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# Geothermal Optimization in Lowex Pilot Buildings

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# Design Philosophy

- Seasonal Coefficient of Performance (SCOP) of 6-10 for heating

Low temperature heating; Small  $\Delta T$  over heat pump

Mean borehole exit fluid temperature of over 5 °C for heating

- Seasonal Energy Efficiency Ratio (SEER) of 80-100 for cooling

Direct ground cooling; Without compressors

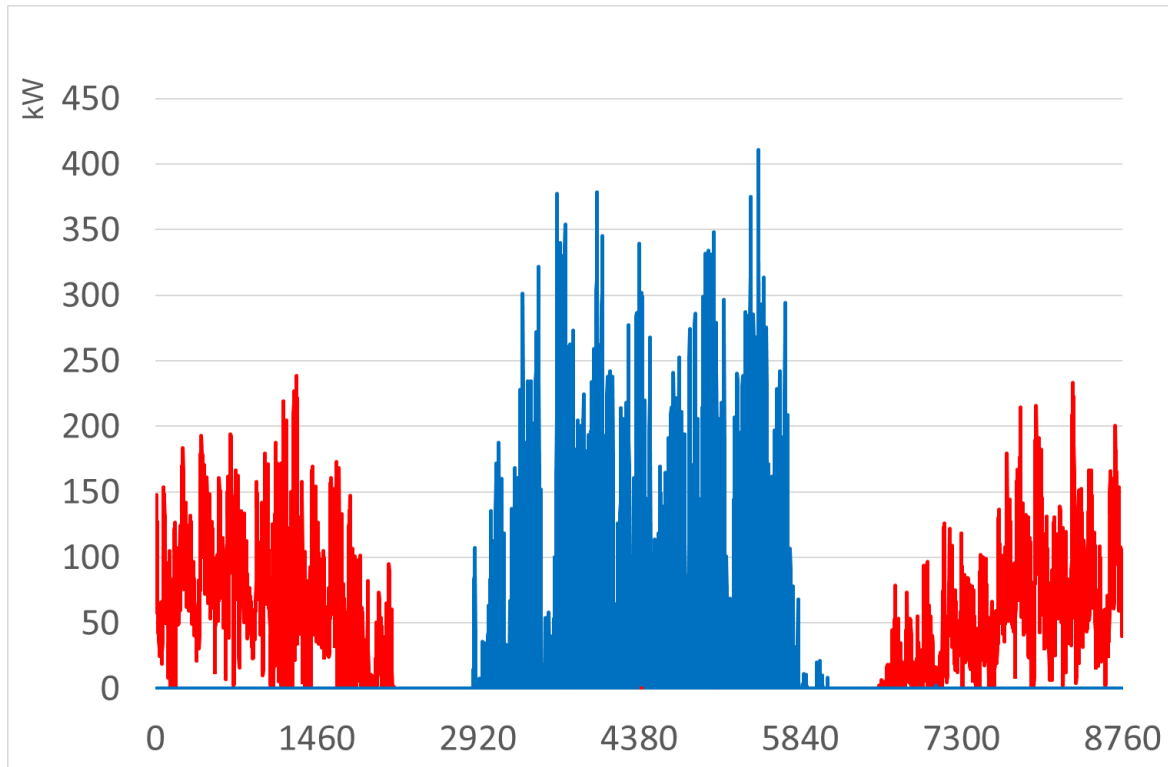
Maximum borehole exit fluid temperature of 15 °C for cooling



## Gullhaug Torg, Nydalen, Oslo



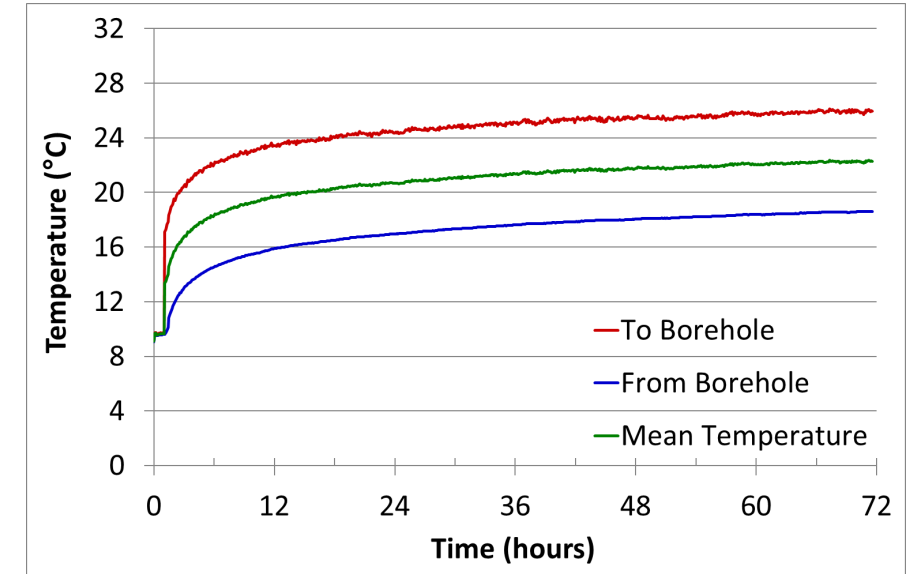
# Building Thermal Loads



| Table: Summary of building heating and cooling demands |         |             |            |              |
|--------------------------------------------------------|---------|-------------|------------|--------------|
| Power / Energy                                         | Offices | Residential | Restaurant | Peak / Total |
| Heating Power (kW)                                     | 160     | 143         | 25         | 238          |
| Cooling Power (kW)                                     | 171     | 127         | 120        | 411          |
| Heating Energy (MWh)                                   | 115     | 144         | 16         | 275          |
| Cooling Energy (MWh)                                   | 87      | 72          | 37         | 195          |



# Thermal Response Test

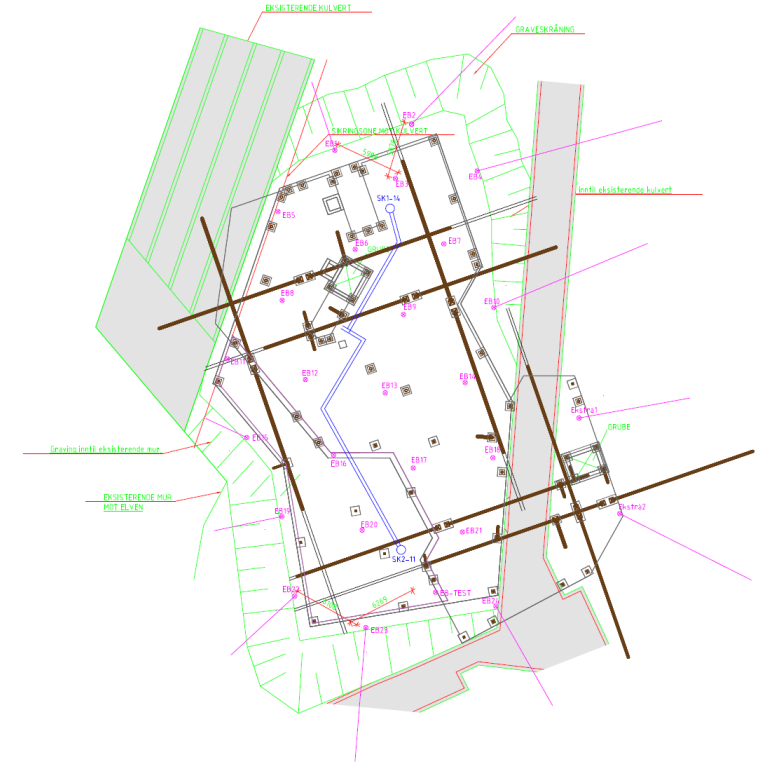


| Table: Measured Thermal Properties |            |
|------------------------------------|------------|
| Undisturbed ground temperature     | 9.0 °C     |
| Ground thermal conductivity        | 2.9 W/m-K  |
| Borehole thermal resistance        | 0.12 m-K/W |

# Borehole Design

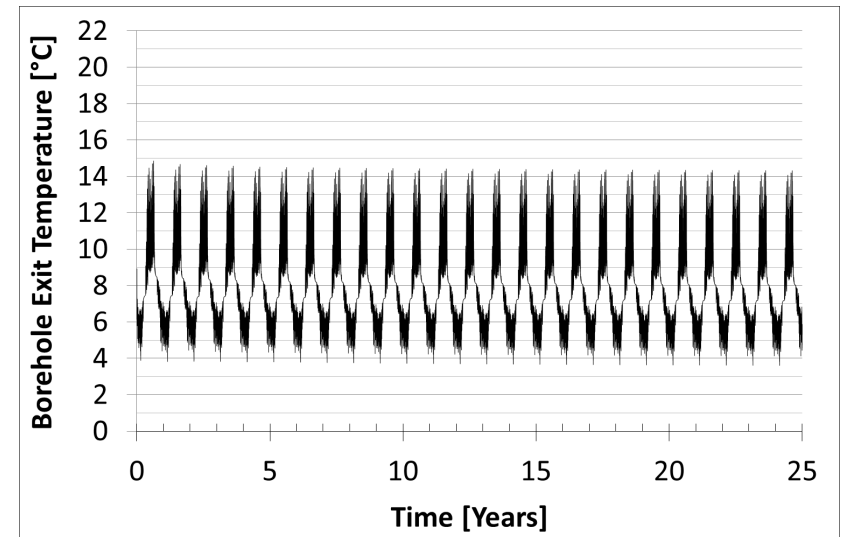
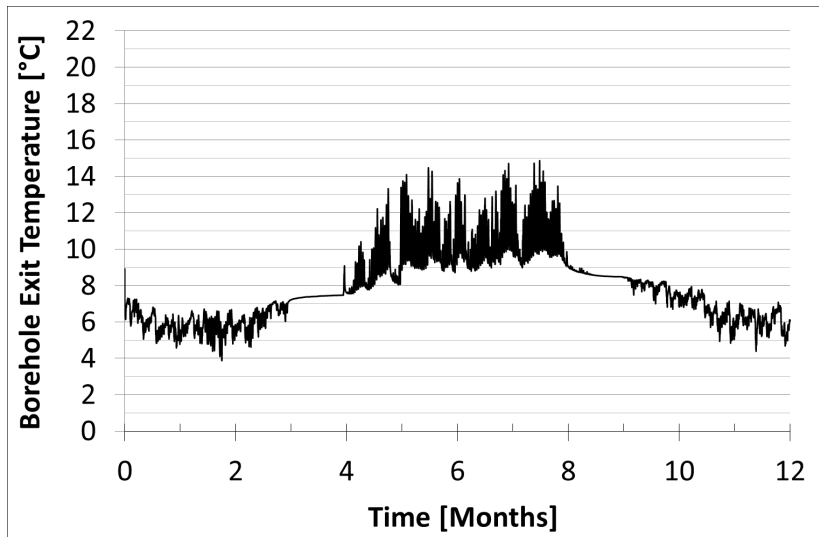
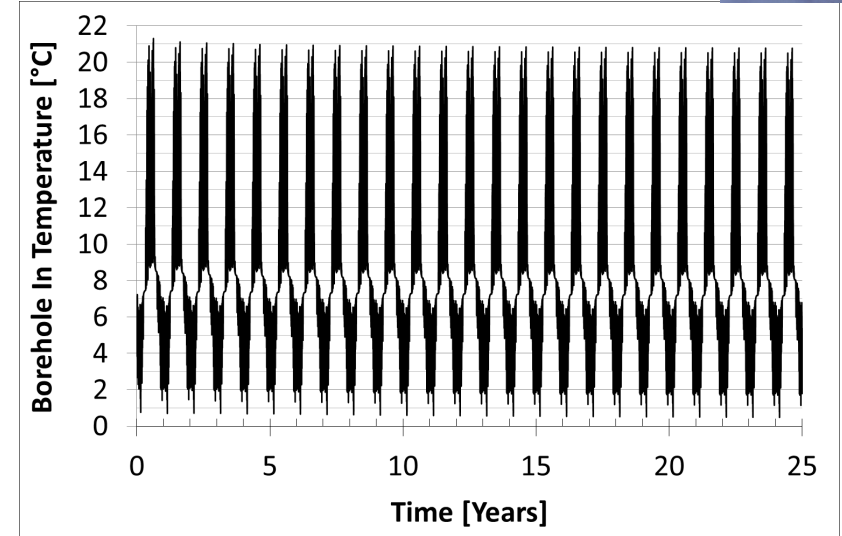
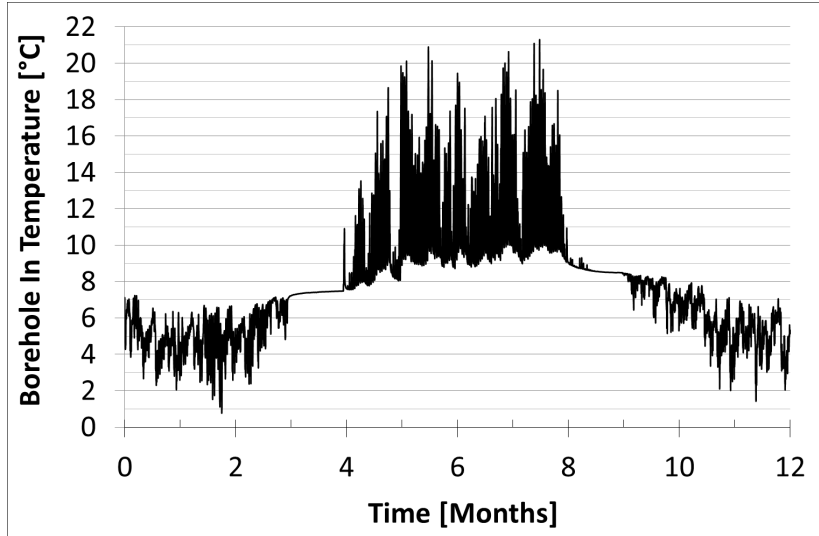


- Superposition Borehole Model (SBM)
- Bioethanol (freezing point  $-5.0\text{ }^{\circ}\text{C}$ )
- Double U-tube (PEM 32x3.0 PN 10 SDR17)
- 115 mm diameter boreholes
- 25 boreholes, each 300 meters deep
- Irregular configuration, with at least 5 m distance





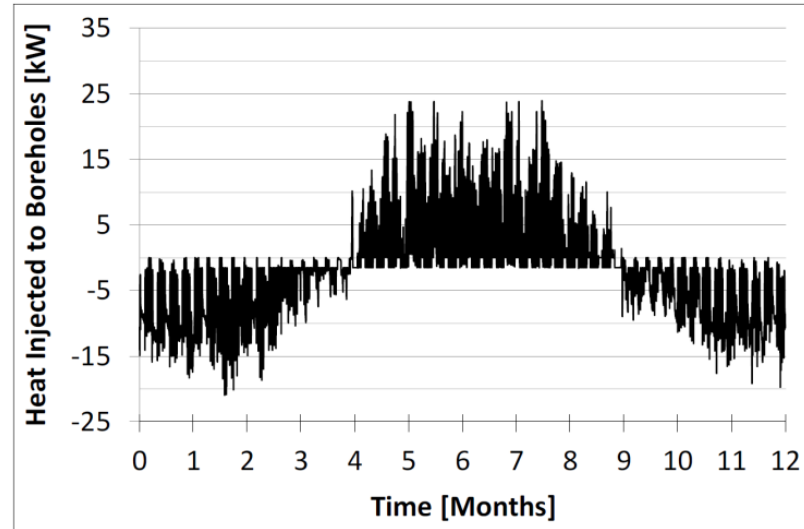
# Borehole Design



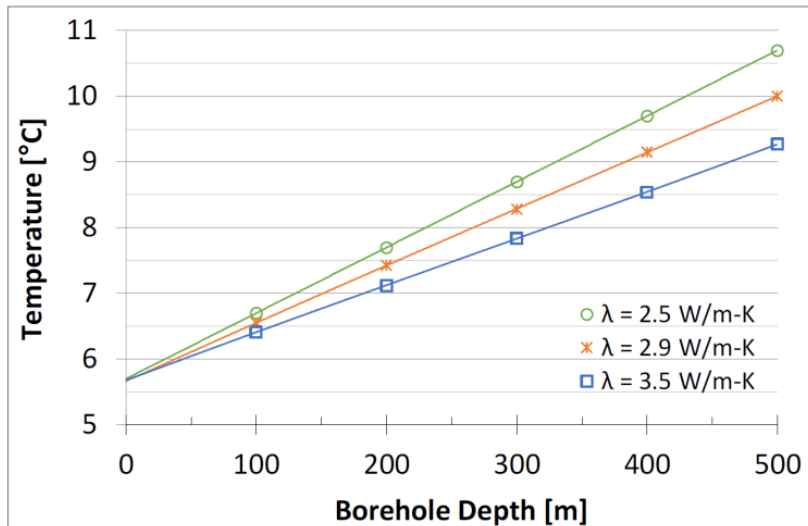


Lia Kindergarten, Oslo

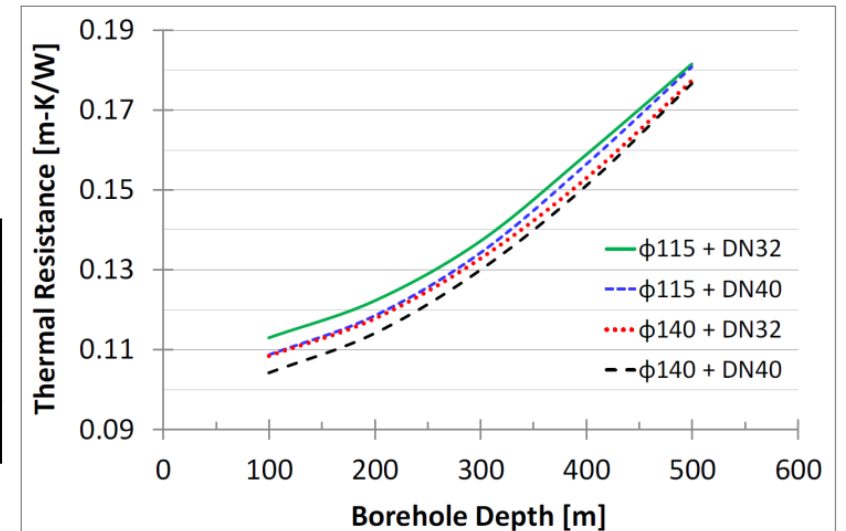
# Design Inputs



- g-value = 0.26 (south)
- g-value = 0.48 (others)



| Table: Estimated Thermal Properties |            |
|-------------------------------------|------------|
| Undisturbed ground temperature      | 8.1 °C     |
| Ground thermal conductivity         | 2.9 W/m-K  |
| Borehole thermal resistance         | 0.14 m-K/W |



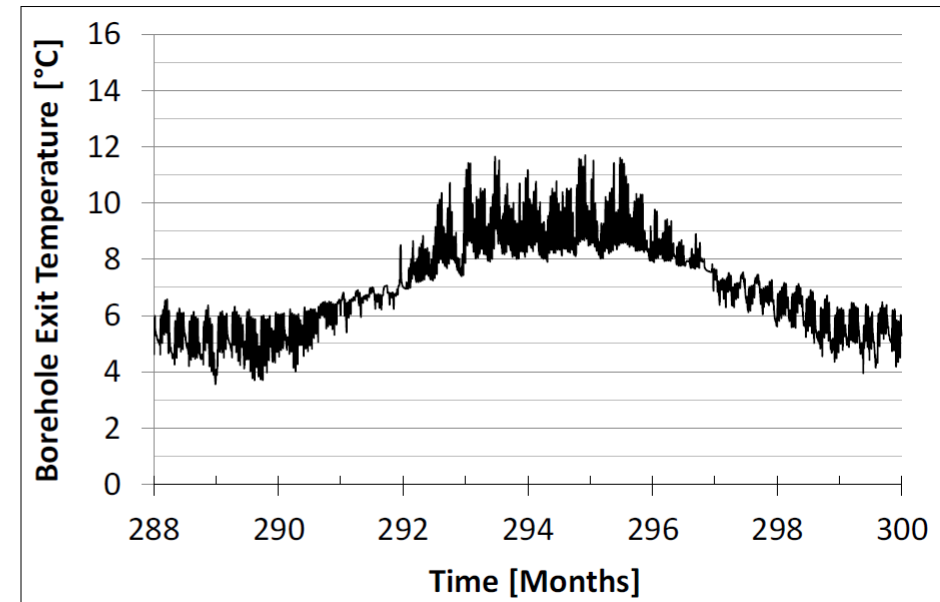
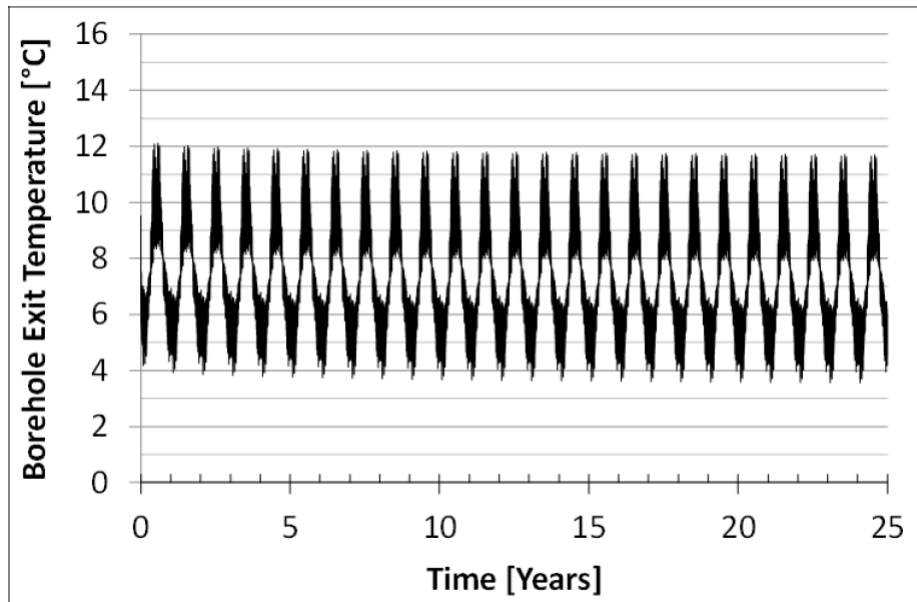


# Base Case Design

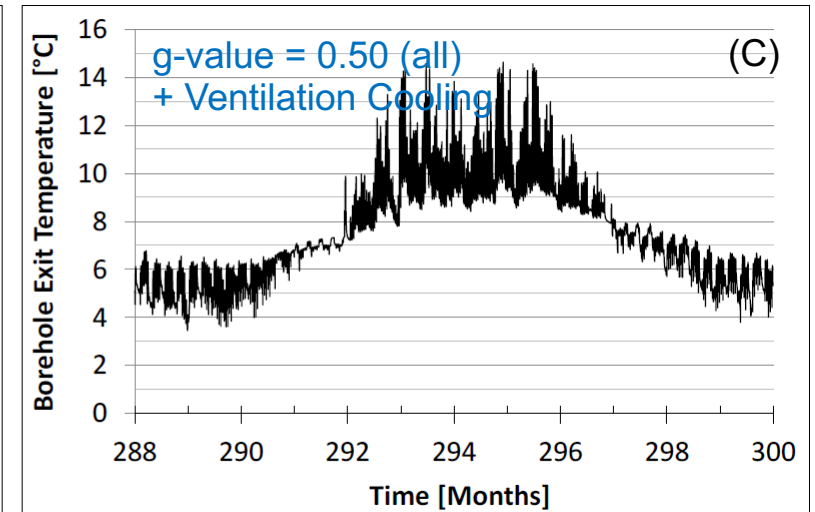
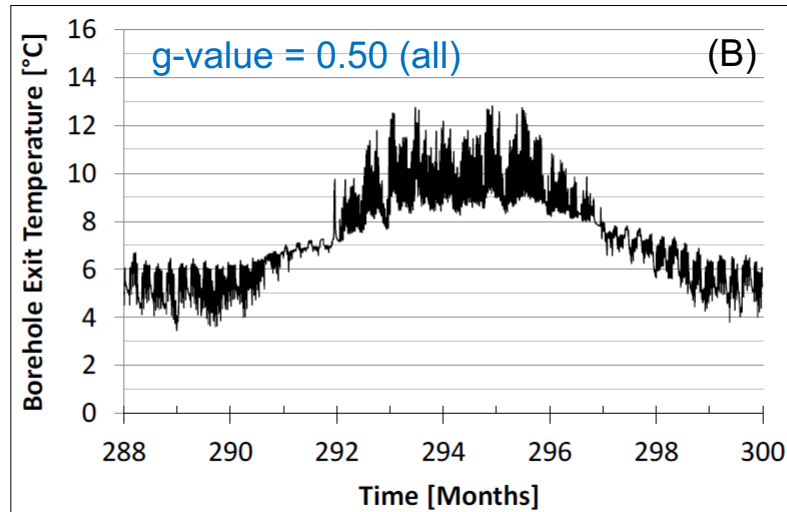
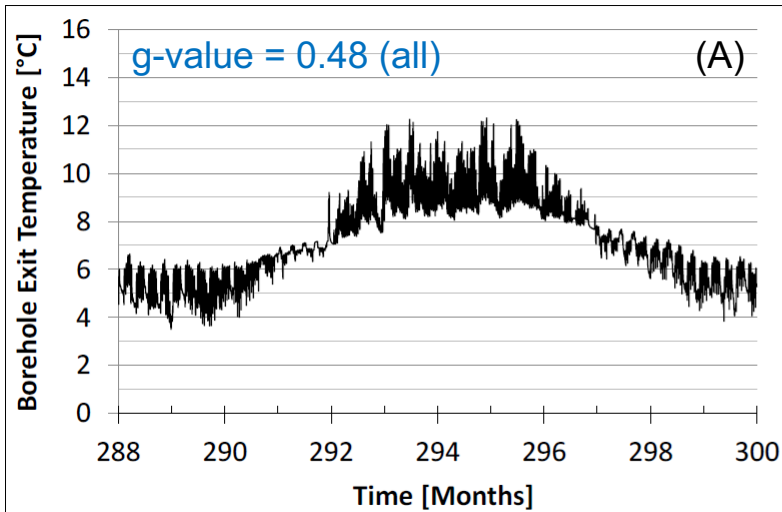
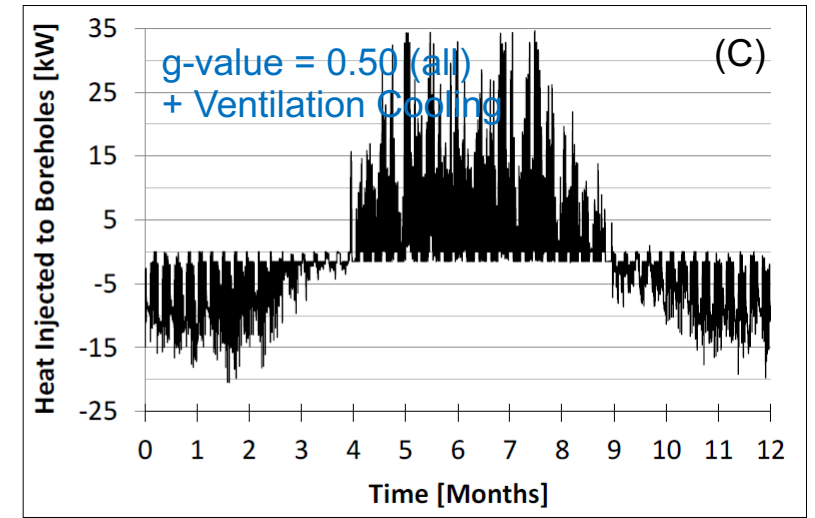
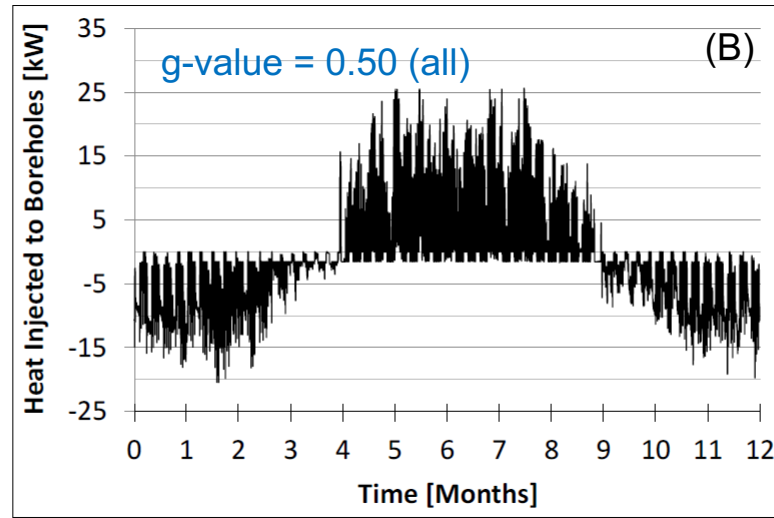
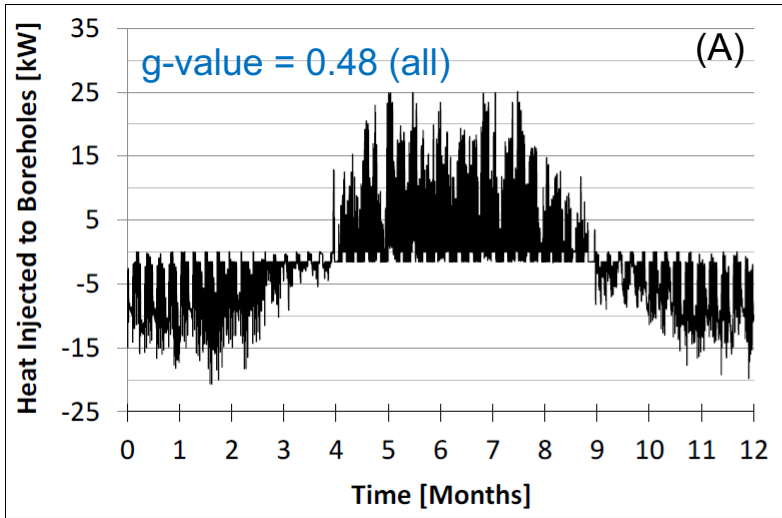


- 3 boreholes, each 280 m deep
- 15 m borehole spacing

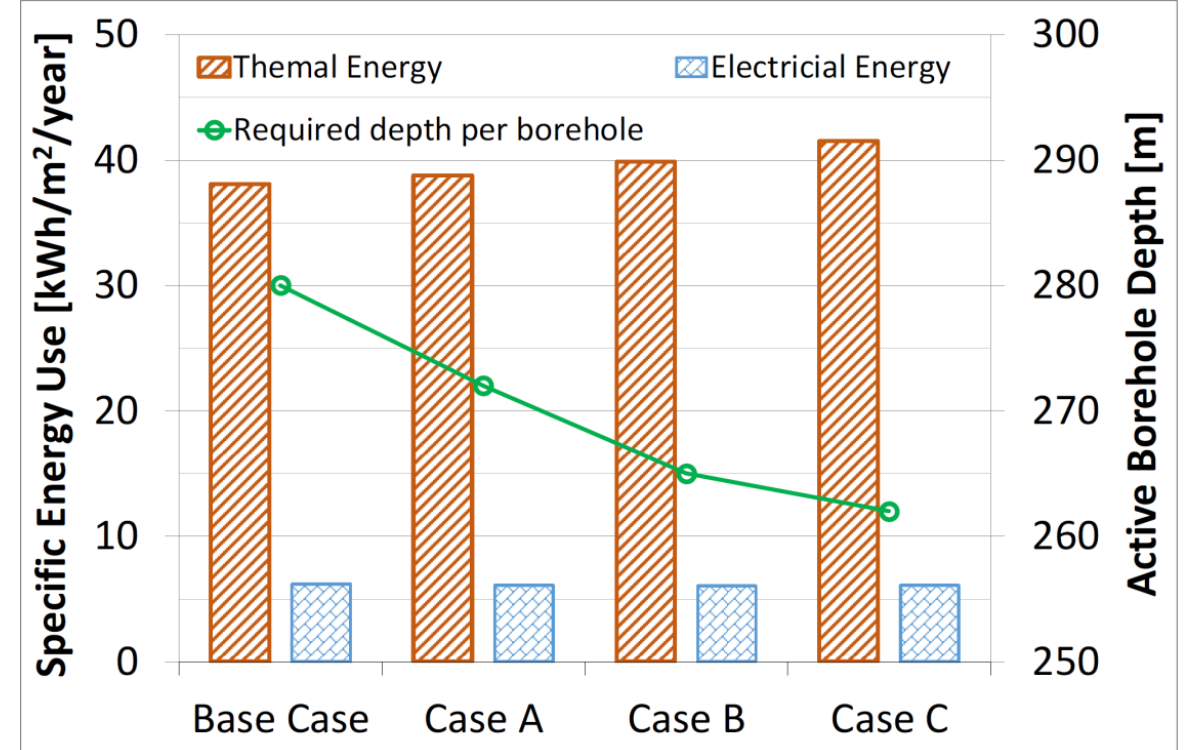
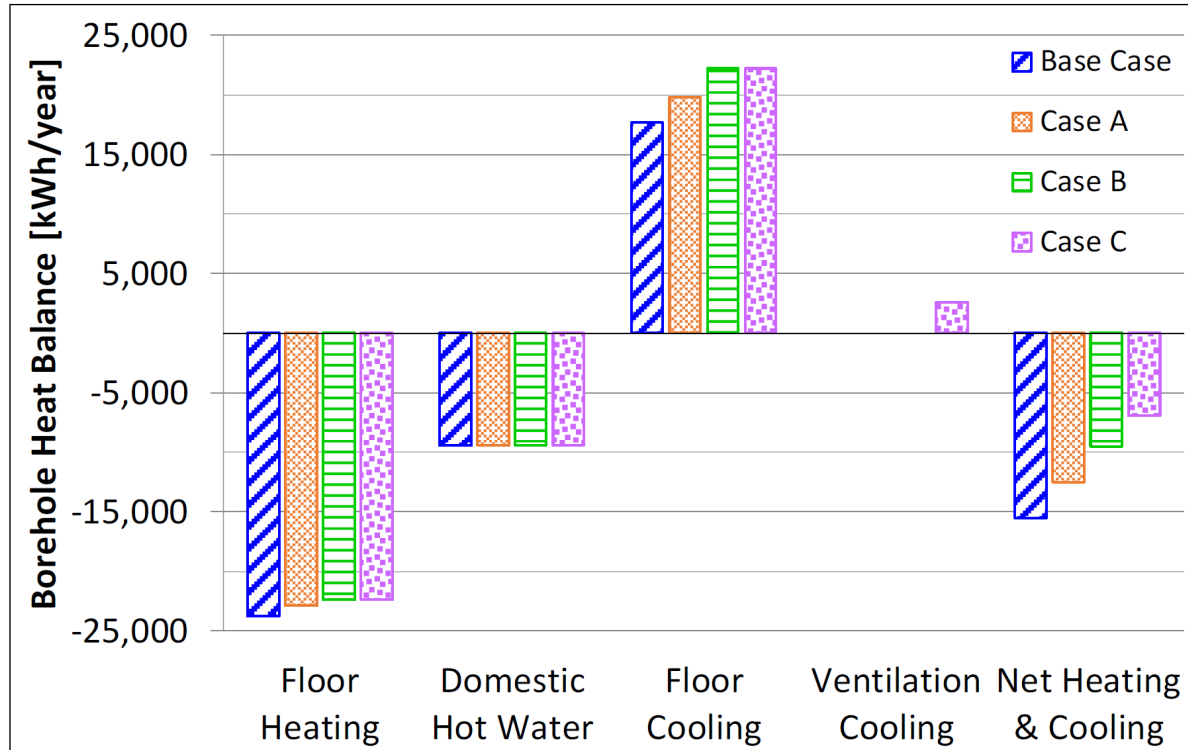
- SCOP = 6.3
- SEER = 86



# Design Optimization

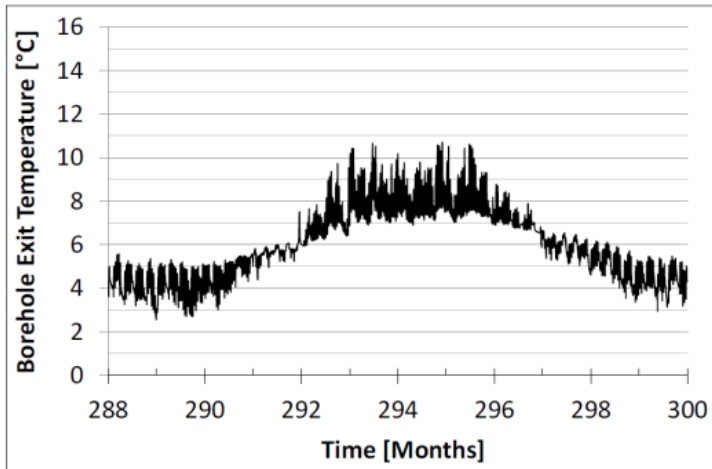


# Design Optimization

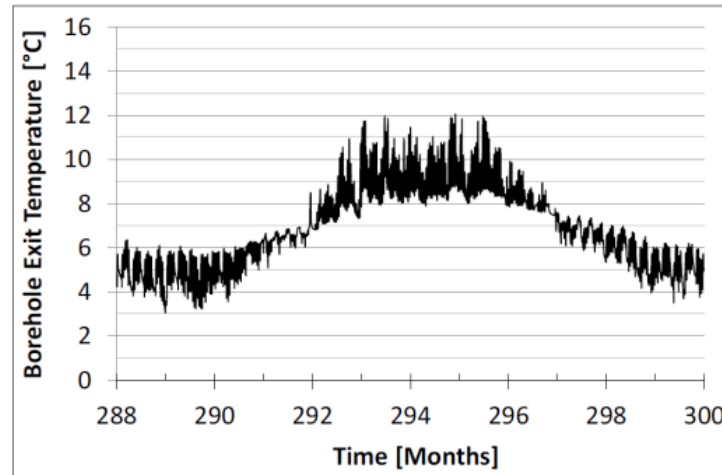




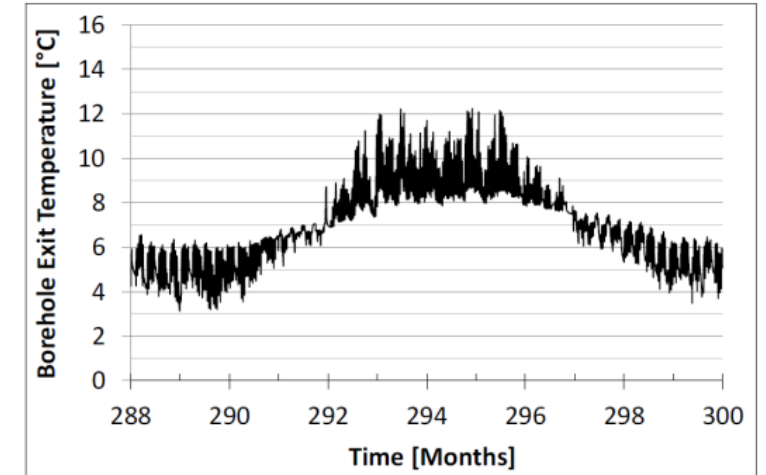
# Design Sensitivity



$T_0 = 7.1\text{ °C}$   
SCOP = -3%  
SEER = +8%



$\lambda = 2.5\text{ W/m-K}$   
SCOP = -1%  
SEER = -4%



$R_b = 0.16\text{ m-K/W}$   
SCOP = -1%  
SEER = -5%



Lindeberg Sykehjem, Oslo

# Lindeberg Sykehjem



Thermal  
Loads

First  
TRT

First  
Design

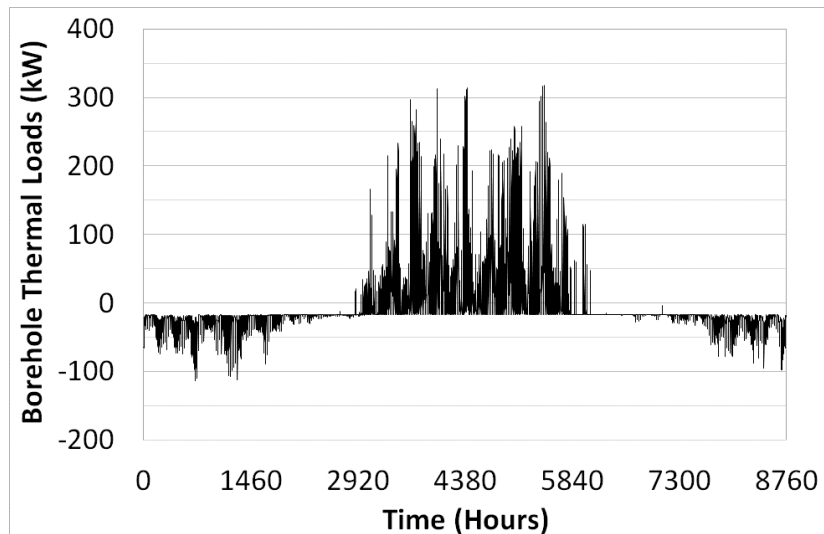
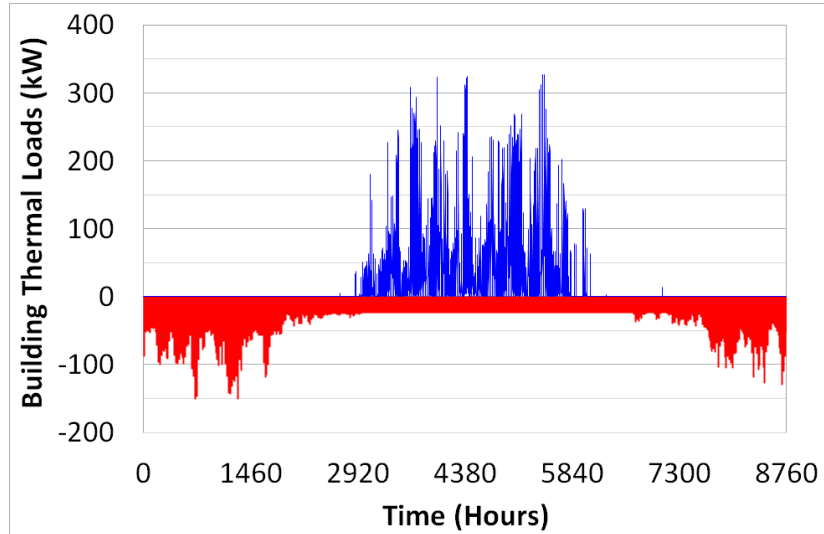
Second  
TRT

Revised  
Thermal  
Loads

Final  
Design



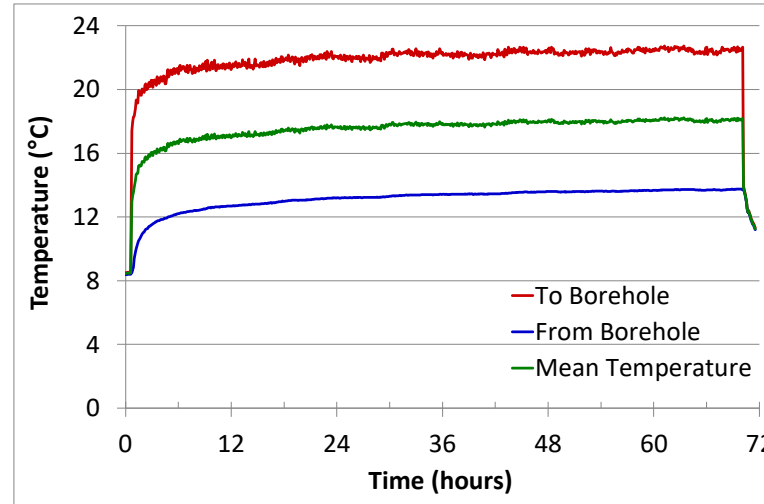
# Thermal Loads



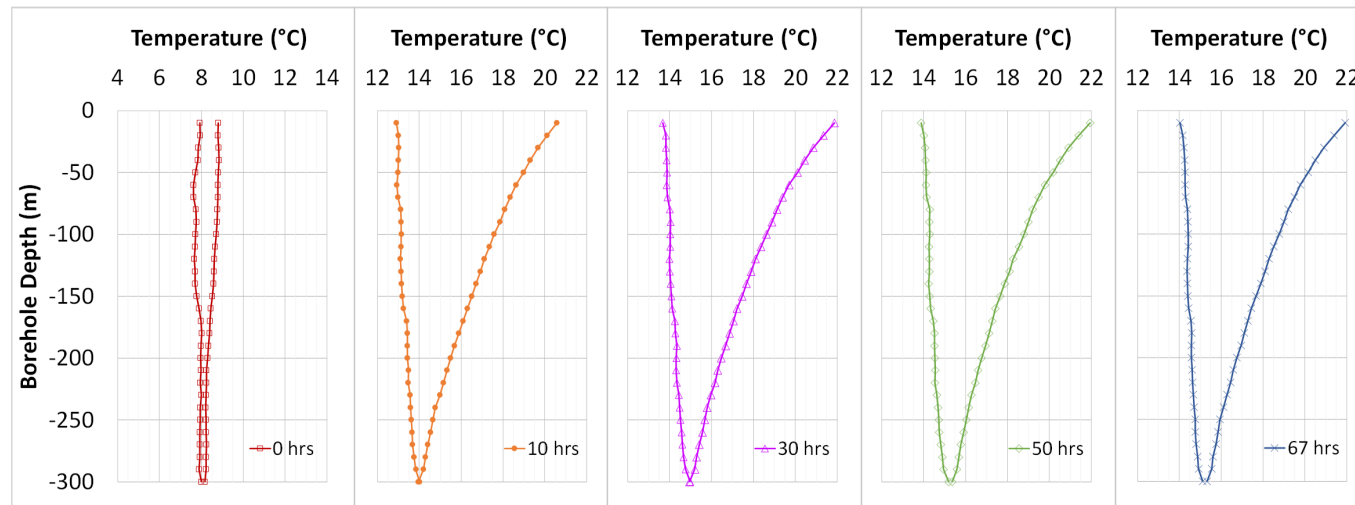
| Table: Summary of heating and domestic hot water (DHW) demands |              |                   |                    |                   |                     |                   |
|----------------------------------------------------------------|--------------|-------------------|--------------------|-------------------|---------------------|-------------------|
| System                                                         | Room Heating |                   | Domestic Hot Water |                   | Total Heating & DHW |                   |
|                                                                | Power (kW)   | Energy (MWh/year) | Power (kW)         | Energy (MWh/year) | Power (kW)          | Energy (MWh/year) |
| Nursery Home                                                   | 128          | 57                | 23                 | 205               | 151                 | 262               |
| Boreholes                                                      | 96           | 43                | 17                 | 152               | 113                 | 197               |

| Table: Summary of cooling demands |              |                   |                         |                   |               |                   |
|-----------------------------------|--------------|-------------------|-------------------------|-------------------|---------------|-------------------|
| System                            | Room Cooling |                   | Ventilation-Air Cooling |                   | Total Cooling |                   |
|                                   | Power (kW)   | Energy (MWh/year) | Power (kW)              | Energy (MWh/year) | Power (kW)    | Energy (MWh/year) |
| Nursery Home                      | 197          | 99                | 130                     | 66                | 327           | 165               |
| Boreholes                         | 202          | 101               | 133                     | 68                | 317           | 169               |

# First Thermal Response Test

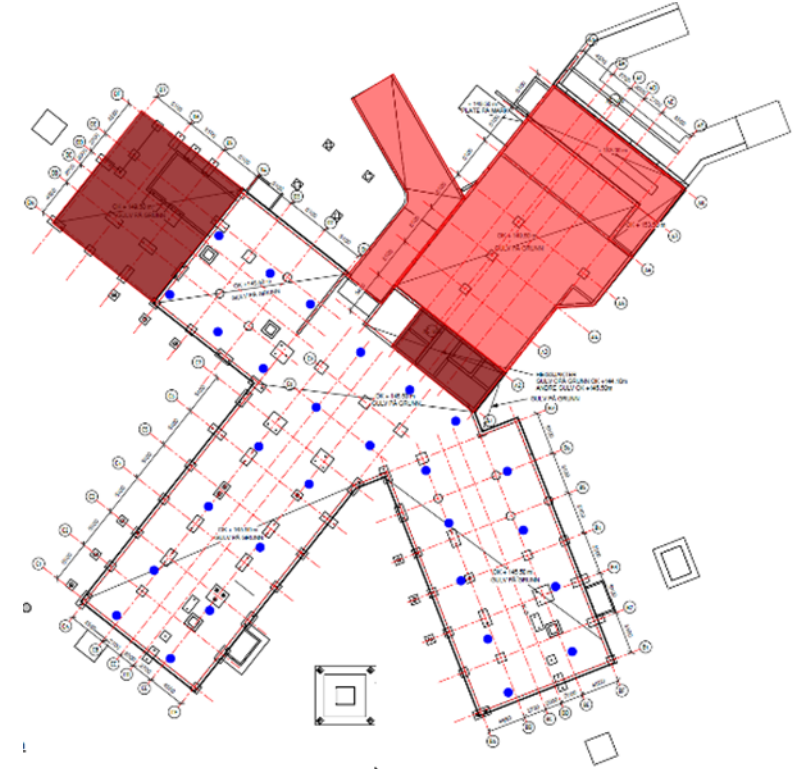


| Table: Measured Thermal Properties |             |
|------------------------------------|-------------|
| Undisturbed ground temperature     | 8.6 °C      |
| Ground thermal conductivity        | 7.3 W/m-K   |
| Borehole thermal resistance        | 0.125 m-K/W |



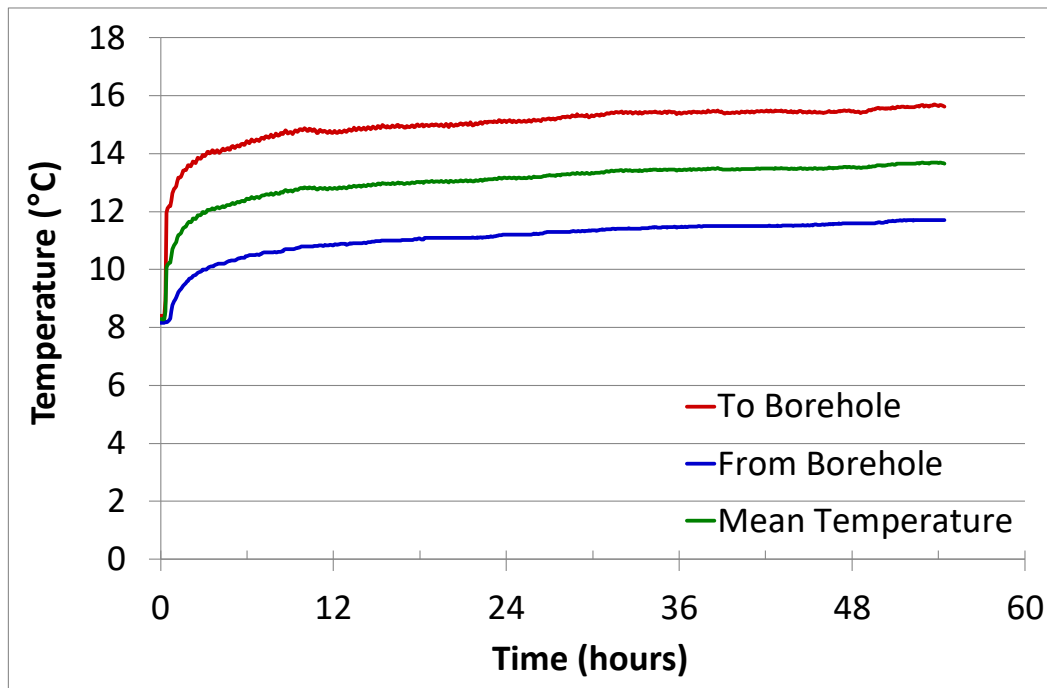
# First Design

- Assuming conservative design inputs
- Superposition Borehole Model (SBM)
- Single U-tube (PEM 40x2.4 PN 10 SDR17)
- 114 mm diameter boreholes
- 28 boreholes, each 300 meters deep
- Irregular configuration, with at least 7.5 m distance
- Bioethanol (freezing point  $-5.0\text{ }^{\circ}\text{C}$ )





# Second Thermal Response Test



## ROTOTEC

CLEVER GEOENERGY PIONEER

| Table: Estimated Thermal Properties |            |
|-------------------------------------|------------|
| Undisturbed ground temperature      | 8.2 °C     |
| Ground thermal conductivity         | 3.59 W/m-K |
| Borehole thermal resistance         | 0.10 m-K/W |

# Actual Borehole Depths

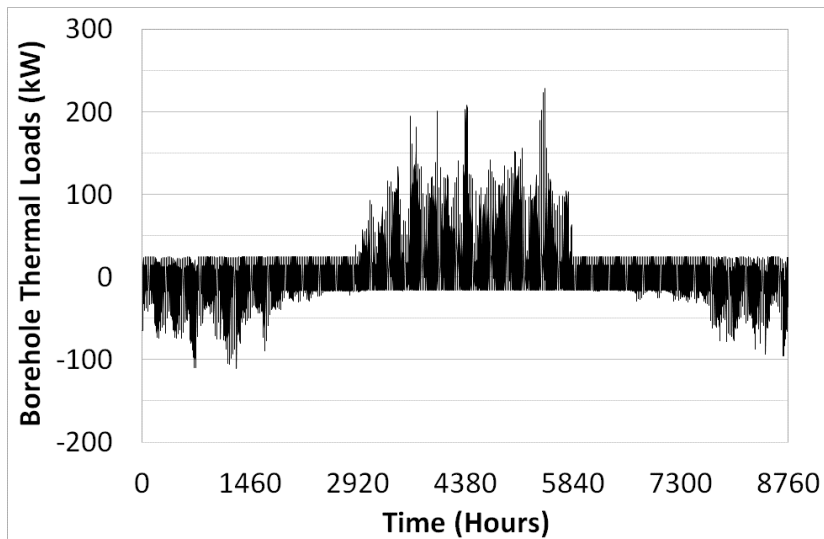
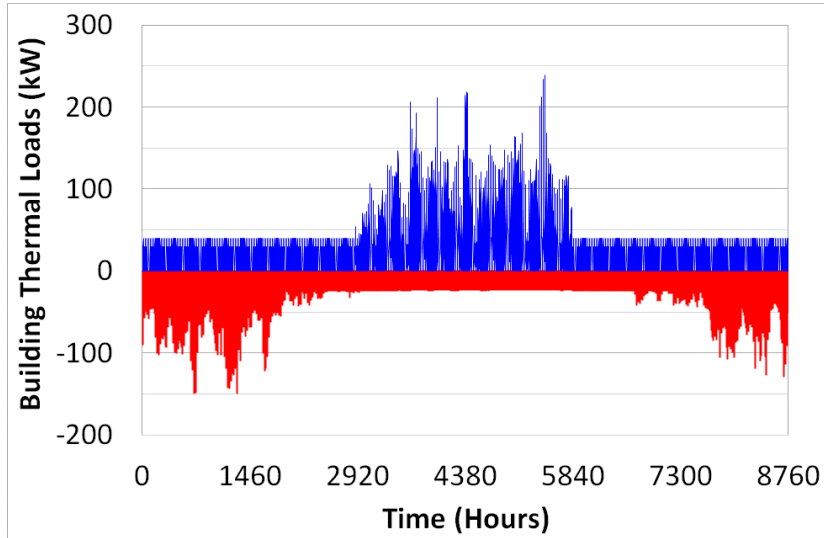


**Table: Planned and actual depths of each borehole**

| Borehole No | Planned Active Depth | Drilled Depth | Collector Length | Water Level | Actual Active Depth |
|-------------|----------------------|---------------|------------------|-------------|---------------------|
| 1           | 300                  | 300           | 300              | 0           | 300                 |
| 2           | 300                  | 282           | 280              | 0           | 280                 |
| 3           | 300                  | 300           | 0                | 0           | 0                   |
| 4           | 300                  | 300           | 300              | 9           | 291                 |
| 5           | 300                  | 300           | 275              | 9           | 266                 |
| 6           | 300                  | 300           | 300              | 5           | 295                 |
| 7           | 300                  | 300           | 300              | 9           | 291                 |
| 8           | 300                  | 300           | 300              | 9           | 291                 |
| 9           | 300                  | 300           | 300              | 9           | 291                 |
| 10          | 300                  | 300           | 300              | 0           | 300                 |
| 11          | 300                  | 300           | 271              | 0           | 271                 |
| 12          | 300                  | 300           | 300              | 10          | 290                 |

|              |              |              |              |     |              |
|--------------|--------------|--------------|--------------|-----|--------------|
| 13           | 300          | 282          | 282          | 5   | 277          |
| 14           | 300          | 282          | 282          | 8   | 274          |
| 15           | 300          | 300          | 300          | 5   | 295          |
| 16           | 300          | 300          | 300          | 6   | 294          |
| 17           | 300          | 300          | 270          | 5   | 265          |
| 18           | 300          | 300          | 300          | 5   | 295          |
| 19           | 300          | 300          | 300          | 0   | 300          |
| 20           | 300          | 280          | 280          | 9   | 271          |
| 21           | 300          | 300          | 300          | 9   | 291          |
| 22           | 300          | 300          | 300          | 9   | 291          |
| 23           | 300          | 300          | 300          | 8   | 292          |
| 24           | 300          | 300          | 200          | 8   | 192          |
| 25           | 300          | 202          | 200          | 8   | 192          |
| 26           | 300          | 300          | 300          | 9   | 291          |
| 27           | 300          | 300          | 260          | 9   | 251          |
| 28           | 300          | 300          | 300          | 0   | 300          |
| <b>Total</b> | <i>8,400</i> | <i>8,228</i> | <i>7,700</i> | --- | <i>7,537</i> |

# Revised Thermal Loads



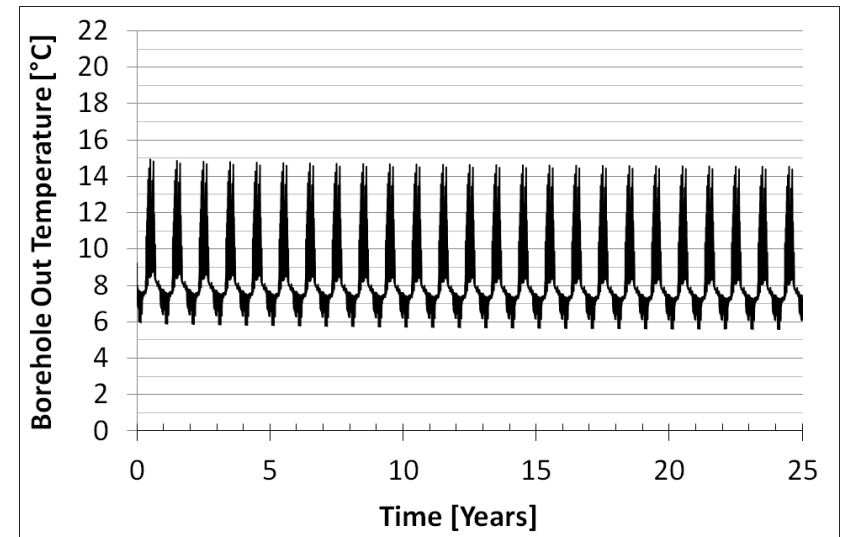
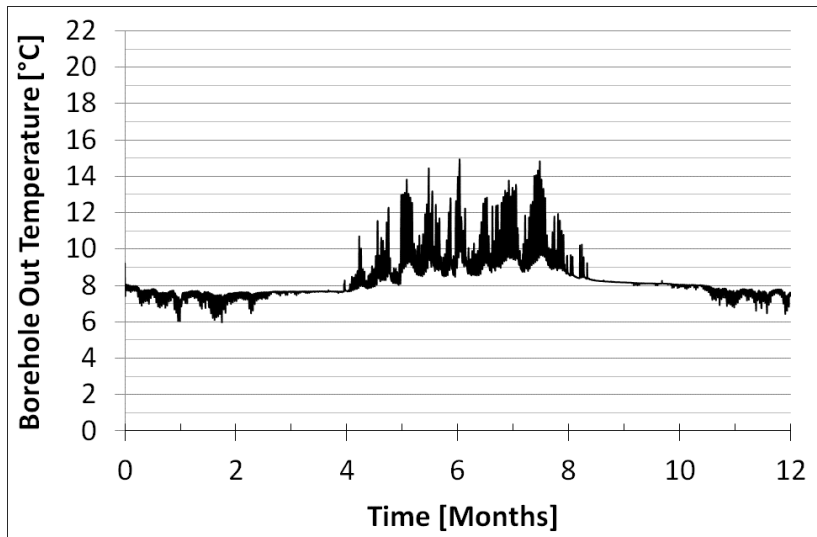
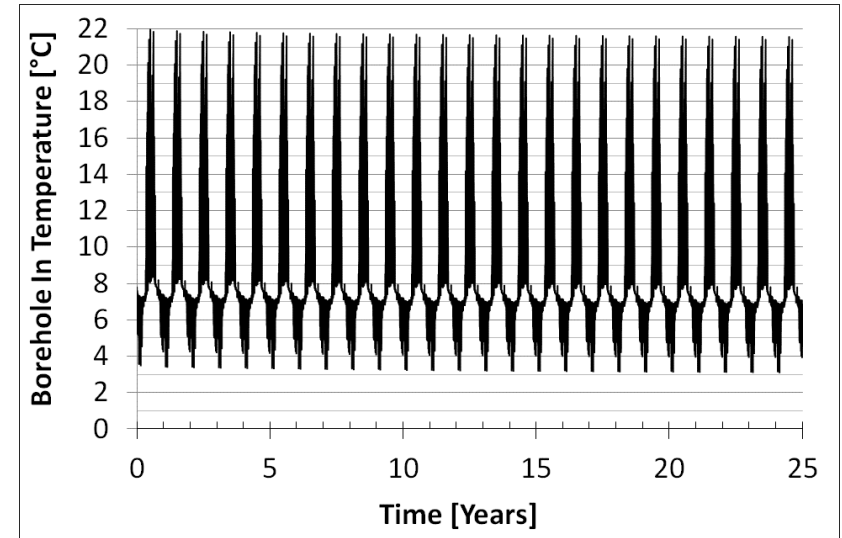
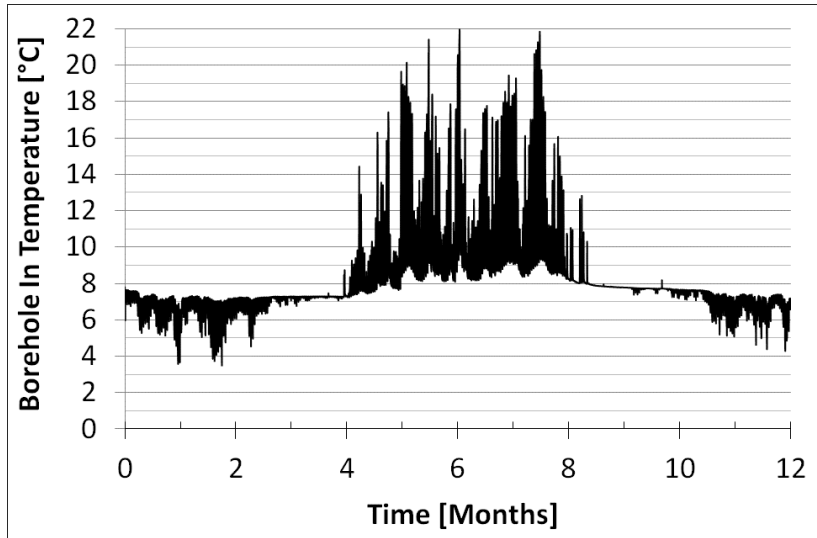
**Table: Summary of heating and domestic hot water (DHW) demands for final design**

| System       | Room Heating |                   | Domestic Hot Water |                   | Total Heating & DHW |                   |
|--------------|--------------|-------------------|--------------------|-------------------|---------------------|-------------------|
|              | Power (kW)   | Energy (MWh/year) | Power (kW)         | Energy (MWh/year) | Power (kW)          | Energy (MWh/year) |
| Nursery Home | 127          | 59                | 23                 | 205               | 150                 | 264               |
| Boreholes    | 95           | 45                | 16                 | 138               | 111                 | 182               |

**Table: Summary of cooling demands for final design**

| System       | Room Cooling |                   | Ventilation-Air Cooling |                   | Total Cooling |                   |
|--------------|--------------|-------------------|-------------------------|-------------------|---------------|-------------------|
|              | Power (kW)   | Energy (MWh/year) | Power (kW)              | Energy (MWh/year) | Power (kW)    | Energy (MWh/year) |
| Nursery Home | 199          | 79                | 40                      | 146               | 239           | 225               |
| Boreholes    | 203          | 80                | 41                      | 149               | 229           | 230               |

# Final Design





# Take Aways

- Robust system
- Energy efficient (High SCOP and SEER)
- Sensitive to building energy demands (simulations)
- Constrained by drilling area, onsite conditions

# Publications



ARCHITECTURAL ENGINEERING AND DESIGN MANAGEMENT  
2019, VOL. 15, NO. 3, 181–195  
<https://doi.org/10.1080/17452007.2018.1555088>



OPEN ACCESS Check for updates

## Design optimization of the borehole system for a plus-Energy kindergarten in Oslo, Norway

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### ABSTRACT

This paper presents the case study of a newly constructed 1600 m<sup>2</sup> kindergarten building in Oslo, Norway. The building has been designed within the framework of the Norwegian Research Council Project LowEx, which aims at engineering solutions to achieve a seasonal coefficient of performance (SCOP) of 6–10 for heating, a seasonal energy efficiency ratio (SEER) of 80–100 for cooling, and an 80% reduction in the purchased electric energy for heating and cooling of the buildings. Several architectural and technical measures have been implemented in the case study building to meet these requirements. This paper first provides an account of the design measures implemented in the building to achieve the ambitious energy performance targets. It then focuses on the design of the ground source heating and cooling system for the building and presents the preliminary design of the borehole system to provide low-temperature heating and high-temperature cooling to the kindergarten. The possibility of improving the borehole system design by optimizing the solar heat gains through the building envelope to balance the ground thermal loads is explored next. Finally, the effect of uncertainties in the design input values of ground thermal conductivity, effective borehole thermal resistance, and undisturbed ground temperature on the final design of the borehole system is evaluated.

### ARTICLE HISTORY

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### KEYWORDS

Heating and cooling; design;  
building energy use; ground-  
source; energy efficiency;  
building envelope

### Introduction

Ground-source heating and cooling systems are among the most environmentally clean heating and cooling technologies available today (Rees, 2016). In recent years, optimizing the design and sizing of the ground-source systems to further enhance their environmental and operational performance has been a topic of great interest and extensive research (Alavy, Nguyen, Leong, & Dworkin, 2013; Javed, 2012; Javed & Spitler, 2017; Kavanaugh & Rafferty, 2014; Ozbek, Yavuzturk, & Pinder, 2015; Rees, 2016). Attention has largely focused on more accurate estimation and calculation of design inputs (e.g. Claesson & Javed, 2018; Fujii et al., 2009), development of computationally efficient design methods (e.g. He, Rees, & Shao, 2011; Javed & Claesson, 2011), and determination of optimum ground loop lengths (e.g. Cui, Zhou, & Liu, 2015; Hackel & Pertzborn, 2011).

The design of the ground-source heating and cooling system for a building depends primarily on the thermal heating and cooling demands of the building, and the thermal properties of the ground and borehole heat exchanger. Thermal demands of a building include space heating, space cooling and domestic hot water (DHW). In general, higher building thermal demands lead to larger borehole

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## Borehole System Design for Lindeberg Sykehjem, Oslo

Saqib Javed

Lund,  
October 2018.



**CHALMERS**

BUILDING SERVICES ENGINEERING

## Thermal Response Test Report for Lindebergveien 10, Oslo, Norway

Saqib Javed, Håkan Larsson

Göteborg  
April 2018

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