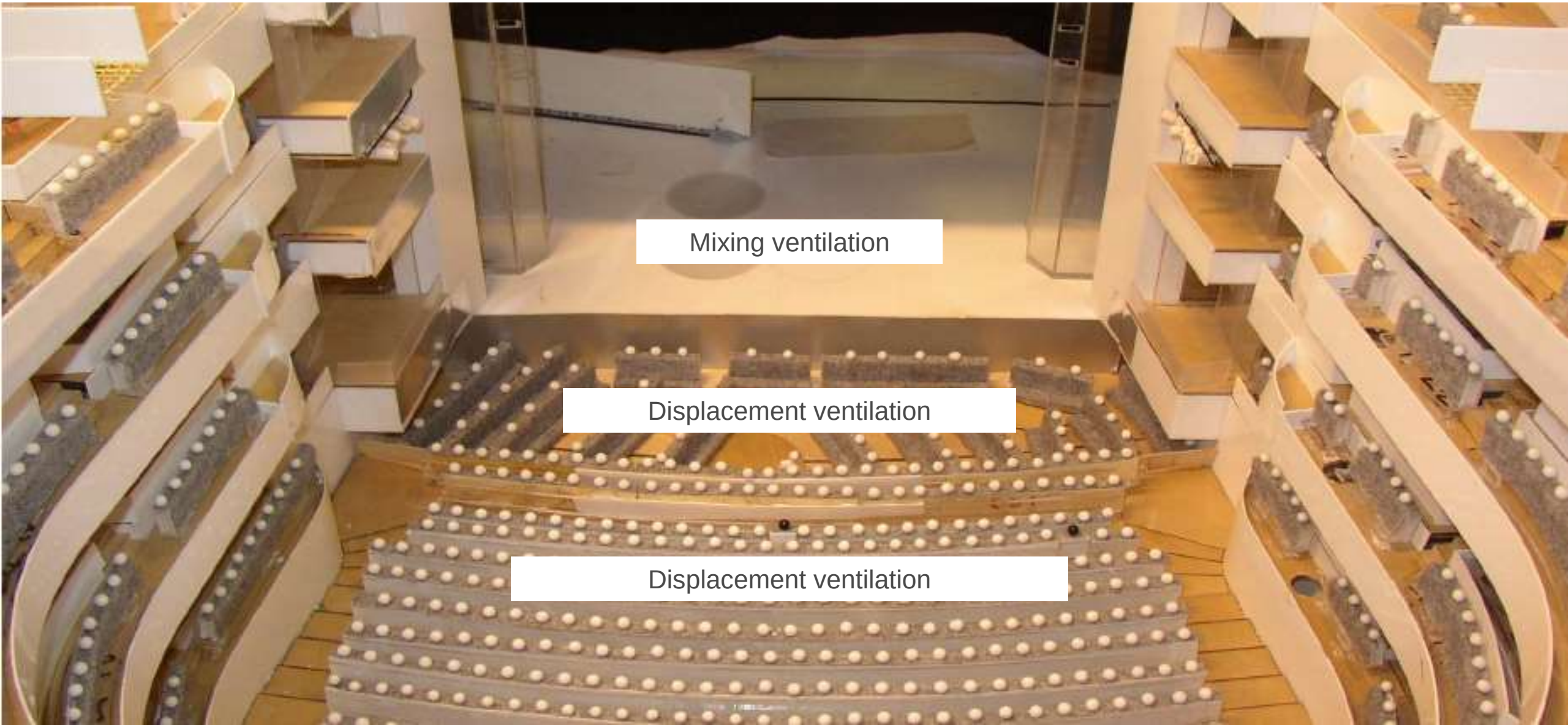

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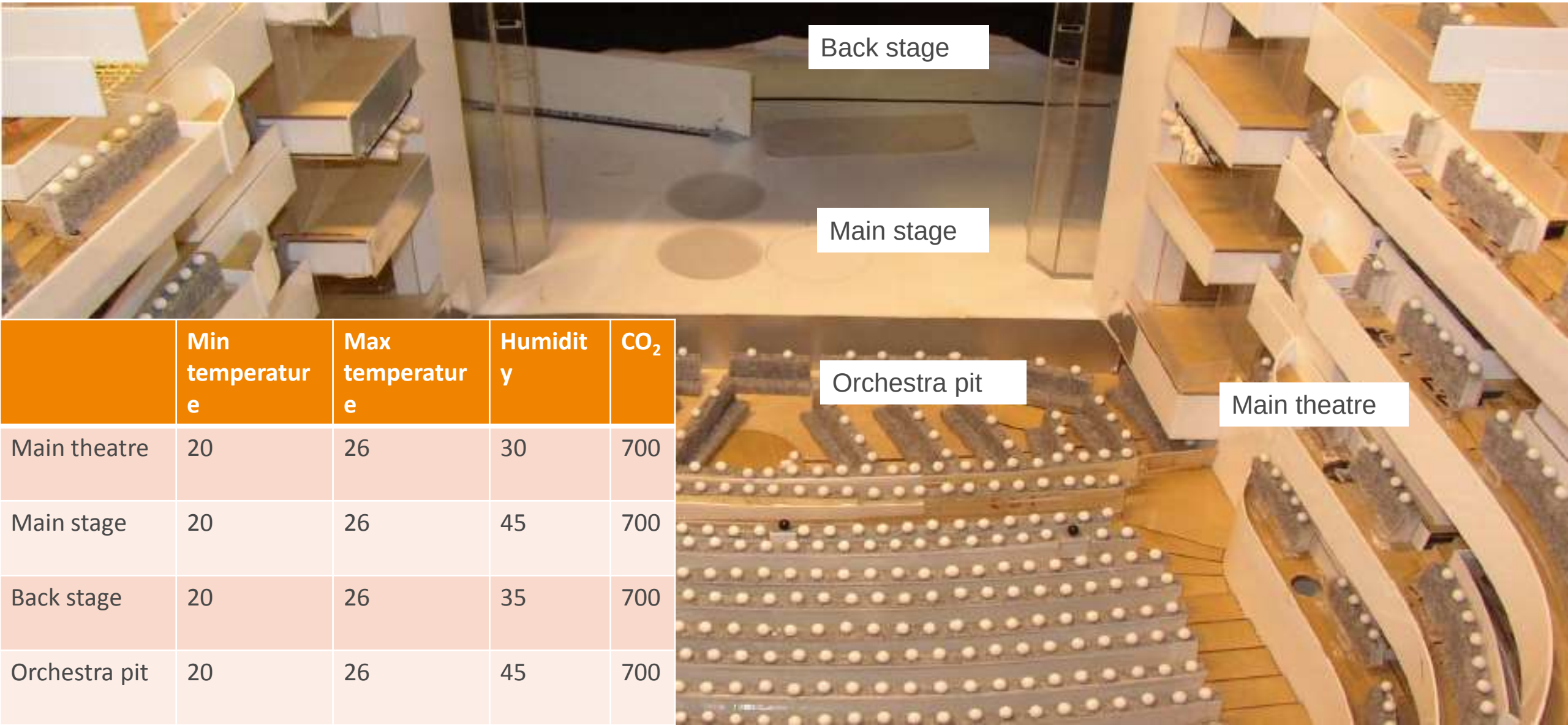

	Min temperature	Max temperature	Humidity	CO_2
Main theatre	20	26	30	700
Main stage	20	26	45	700
Back stage	20	26	35	700
Orchestra pit	20	26	45	700

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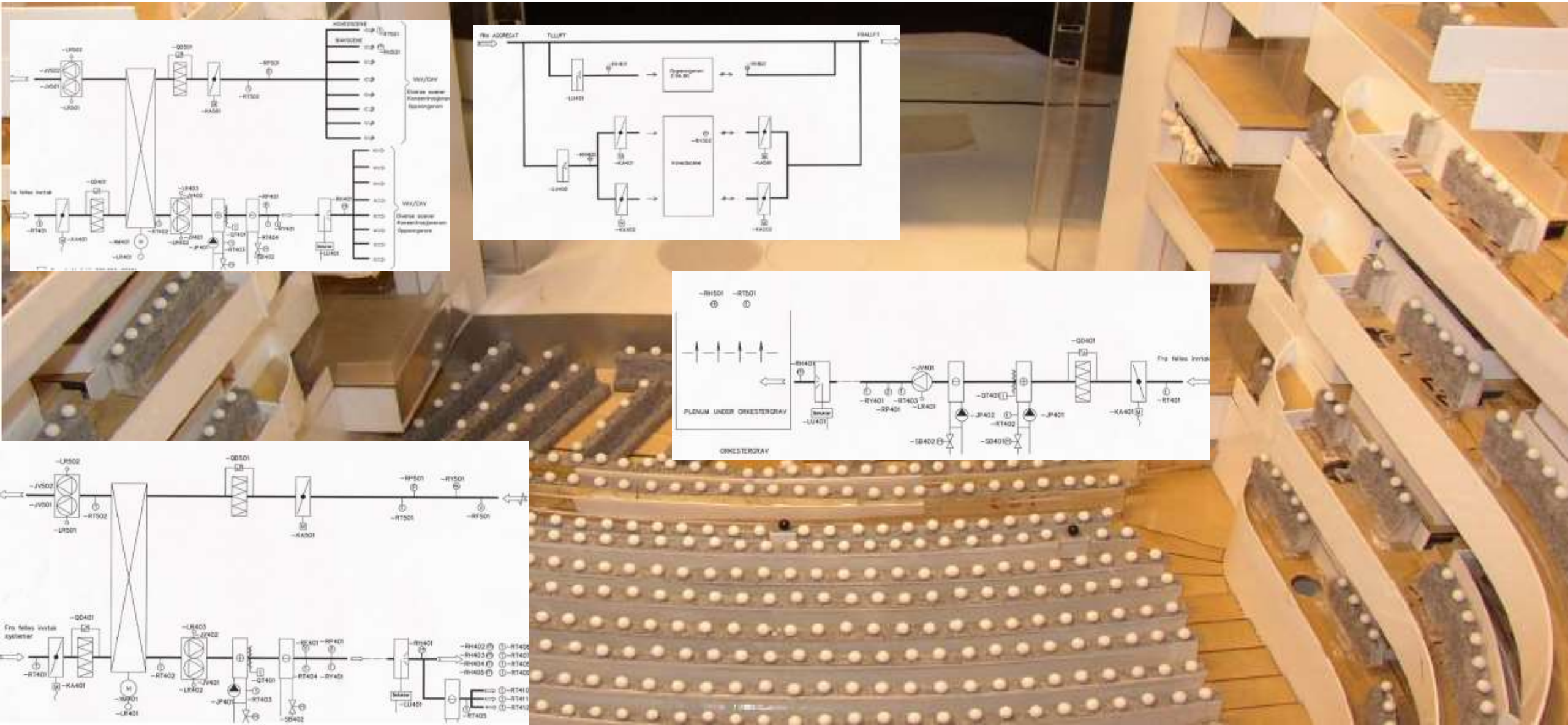

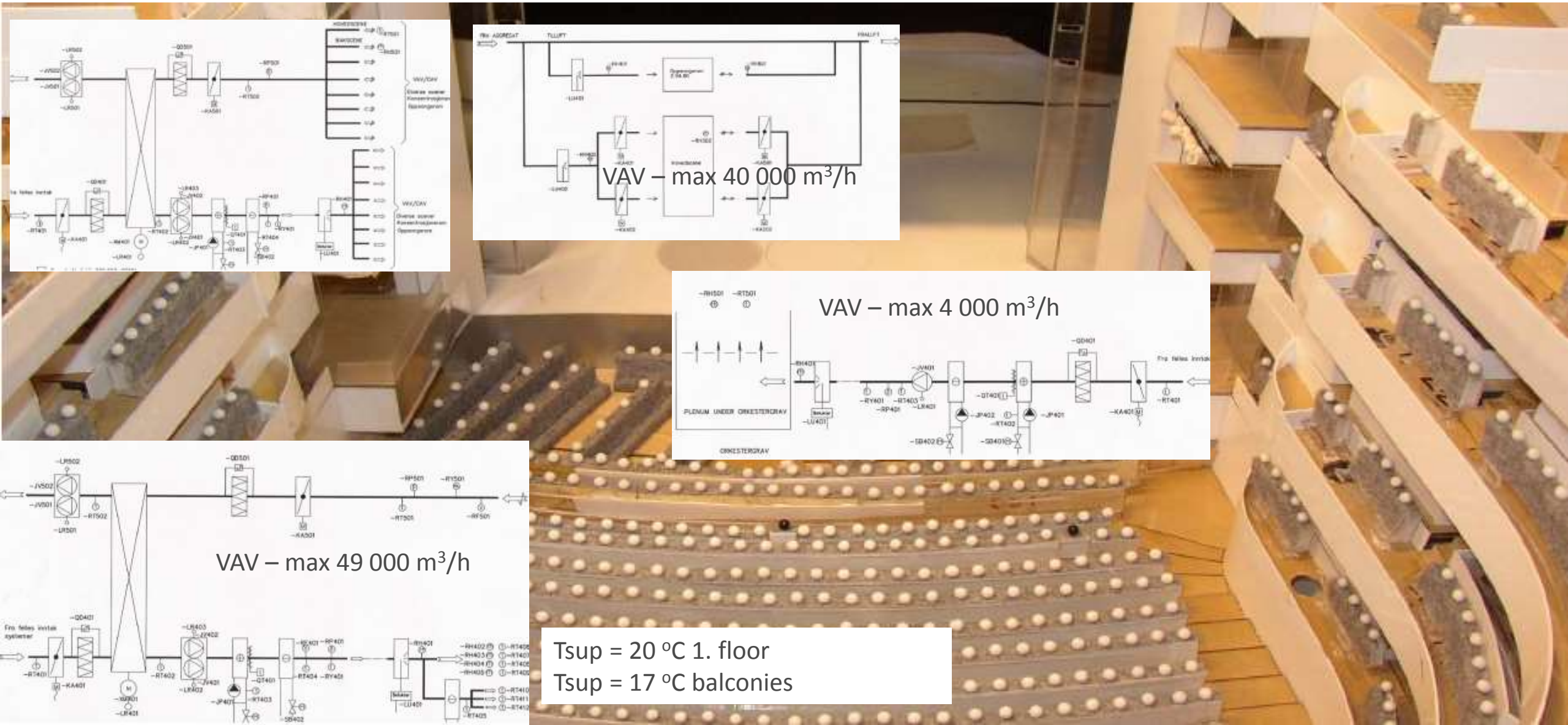
VAV – max 40 000 m³/h
VAV – max 4 000 m³/h
VAV – max 49 000 m³/h
Tsup = 20 °C 1. floor
Tsup = 17 °C balconies

Supply air units

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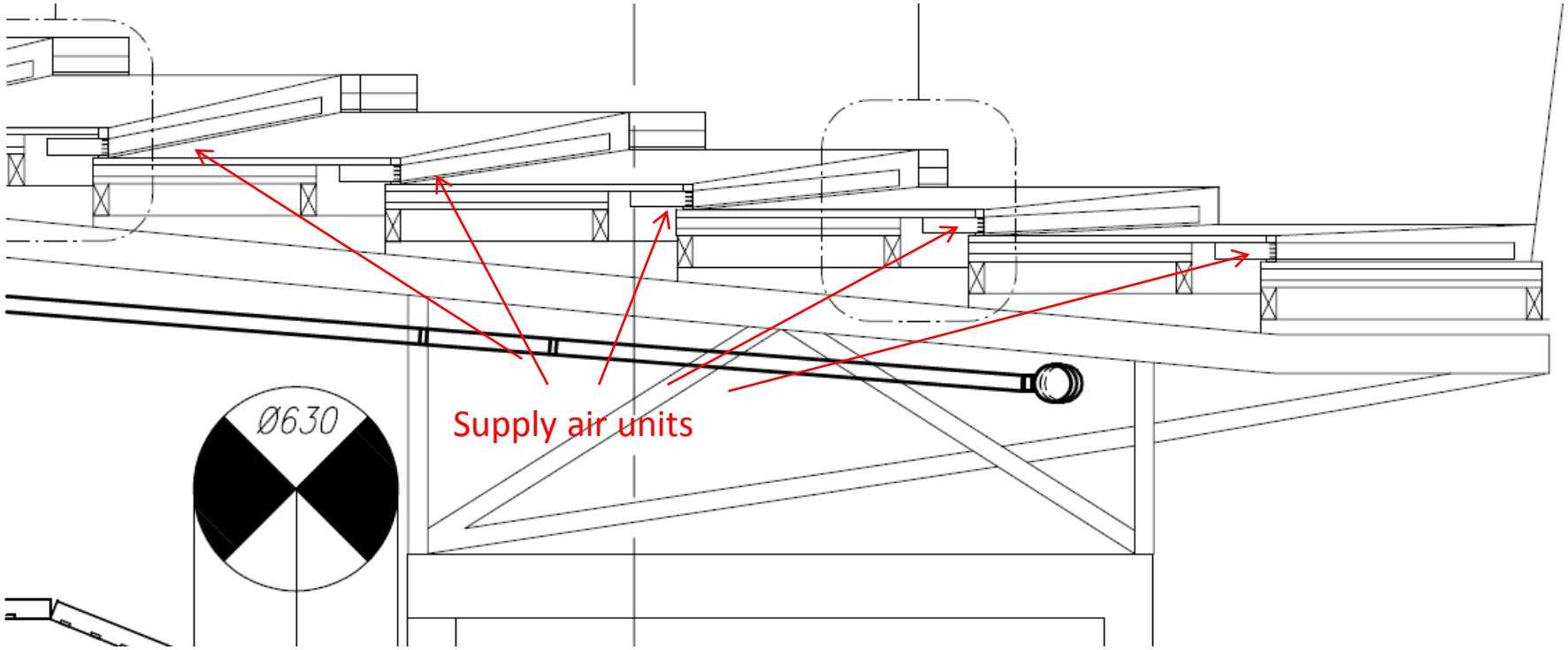
Two of the challenges

- Supply air units
- Climate in orchestra pit

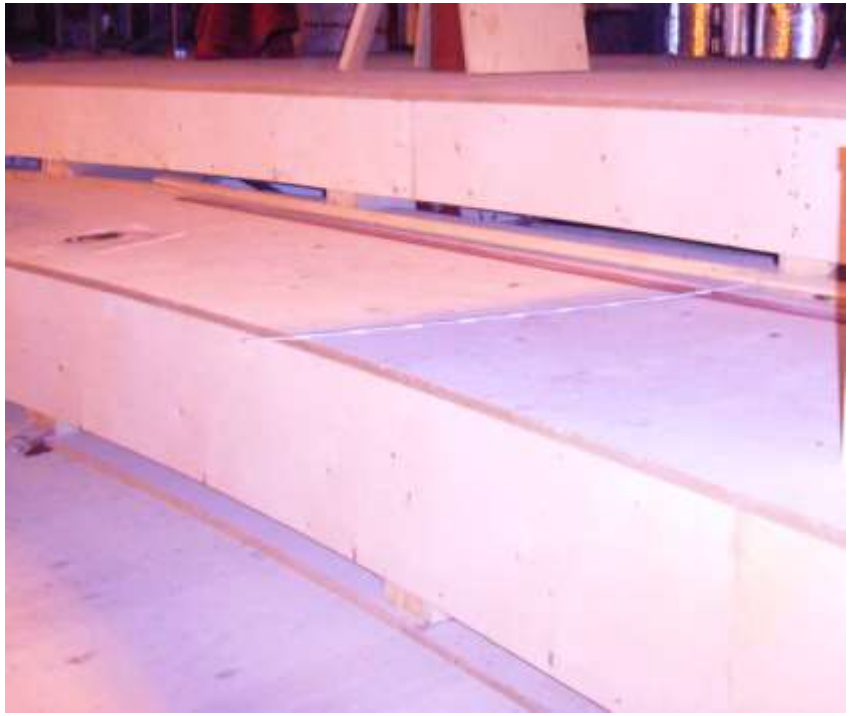
Supply air units in main theatre

- Supply air from under seats from a plenum
- Complex construction



Above floor

- Small openings
- A lot of contruction wood



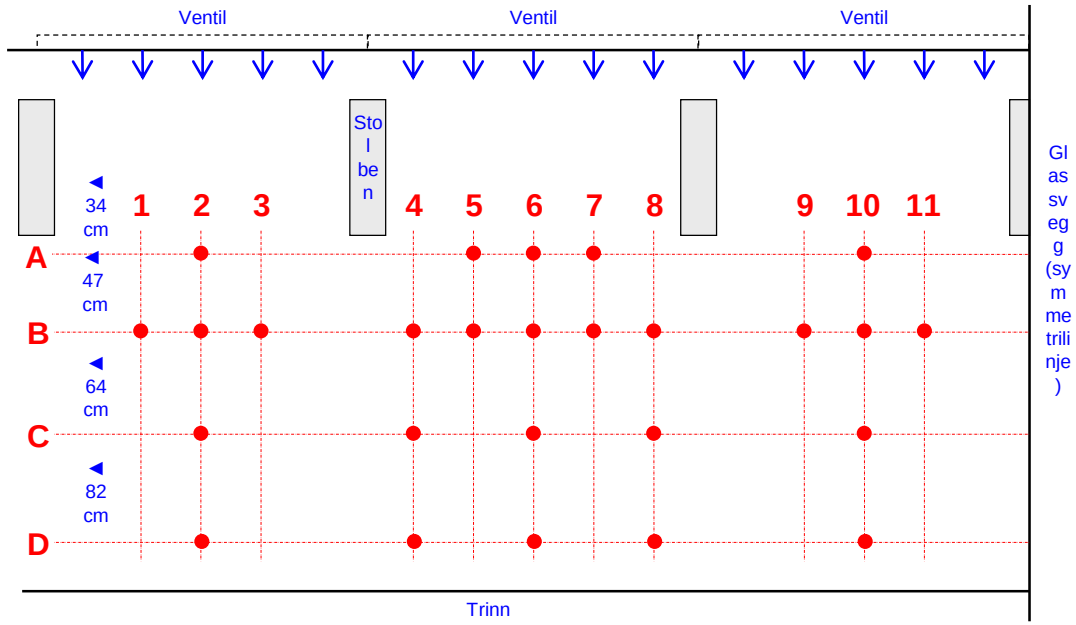
Under floor

- Many installations
- Steel constructions & Wood constructions

Supply air unit

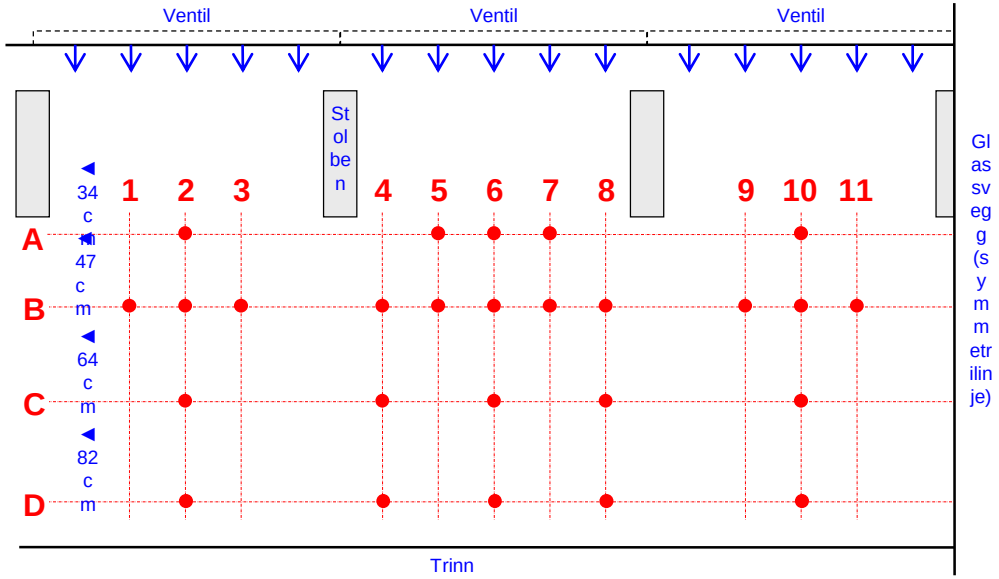
- The reduced opening area lead to redesign with a combination of units in the floor and in the step
- First test of units from Lindab and Swegon showed that none of the fulfilled the sound and comfort criteria
- Swegon and the sound designer of the operahouse redesigned the supply air unit and made three prototypes
- The prototypes were tested

Supply air units



Supply air units

	5	10	20	30	35	cm above floor
	0,192	0,151	0,097	0,135	0,105	m/s
B11	0,067	0,066	0,045	0,050	0,050	SD
	34,896	43,709	46,392	37,037	47,619	Tu
	23,453	18,862	10,105	15,152	11,568	DR
	0,171	0,165	0,077	0,124	0,106	m/s
B9	0,073	0,068	0,046	0,056	0,059	SD
	42,690	41,212	59,740	45,161	55,660	Tu
	22,077	20,714	7,221	14,523	12,478	DR
	0,158	0,130	0,032	0,090	0,130	m/s
B8	0,069	0,069	0,026	0,065	0,062	SD
	43,671	53,077	81,250	72,222	47,692	Tu
	20,054	16,649	0,000	10,551	15,891	DR



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Supply air units

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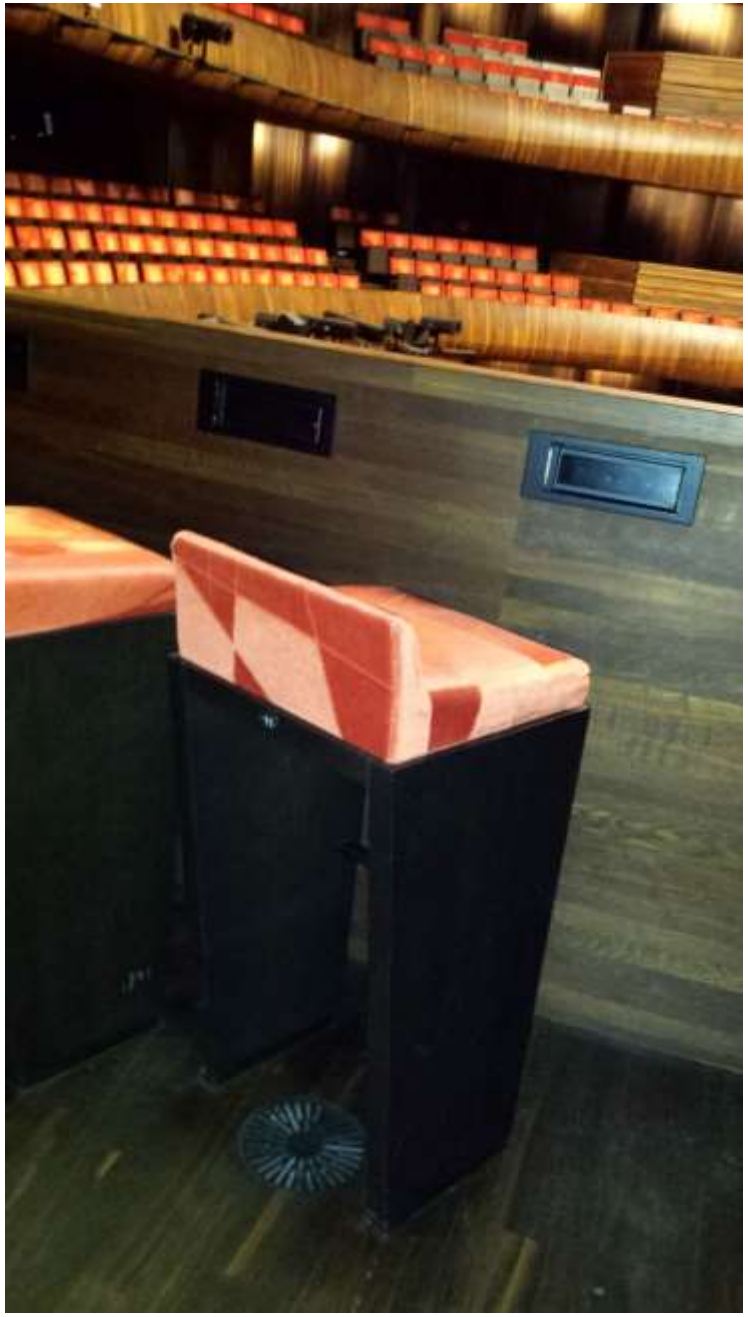
Supply air units



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Climate

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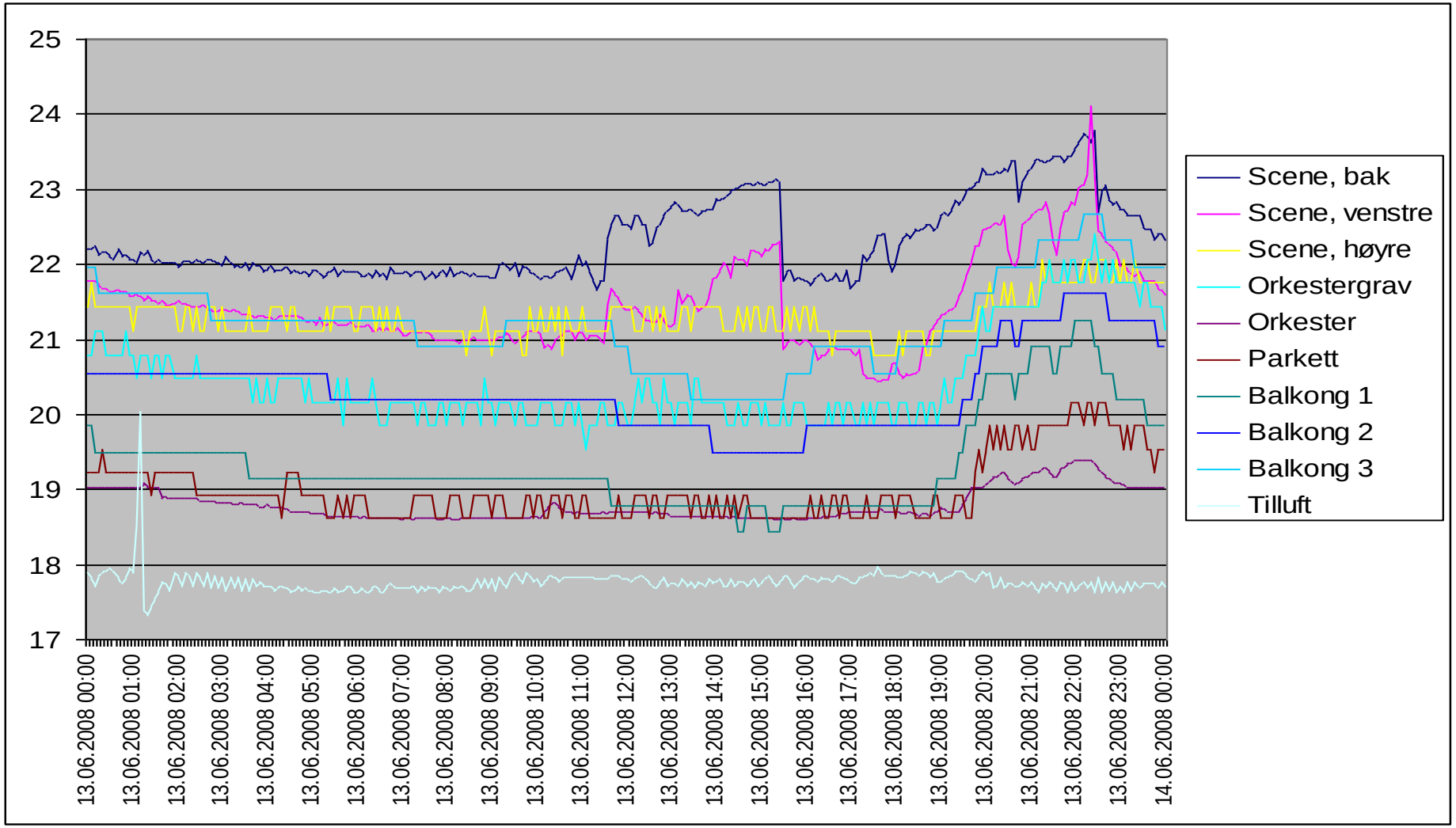
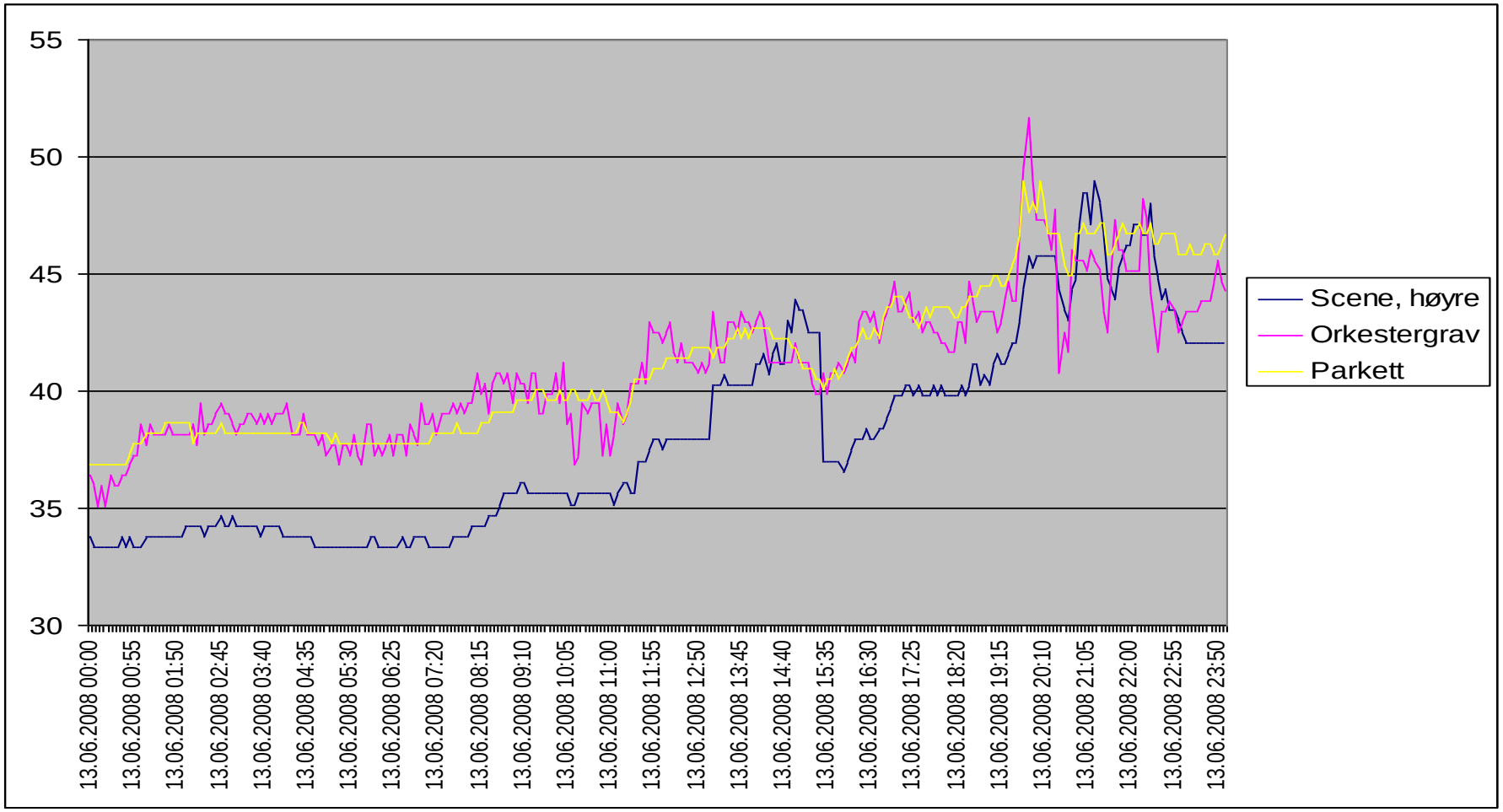
Temperatures

- fully occupied main theatre in the evening



Humidity

- fully occupied main theatre in the evening



- The main theatre and stage has very good acoustics and indoor climate.
- Perfect conditions even during hot and cold outdoor conditions
- No complaints
- Temperature well within limits

- The orchestra pit has challenges with humidity

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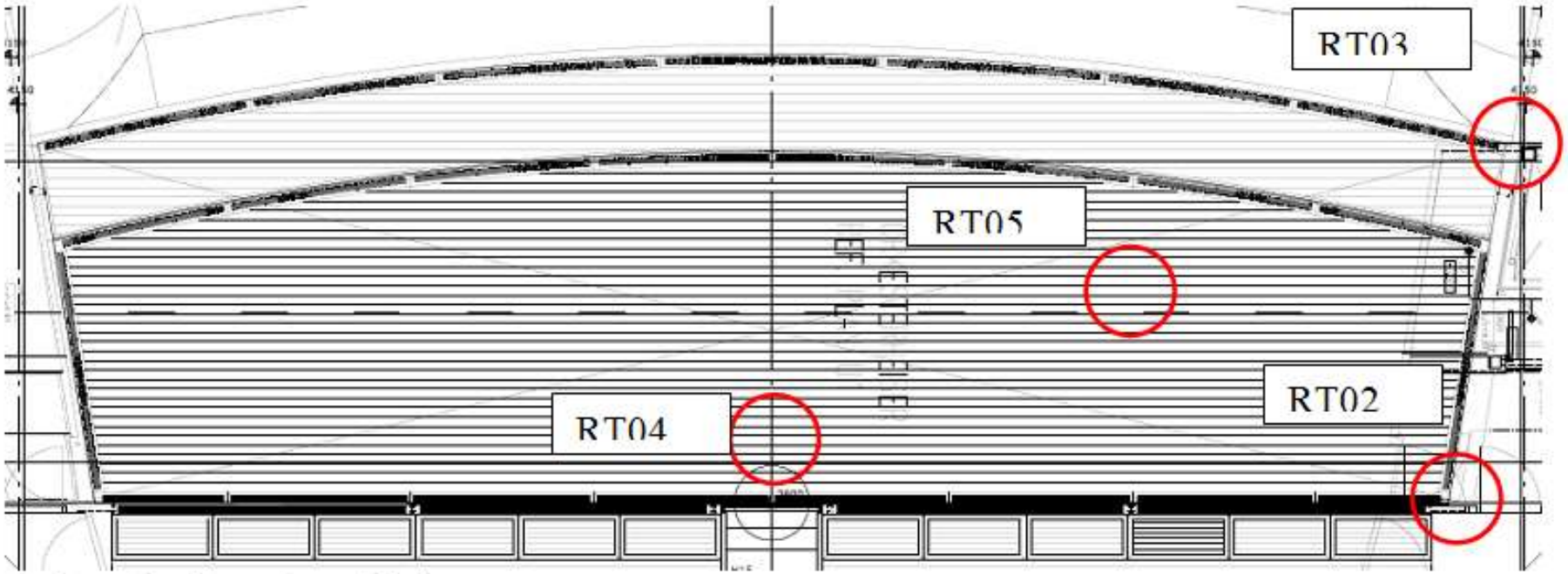
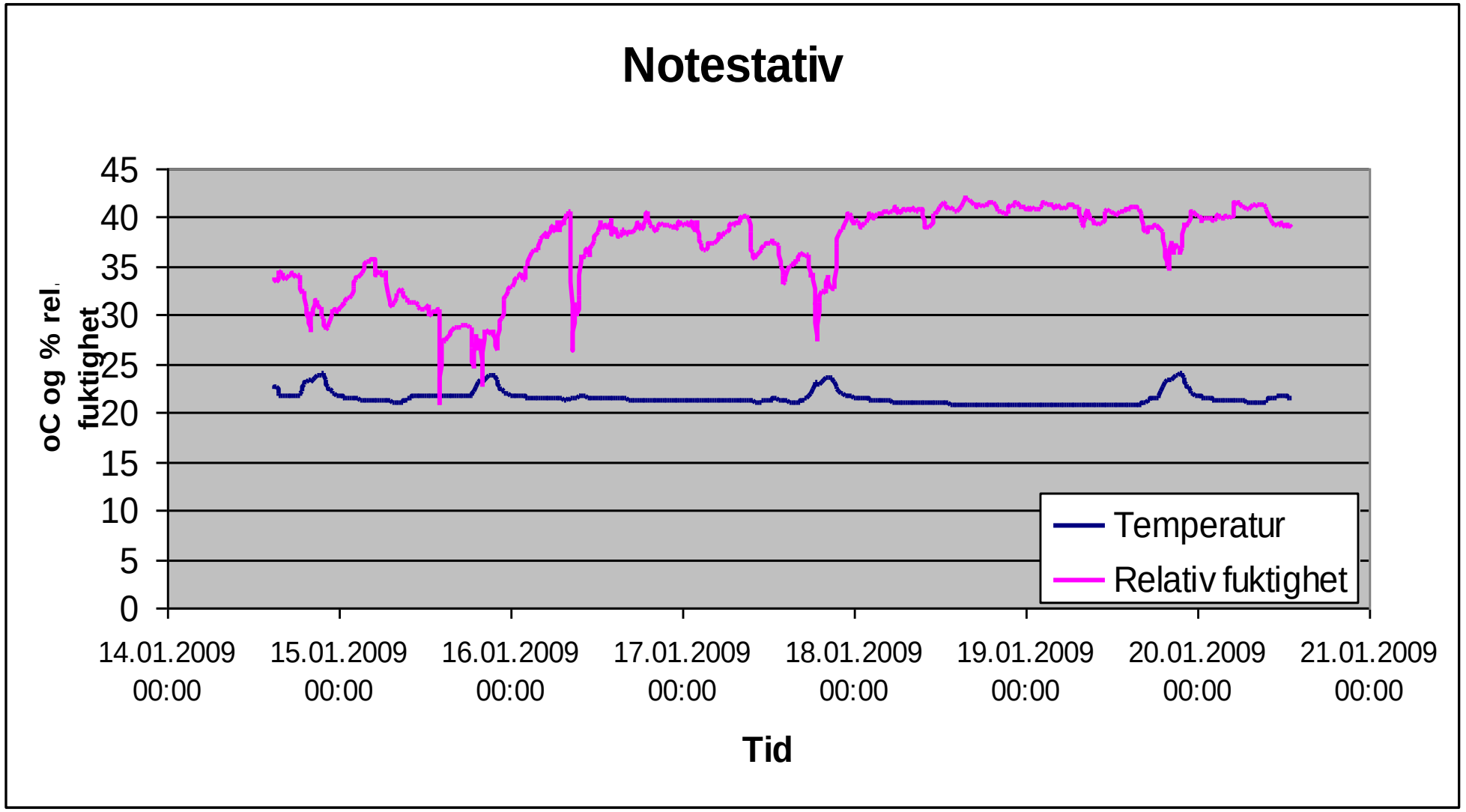
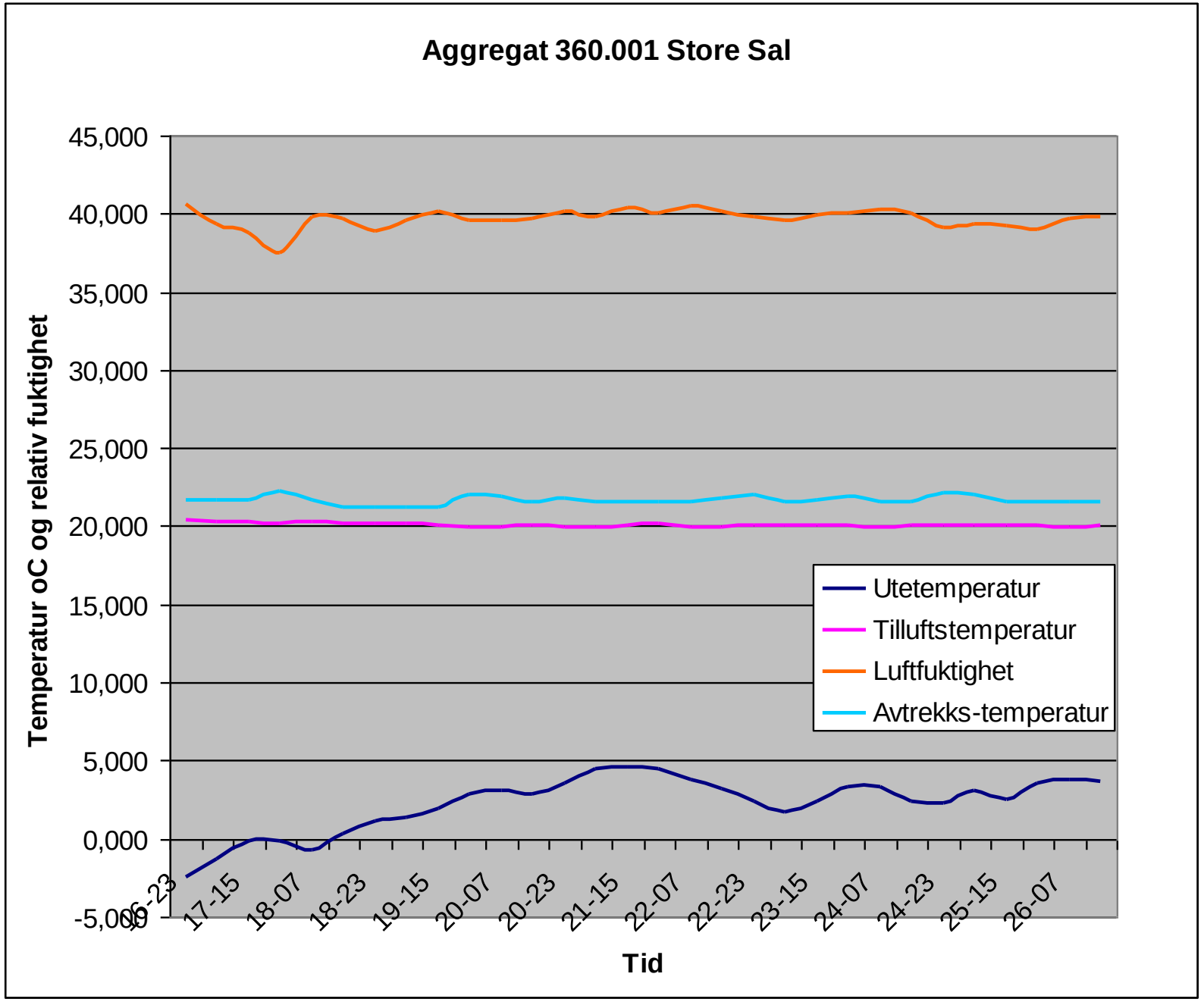
More testing in orchestra pit



Følgende plassering gjelder:
RT02: Mellom Scene og orkestergrav
RT03: Mellom sal og orkestergrav
RT04: Ca 80 cm over gulv i grav innunder scenen
RT05: På et notestativ.

RT04


Notestativ
45
40
35
30
25
20
15
10
5
0
oC og % rel. fuktighet
14.01.2009 00:00
15.01.2009 00:00
16.01.2009 00:00
17.01.2009 00:00
18.01.2009 00:00
19.01.2009 00:00
20.01.2009 00:00
21.01.2009 00:00
Tid
Temperatur
Relativ fuktighet


Aggregat 360.001 Store Sal
Temperatur oC og relativ fuktighet
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0,000
-5,000
16-23
17-15
18-07
18-23
19-15
20-07
20-23
21-15
22-07
22-23
23-15
24-07
24-23
25-15
26-07
Tid
Utetemperatur
Tilluftstemperatur
Luftfuktighet
Avtrekks-temperatur

- It is likely that the fluctuations in humidity is caused by open doors out to areas with no humidification
- They try to keep doors closed, but it is hard to make it completely
- They are still not satisfied with the humidity in the orchestra pit

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The Foyer

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FOYER

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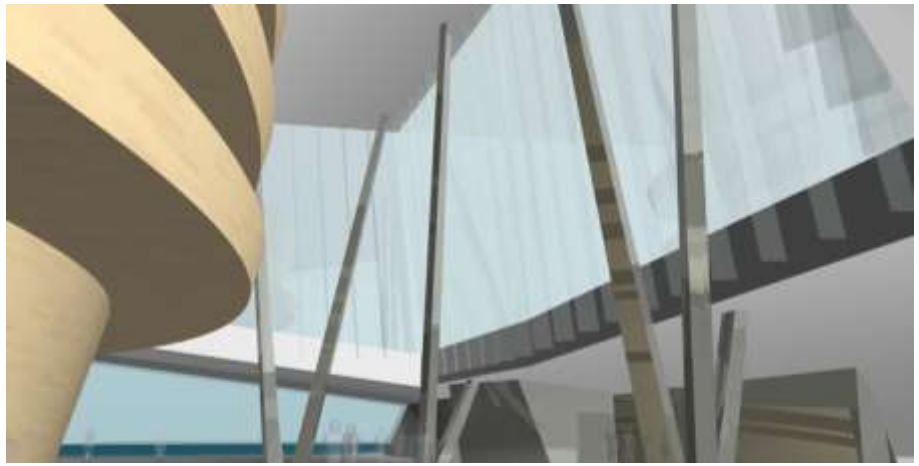
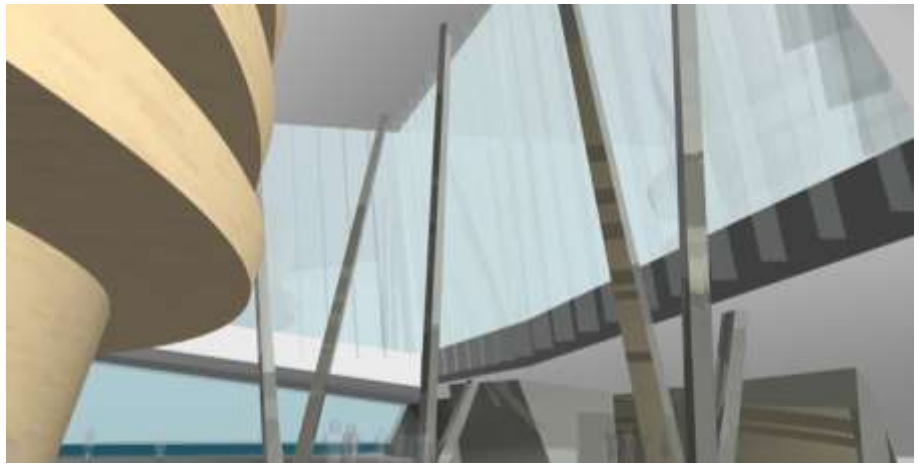
- Challenges:
  - Architects wishes:
    Open, light, clear glass, transparent
  - Large glazing area
    towards south: (570m2)
    west: (389m2)
    north: (757m2)
  - High number of persons (700 pers) when solar gain is higest (evening)
  - Open balcony towards the glazing

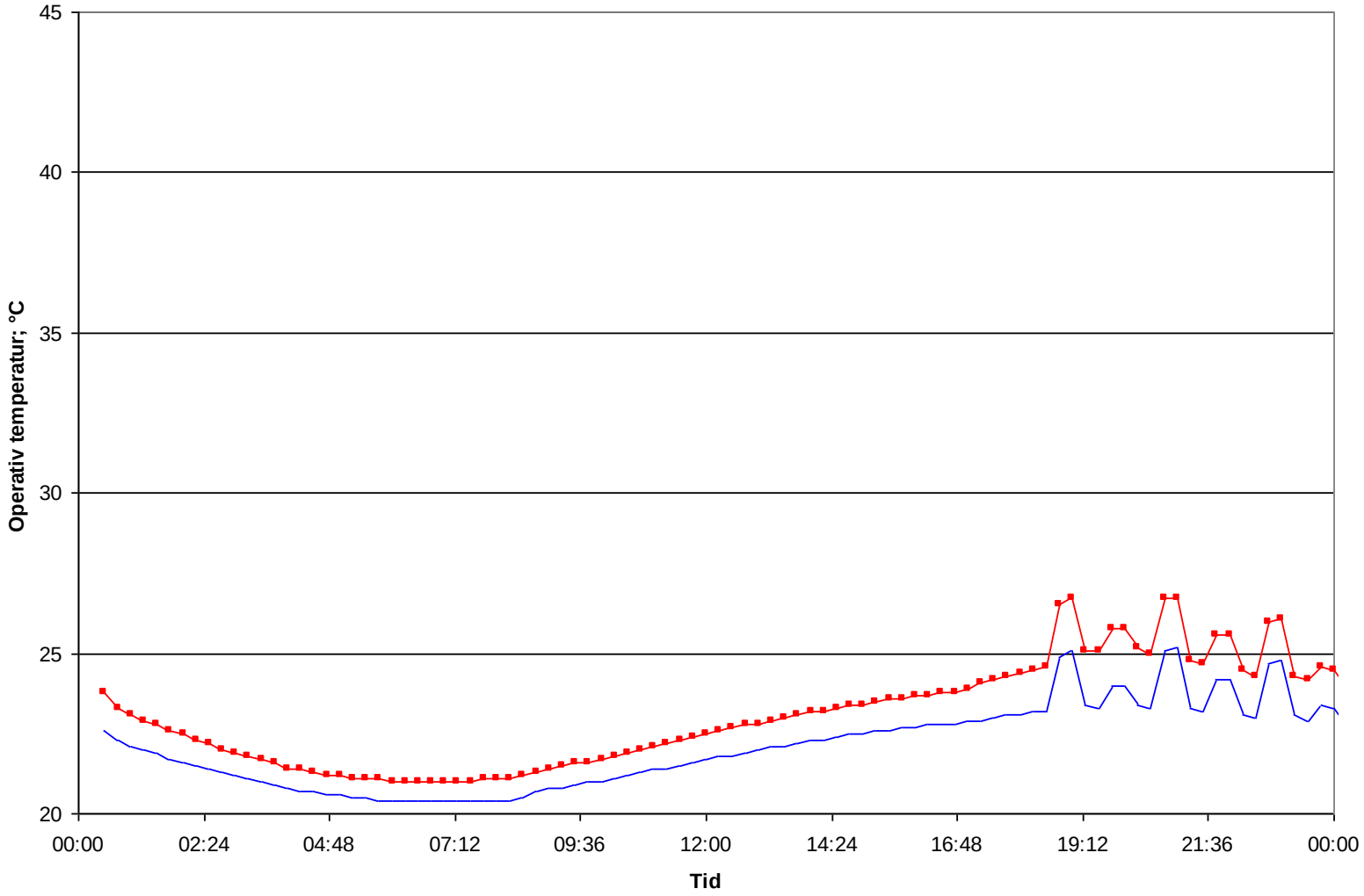


FOYER

- Strategy summer:
  - Displacement ventilation
  - Solar protection glazing
  - Solar shading
    - Solar cells
    - Screen
  - Cooling only in the balconies



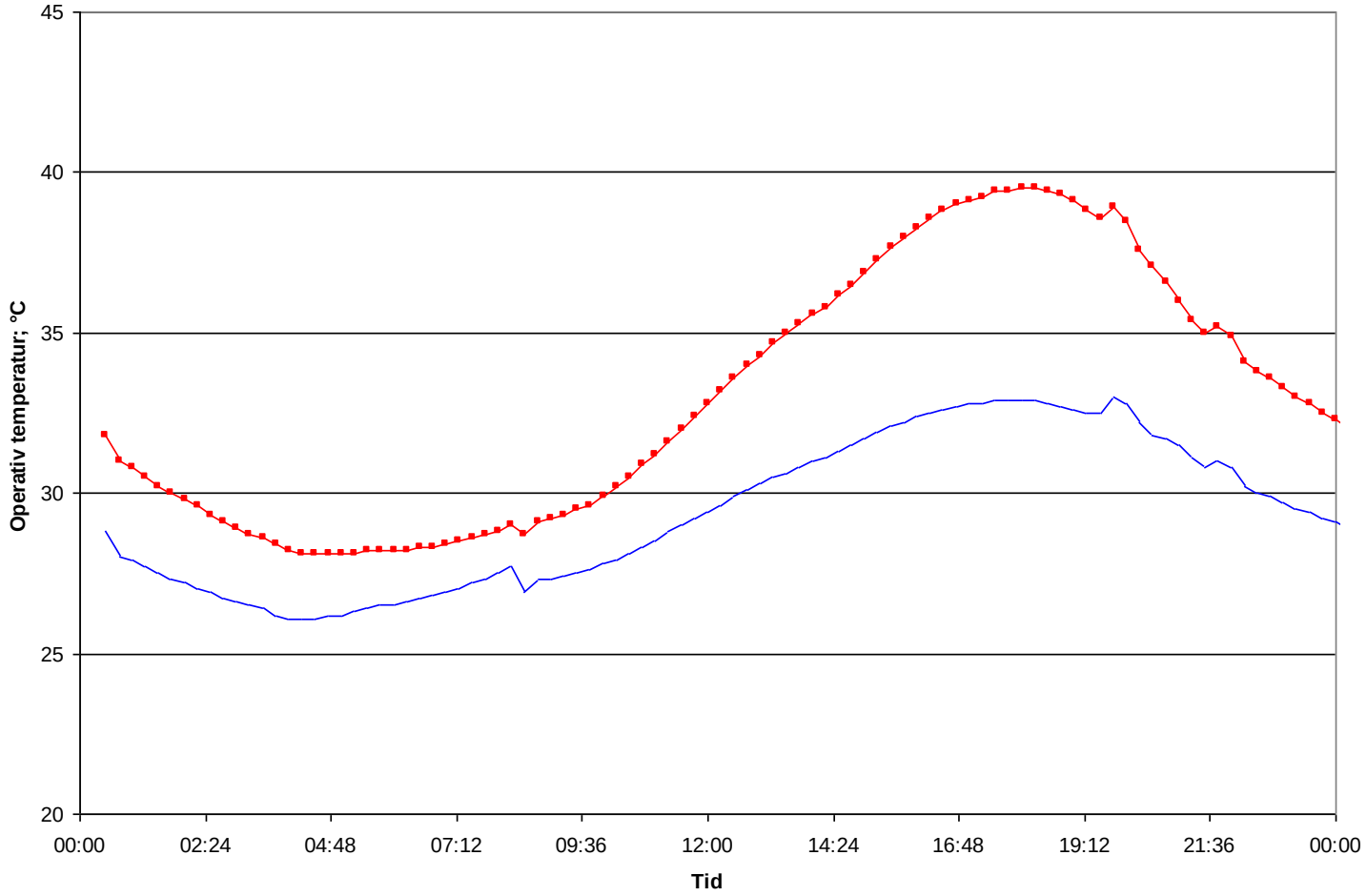
FOYER – lower part



FOYER

– upper part – outside balconies

Calculations summer (Tamb 13,1-26,7°C), no local cooling:



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Perfect thermal comfort in foyer

- The foyer is a place where people hide when it is too hot outside

FOYER

- The foyer is used for high standard conferences
- And parties for sponsors
- This summer 1500 people partied there for 4 hours when it was 26 oC and sun outside.
- Perfect inside

FOYER

- Strategy winter:
  - U-value 1.2 W/m2 oC
  - Floor heating
  - Radiators by floor windows
  - Spoilers at windows

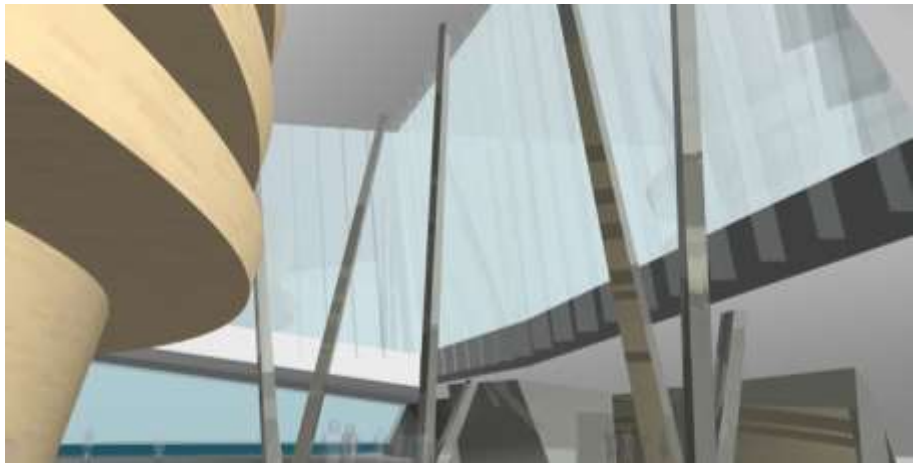

Figure 5.11: The snow is not melting on the windows in the foyer. A sign of energy efficiency

Solar cell facade produces more than expected

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Life Science building, UiO

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VEV: Life Science – University of Oslo

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Biology, chemistry, pharmacy
Education and research
65 000 m²

Laboratory building
BREEAM Excellent

VEV

- Targets:
  - Flexibility for users
  - BREEAM Excellent
  - NZEB (Near Zero Energy Building)

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Climatisation and Energy concept

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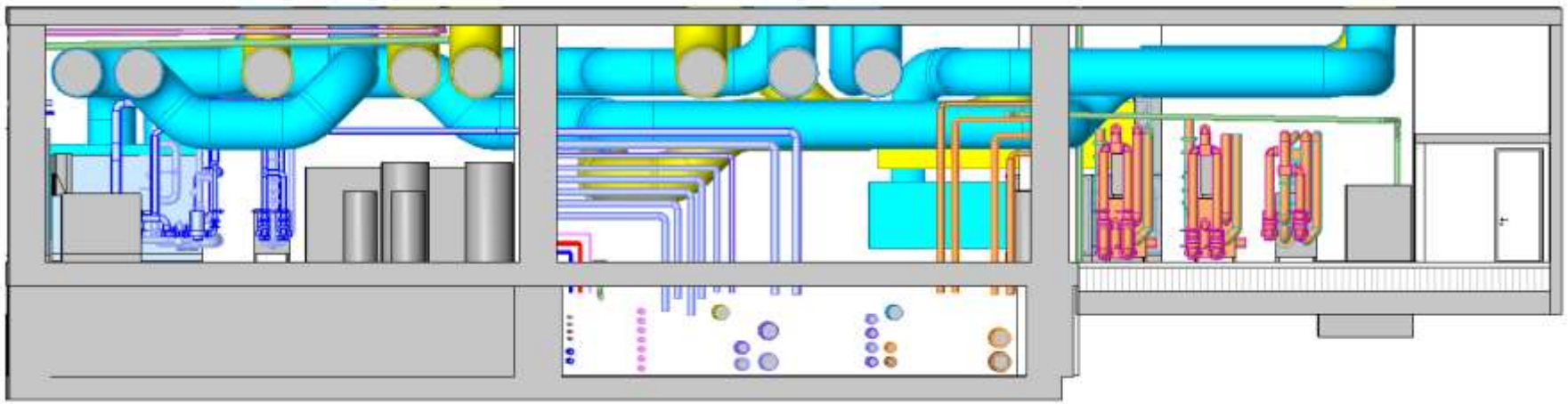
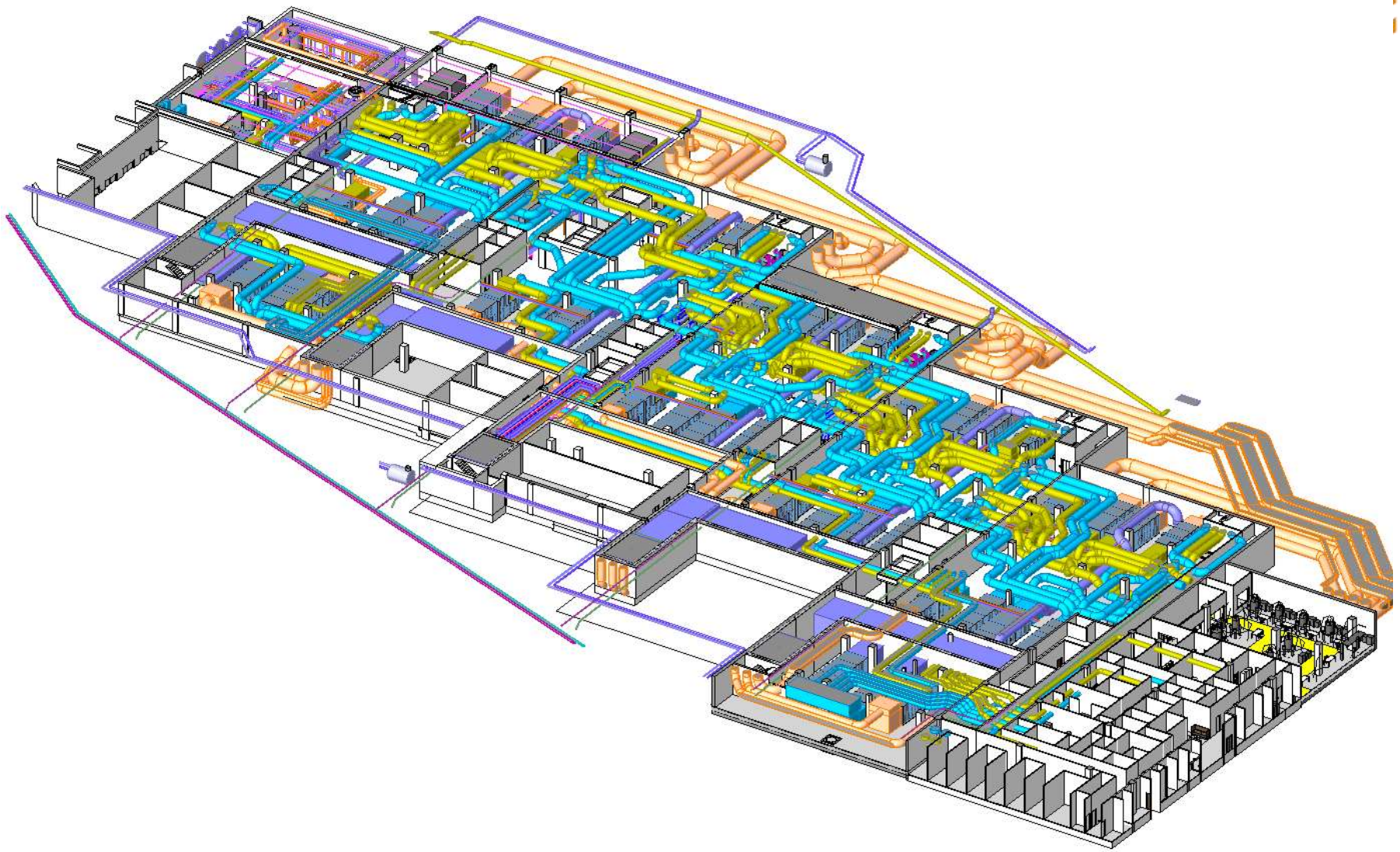
- The building
- Ventilation demand
- Power demand from user equipment
- Power demand for heating and cooling
- Nominal and expected energy use

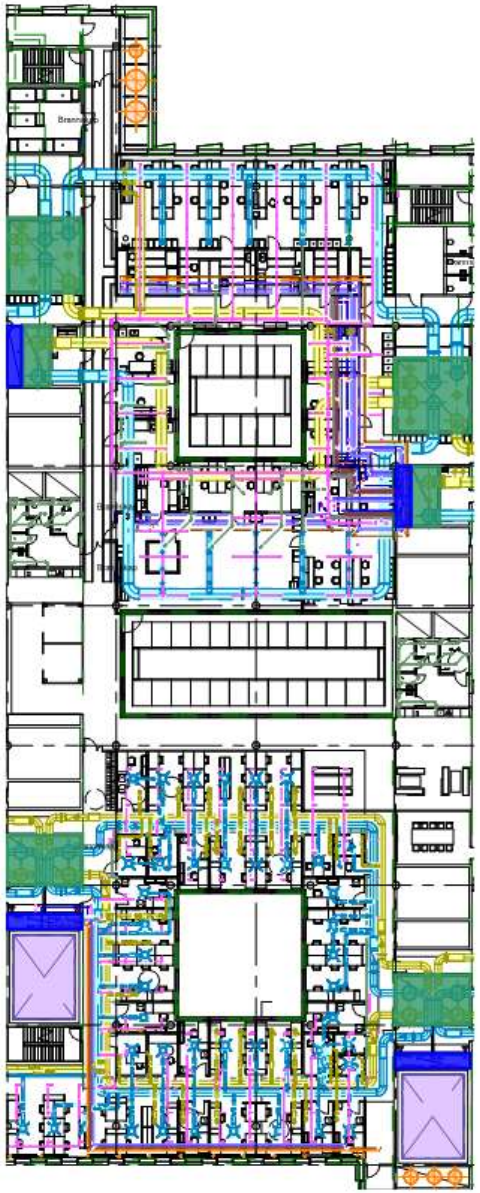
User functions

- Teaching students
- Research
- Heavy labarotories for life science
- Heavy use of computers
- Laboratory activities for bachelor, master and ph.d students

http://www.ratioark.no/no/prosjekt/101







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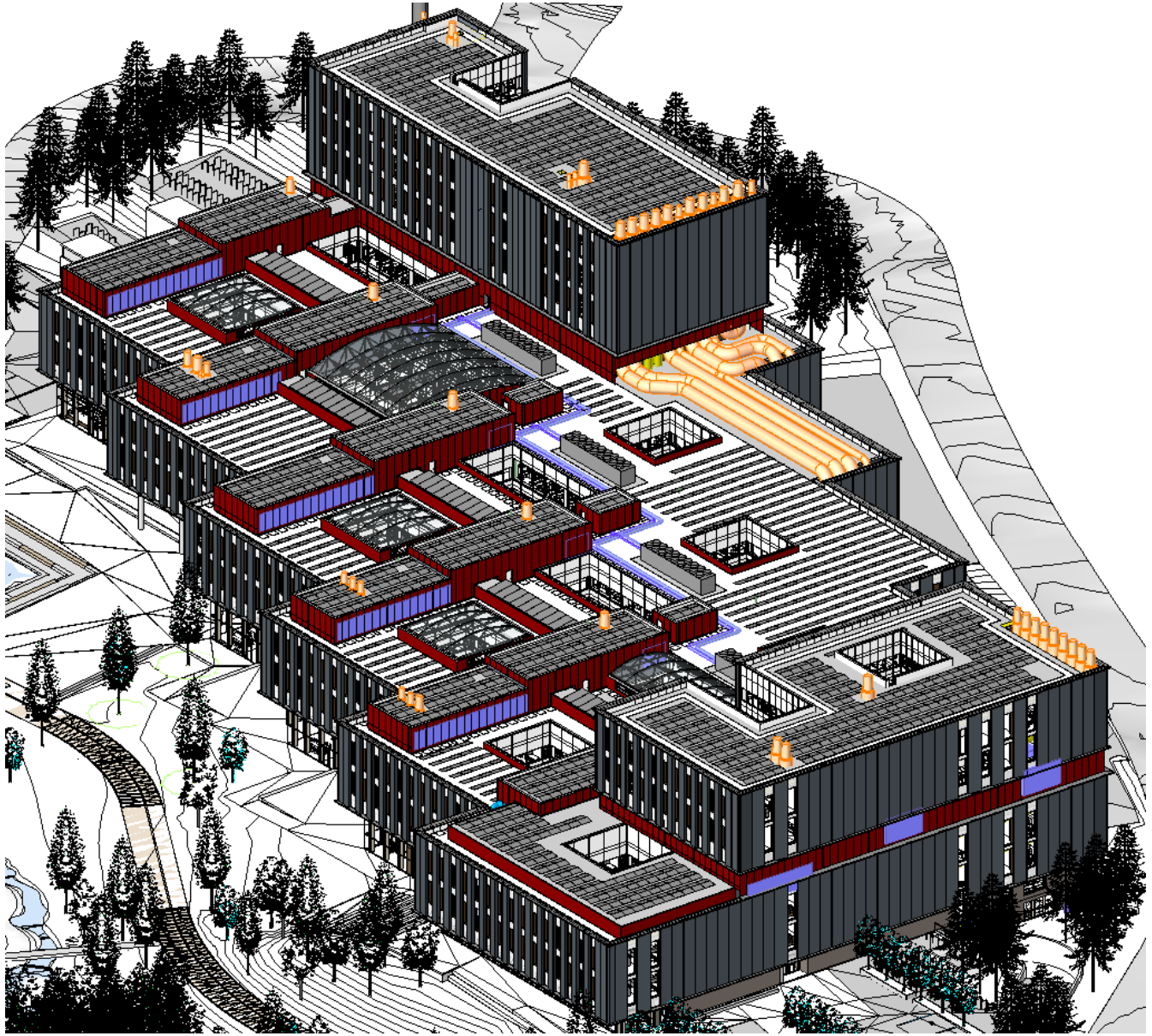

BREEAM

BREEAM® NOR

Code for a Sustainable Built Environment
www.ngbc.no
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Foreløpig sertifikat for Design- og prosjekteringsfasen
Det bekreftes at:

Livsvitenskapsbygget
University of Oslo – Blindern
Gaustadalléen 25
0373 OSLO

er blitt vurdert i henhold til
BREEAM NOR ver.1.1 (2012): Undervisning
Nybygg innredet

av en lisensiert revisor for
Statsbygg

og har oppnådd en poengsum på 83.8%
Excellent

Sertifikatnummer: BREEAM-0057-8997 Versjon: 01

BREEAM ENE 1 Energy efficiency

Tabell 6.1 Prosentvis forbedring i forhold til gjeldende standard for energikarakter C i energimerkeordningen.

BREEAM-poeng	Nybygg og hovedombygging	Oppussing
1	5%	-20%
2	7%	-9%
3	11%	0%
4	15%	8%
5	19%	15%
6	25%	21%
7	31%	28%
8	37%	36%
9	45%	45%
10	55%	55%
11	70%	70%

VEV – climate and energy strategy

Passive house principles

Energy efficient ventilation

Low temperature heating and high temperature cooling

Reuse of energy from cooling and energy storage

Solar cells on roof and facade

Theory and reality

Lot of laboratories and energy demanding equipment

High ventilateion rate 24 h

High rate of laboratory exhaust

Risc of contamination with high efficiency heat recovery

Extreeme variation in ventilation rates

UNIVERSITY of CALIFORNIA · IRVINE

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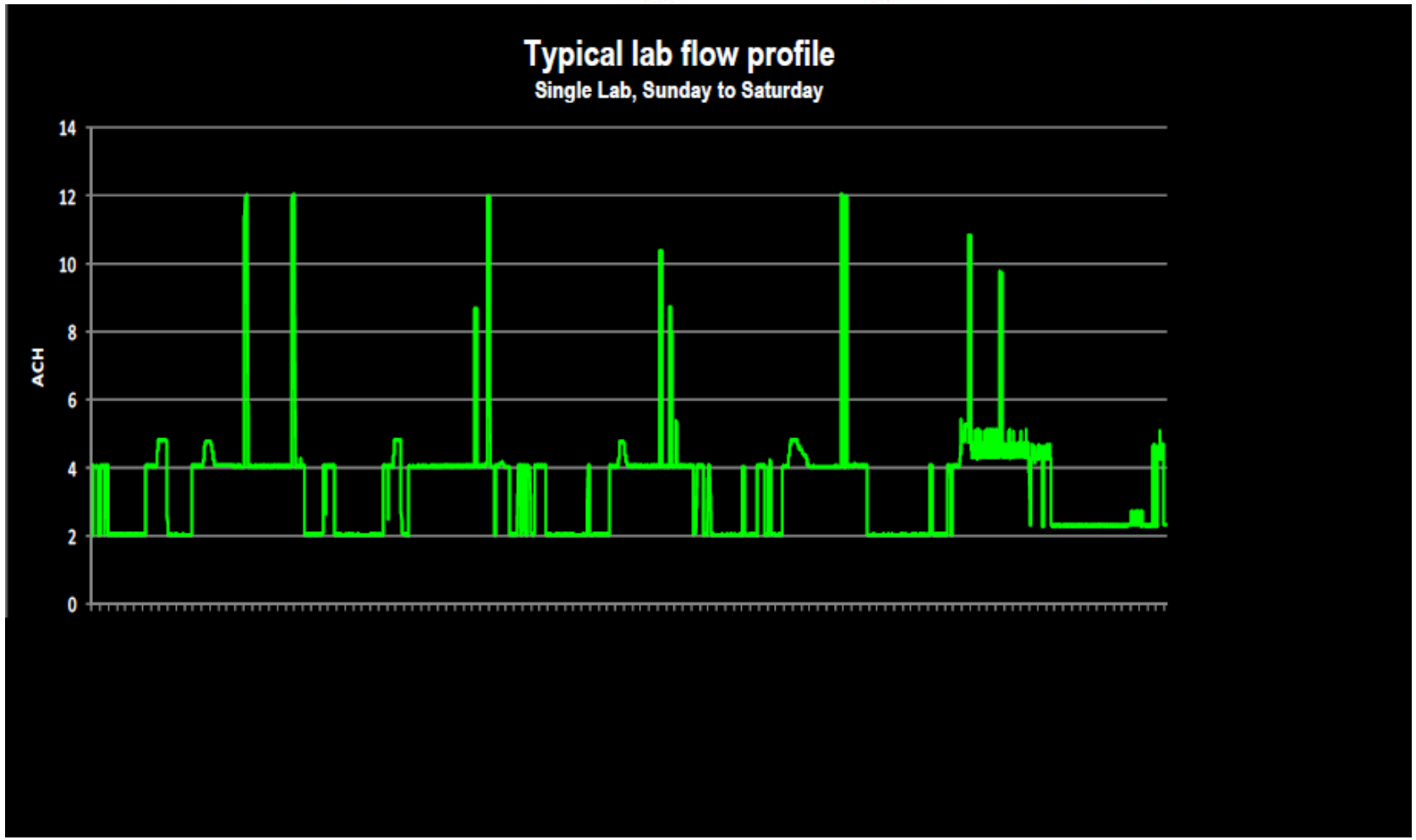
Smart Laboratories Cut Energy Consumption More Than Half

48 m3/hm2

16 m3/hm2

8 m3/hm2



Effekt og energibehov i laboratoriebygg

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Energy Consumption of University Laboratories: Detailed Results from S-Lab Audits

Lisa Hopkinson, Peter James, Nigel Lenegan,
Tom McGrath and Malcolm Tait

Developed by the
S-Lab (Safe, Successful and Sustainable Laboratories) initiative of
HEEPI (Higher Education for Environmental Performance Improvement)
See www.goodcampus.org

Lab-CURE: Chemicals, Utilities, Resources and Environment in Laboratories

Power and energy use in laboratory buildings UK

Table 1: Summary of Laboratory Features

	Date Built	Floor Area (sq.m)	Total Energy (kWh/y)	Total Electricity (kWh/y)	Total Gas (kWh/y)	Energy Use per Unit Area (kWh/sq.m/y)	Energy Cost per Unit Area (£/sq.m/y)	Ventilation-related as % of Total Energy	Equipment as % of Total Energy
Cambridge - Chemistry Building	1950's (major refurb 1990s)	27,603	19,537,914	10,251,111	9,286,803	707	40	51%	17%
Cambridge - Chemistry Building Excluding Server Room Energy		As above	17,698,506	8,411,703	As above	641	33	57%	19%
Edinburgh Cancer Research Centre	2002	3,000	2,937,408	1,268,111	1,669,297	979	67	38%	21%
Edinburgh - Cancer Research Centre Excluding Autoclave Energy		As above	2,421,480	As above	1,153,369	807	60	47%	26%
Liverpool – Biosciences Building (Academic Section)	2003	7,750	5,237,743	3,092,930	2,144,814	676	40	43%	23%
Manchester - Chemistry Building (Extension)	2006	3,816	2,488,242	883,407	1,604,835	652	28	61%	12%
York - Department of Biology (Blocks K, L & M)	2002	12,740	8,660,308	5,024,386	3,635,922	679	36	45%	22%

Ventilation VEV

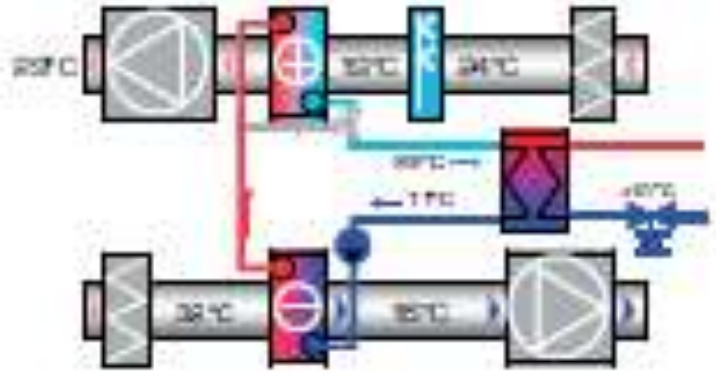
Total 1 139 000 m3/h air

Solutions:

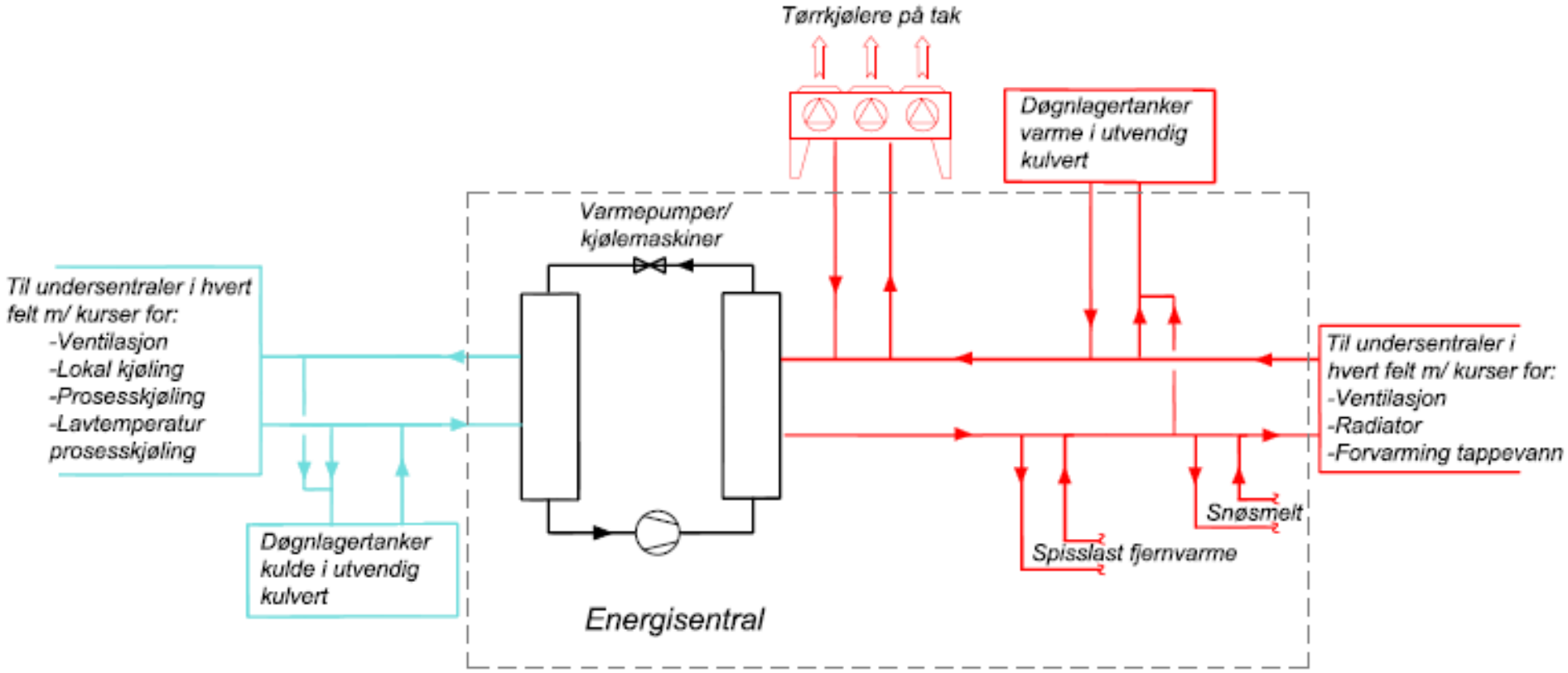
low SFP

high ventilation efficiency 80 %

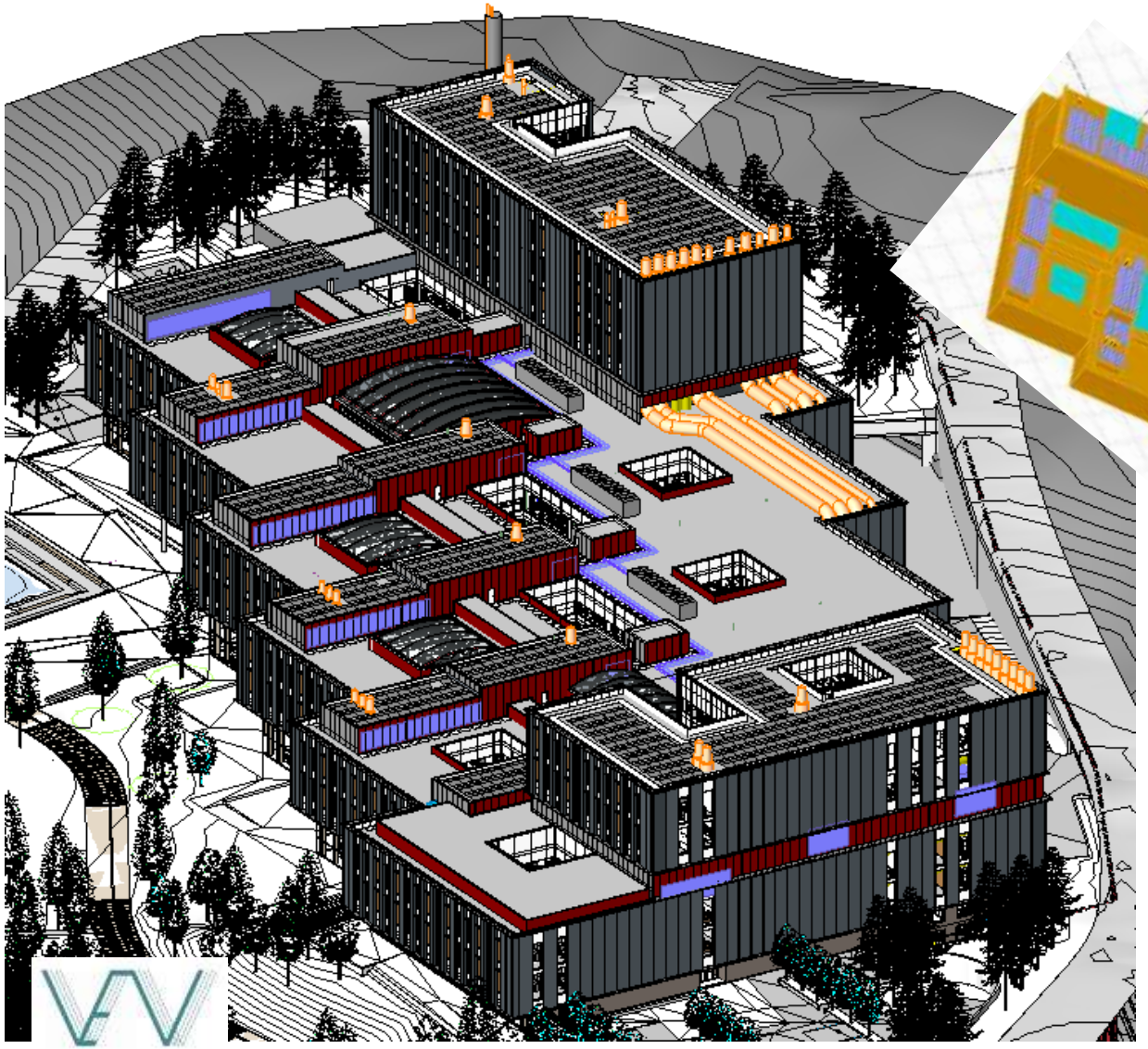
demand control

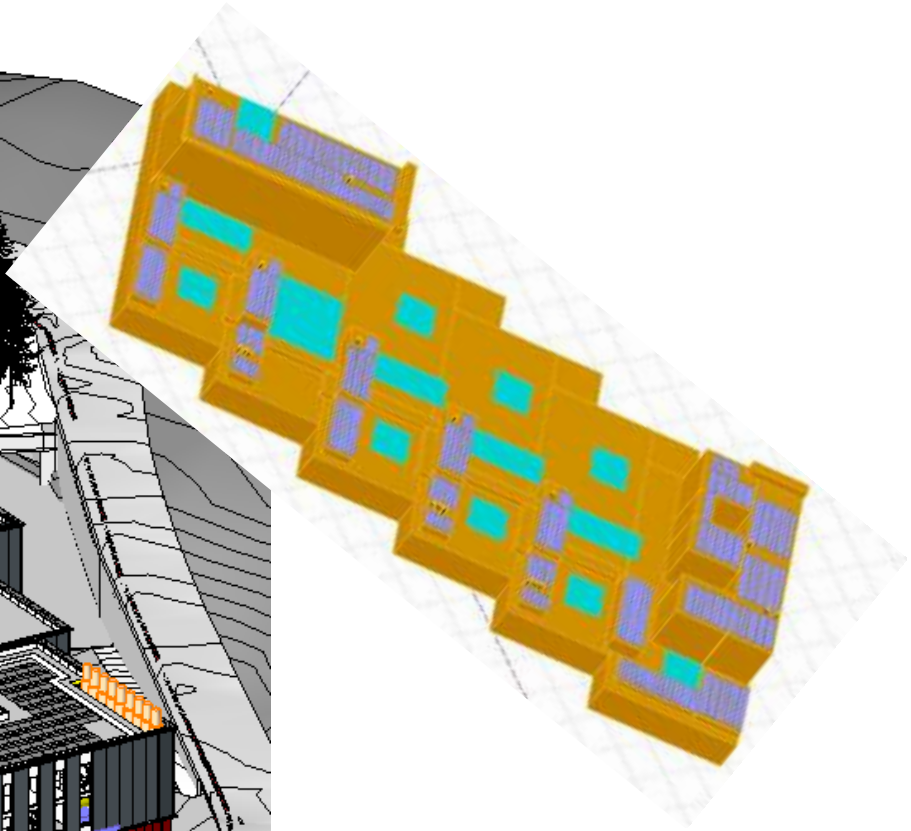


SYSTEM ENERGY SUPPLY



Solar celles in facades and roof





Theory – Standard calculation

	kWh/m²
Need for delivered energy	83,5
Produsedsolar energy	12,3
Net need for delivered energy	**71,2**

Tabell 6-5 Samlet behov for netto levert energi beregnet iht. NS3031:2014 og med NVE sine føringer på systemvirkningsgrader.

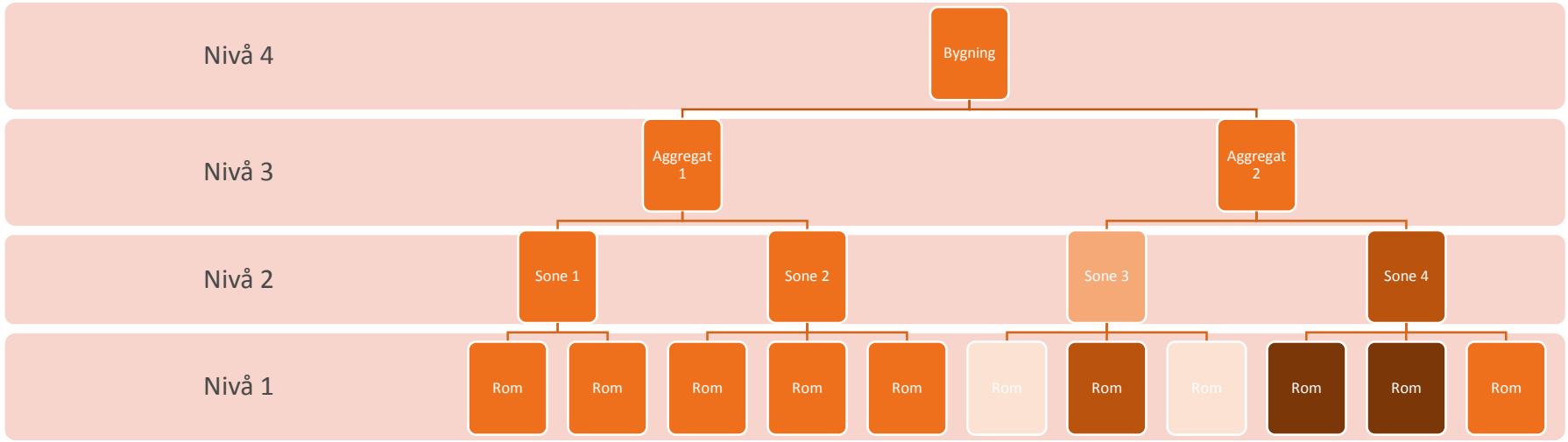
What will be the real power and energy demand?

% of total local capasity on ventilation	Power MW		Power MW	
	Heating		Cooling	
40 %	3,0	- 22,5 %	2,0	-18,5 %
60 %	3,9	-	2,4	-
80 %	4,7	+22,5%	2,9	+18,5 %

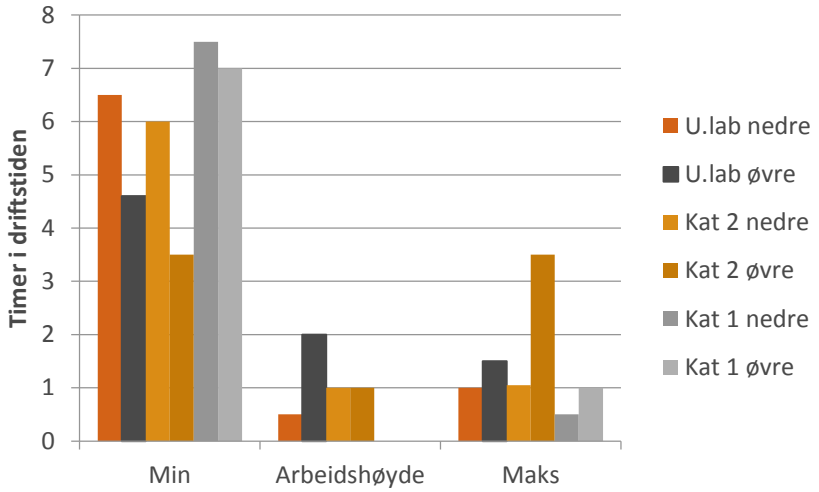
Ventilation system principle and use is critical.

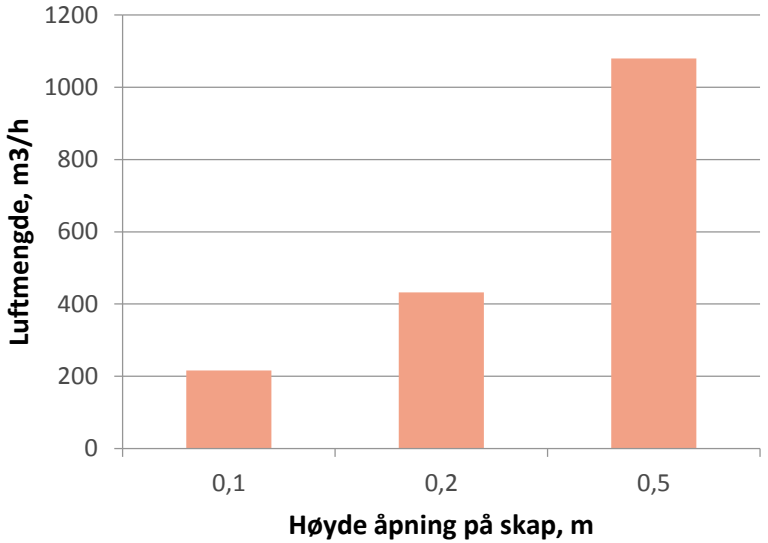
SIMULTANEITY

- Nivå 1: Room
- Nivå 2: Floor
- Nivå 3: Plant
- Nivå 4: Whole building

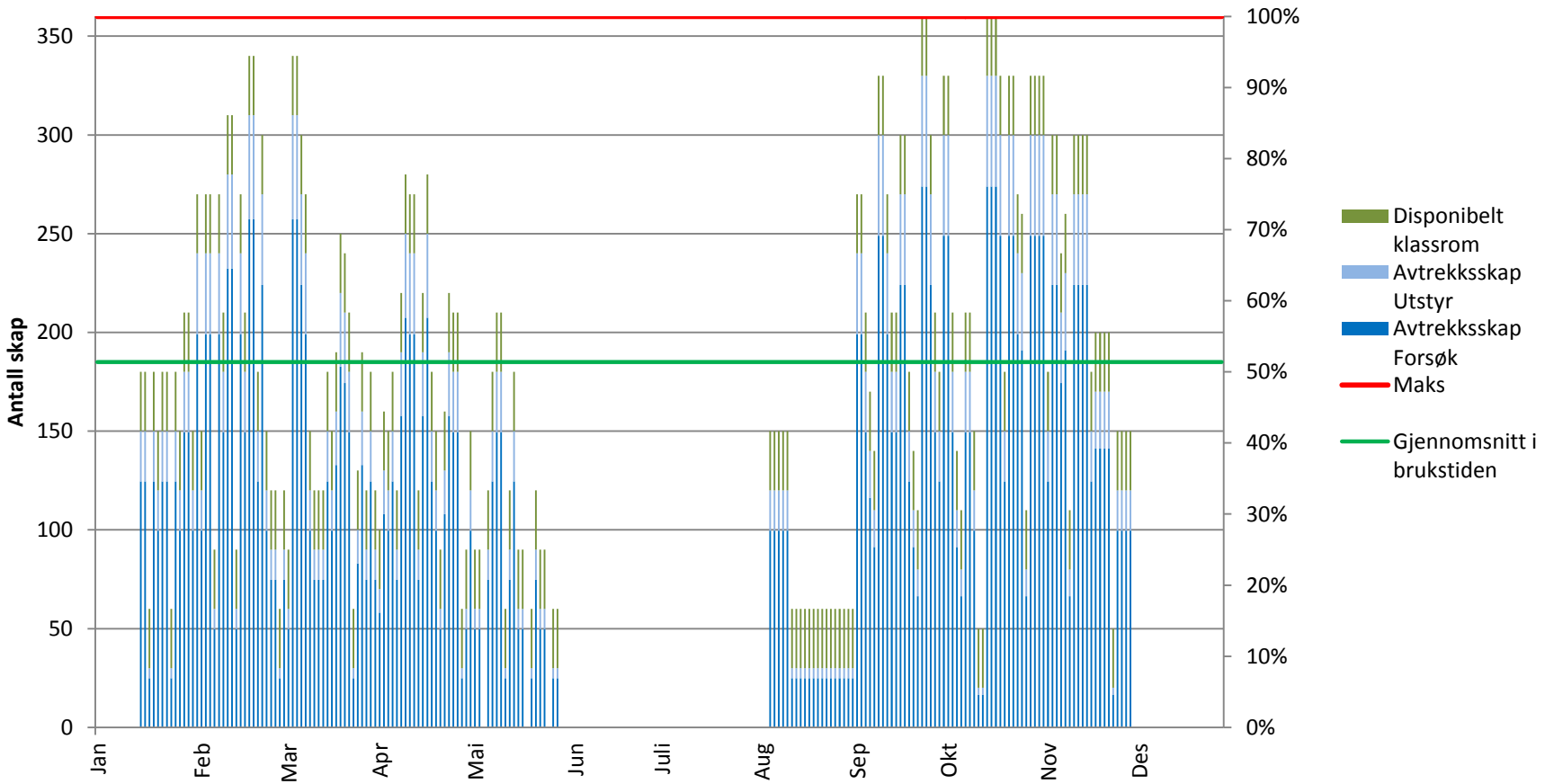


FUME HOODS (NIVÅ 1)





FUME HOODS IN EDUCATIONAL LABS



Bruk av avtrekksskap

Luftmengder

Oppvarming og kjøling

Energiforsyning

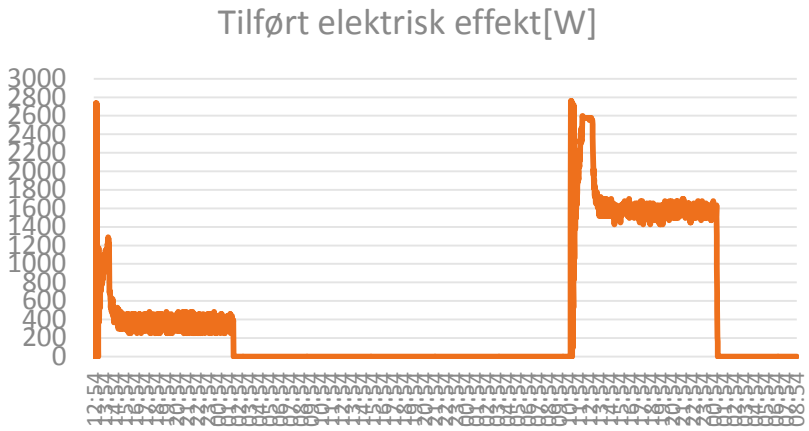
Master study spring 2018

- Research lab 6 persons
- Educational lab 25 students
- "Norwegian and danish" solution
- Supply air units
- Control strategy
- Location of fume hood
- Draught

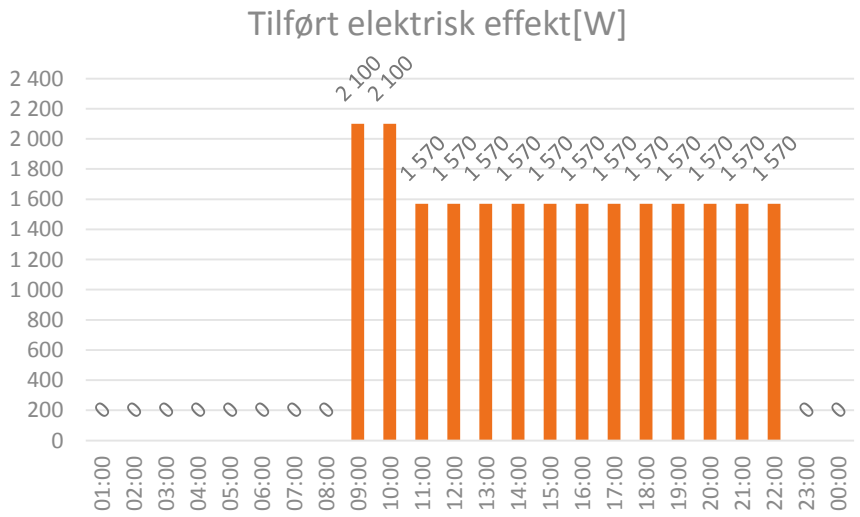
MEASURING USE OF LAB EQUIPMENT

Ovnsrom-Kat 3	Analysatorrom Kat 3	Røntgenrom Kat 3
Høytemperatur ovn	MS (Mr. Hiccup)	Kontroll PC m/skjerm
Muffelovn 14 liter	Vakuumpumpe Mr. Hiccup	Recx-1-Ekstern vannkjøling
Muffelovn 13 liter	Vakuumpumpe Mr. Hiccup	Recx-2 -internkjøling
Rørovn nr. 4	MS –Orbitrap	Recx-4-luftkjøling
Rørovn nr. 14	Vakuumpumpe orbitrap	Reck-5-Ekstern vannkjøling
Muffelovn med avtrekk	LC Mr. Hiccup	Kjølekurs til røntgenmaskiner
Romtemperatur	LC Orbitrap	Romtemperatur
	Kontroll PC m/ skjerm	
	Romtemperatur	

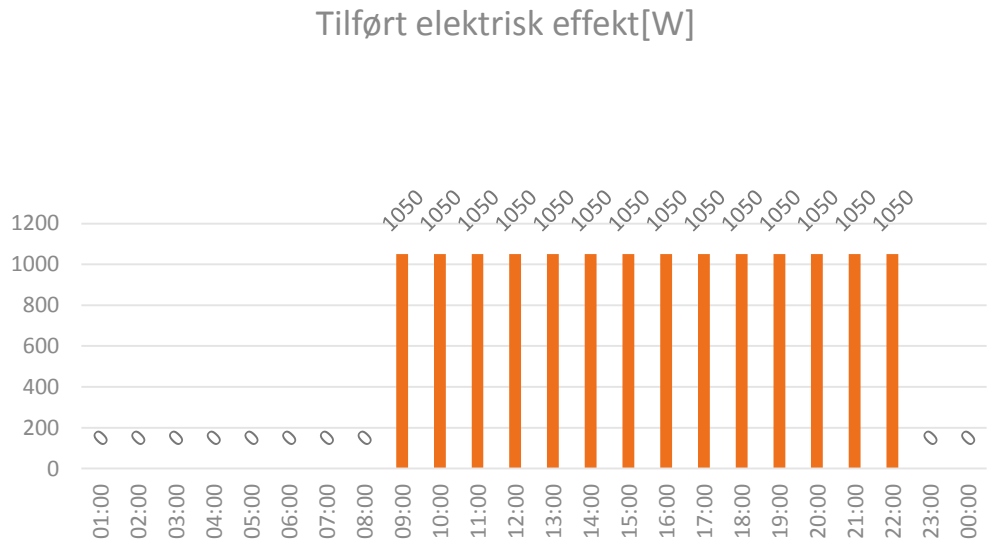
USE OF MEASURED DATA



Figur A-1: Resultater fra måling.



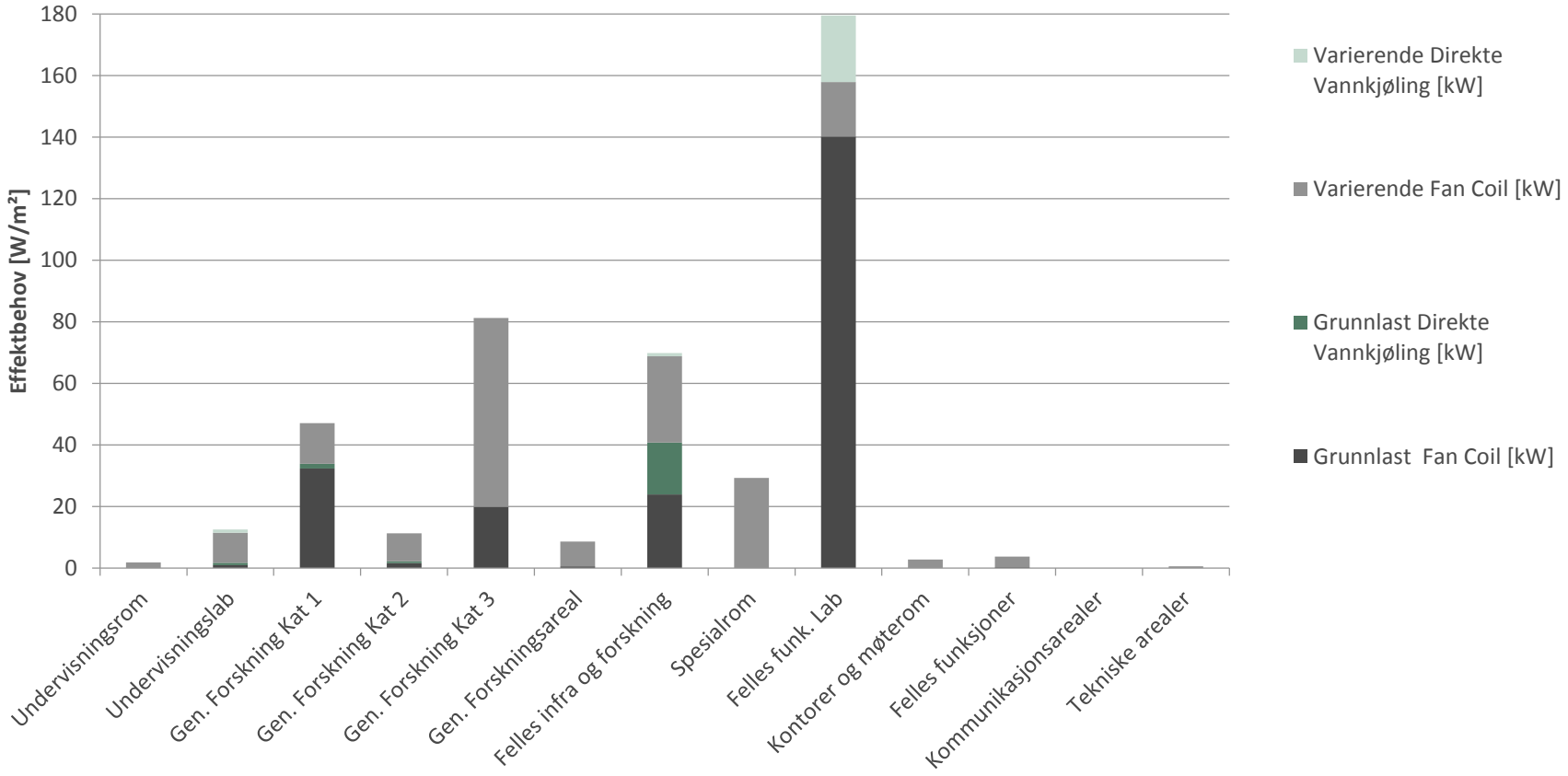
Figur A-3: Tilført elektrisk effekt for en dimensjonerende driftsdag til bruk for dimensjonering av de klimatekniske installasjoner



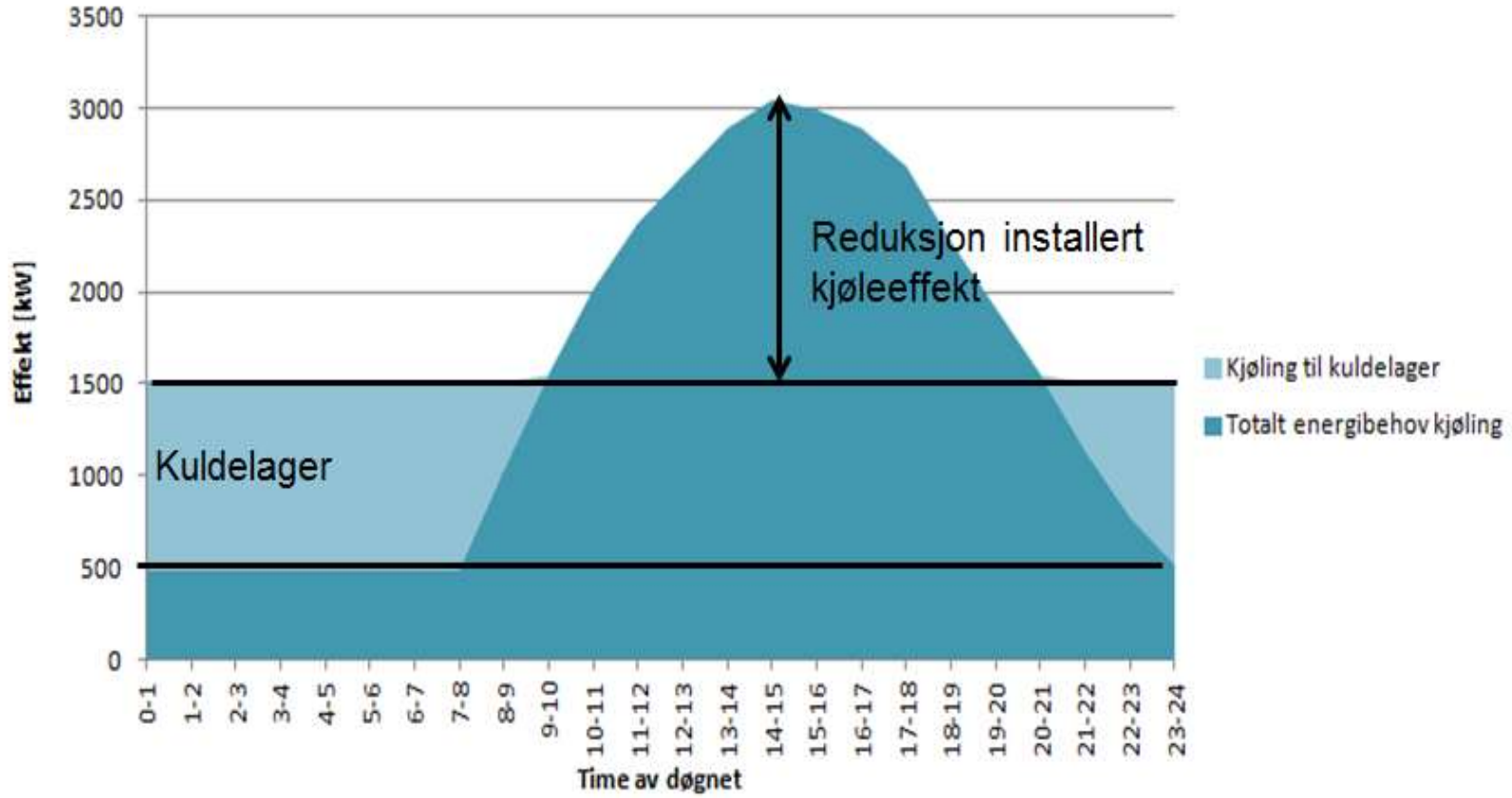
Figur A-4: Tilført elektrisk effekt for en typisk driftsdag til bruk for dimensjonering av energisentral.

USE OF MEASURED DATA

- Antall
- Bruksmønster
- Samtidighet



Kulde- og varmelagertanker - dimensjoneringsprinsipp



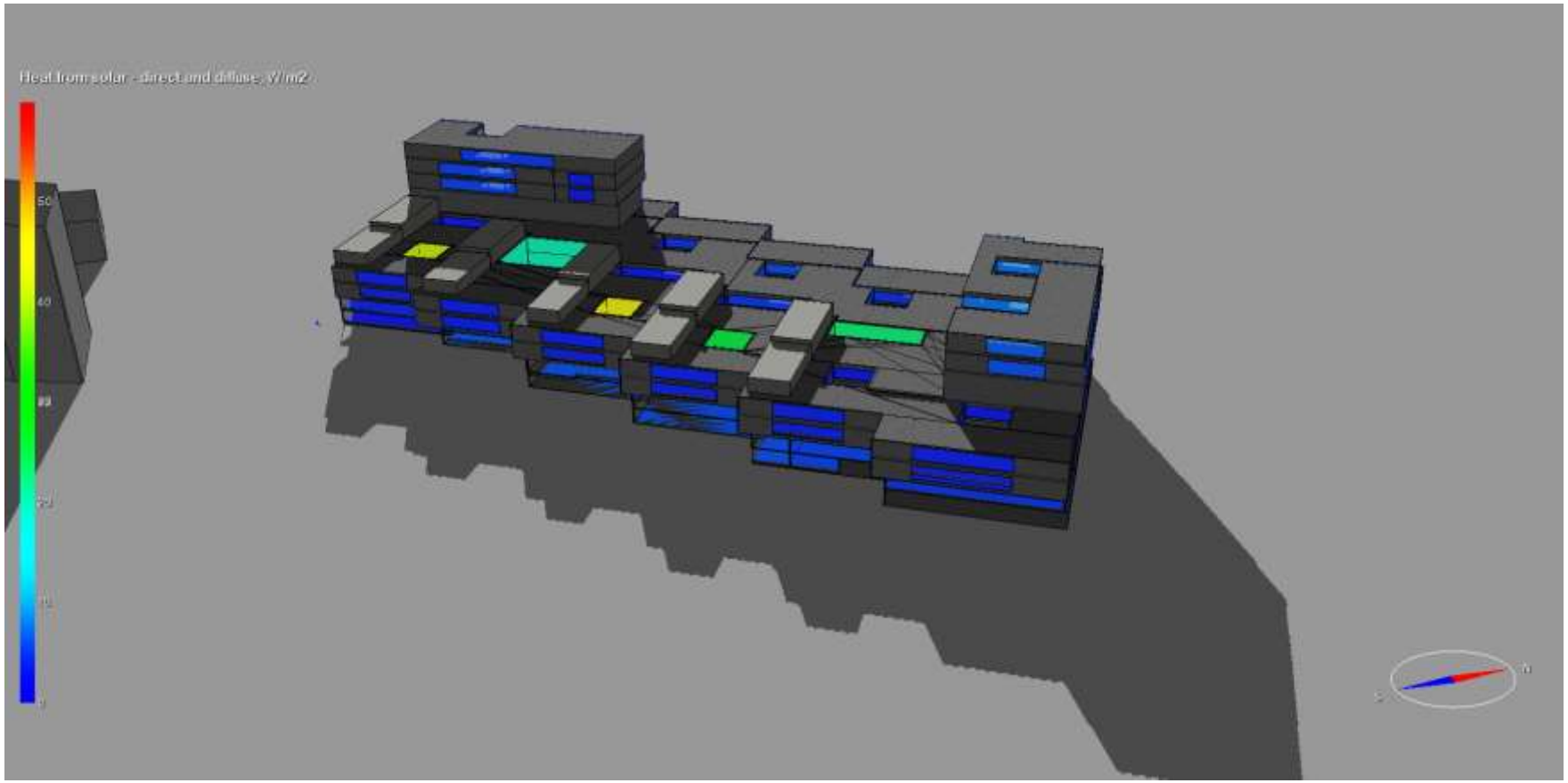
Formål: Senke effekt-topp for kjølebehov som igjen reduserer installert kjøle-effekt

Kulde- varmelagertanker del 2

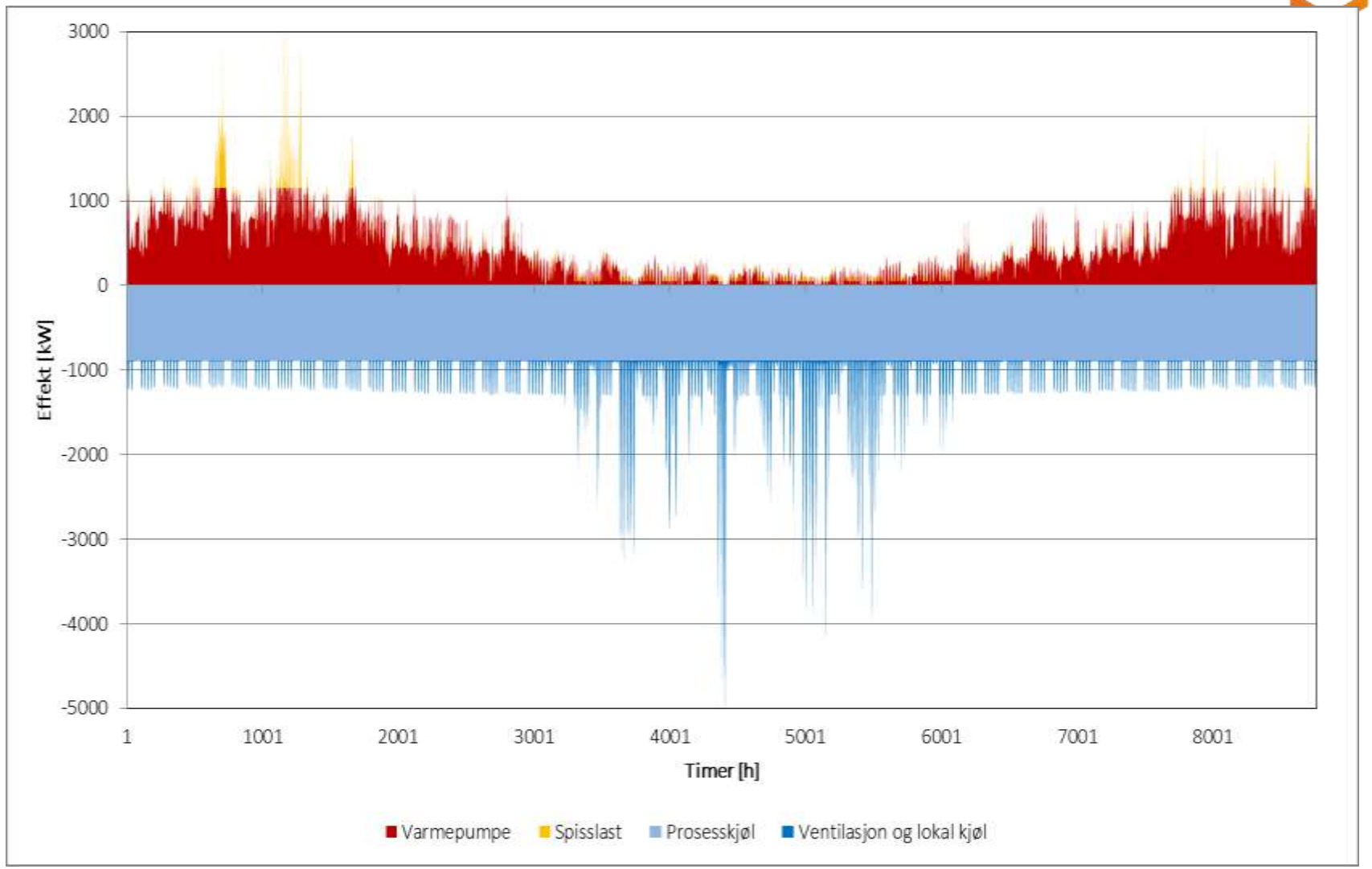
Kjøleelementer som inneholder saltblanding.

- smelter og fryser på 13 °C for kjølelager, 32 °C for varmelager.
- Vann sirkulerer gjennom tanken og henter/lagrer energi etter behov

IDA ICE Simulation Model



Heating and cooling power through the year



-Gir et bedre bilde av samtidighet for varme- og kjølebehov

VIRKELIG ENERGIBRUK LIVSVITENSKAP – ESTIMATER– STOR USIKKERHET

Energivare	Nedre grense		Øvre grense	
	kWh	kWh/m²	kWh	kWh/m²
El.	17 223 811	265,0	23 446 704	360,7
Fjernvarme	144 619	2,2	530 466	8,2
Strøm fra solceller	-800 000	-12,3	-640 000	-9,8
Sum levert energi	16 568 430	254,9	23 337 170	359,0

Tabell 6-9 Estimat på forventet samlet behov for levert energi per år

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