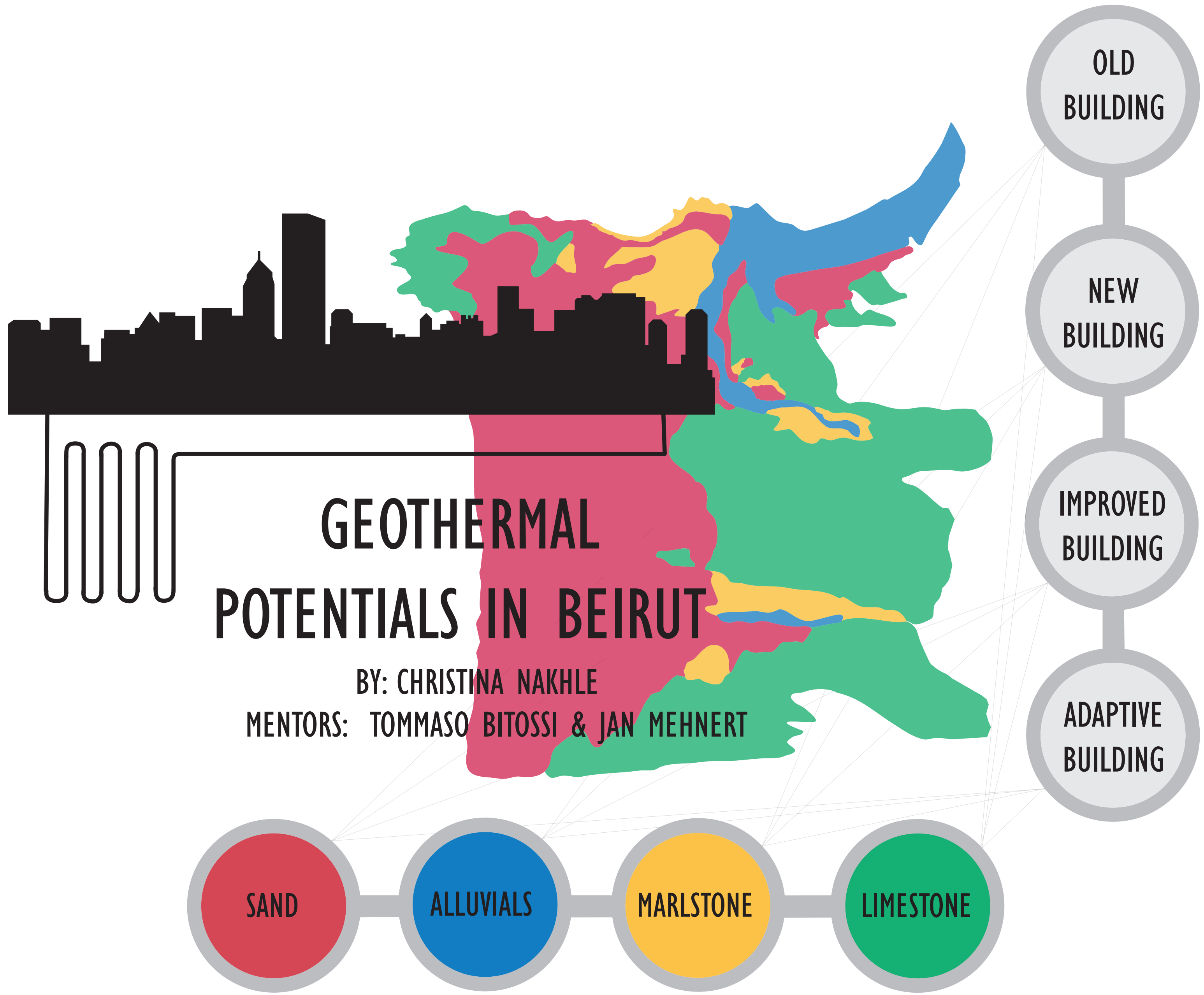

Geothermal Potentials in Beirut

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With the help of:
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Jan Mehnert

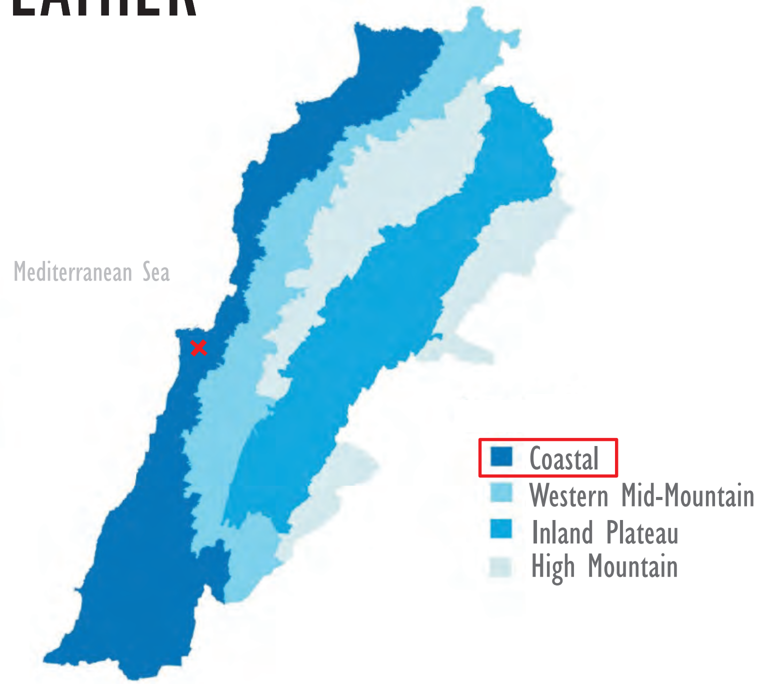
TARGET

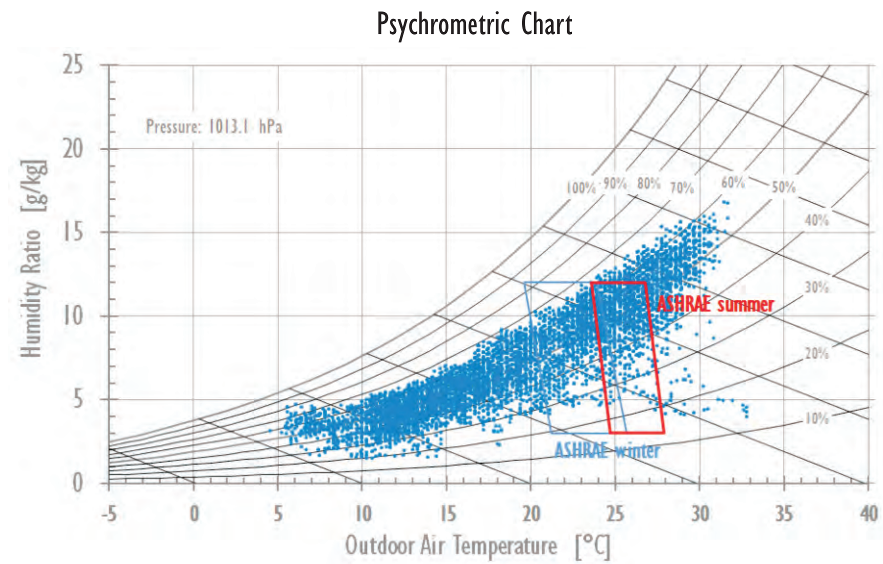
A GUIDELINE FOR GEOTHERMAL SYSTEMS IN BEIRUT:
FOR DISTINCT BUILDING TYPOLOGIES AND SOIL PROFILES.

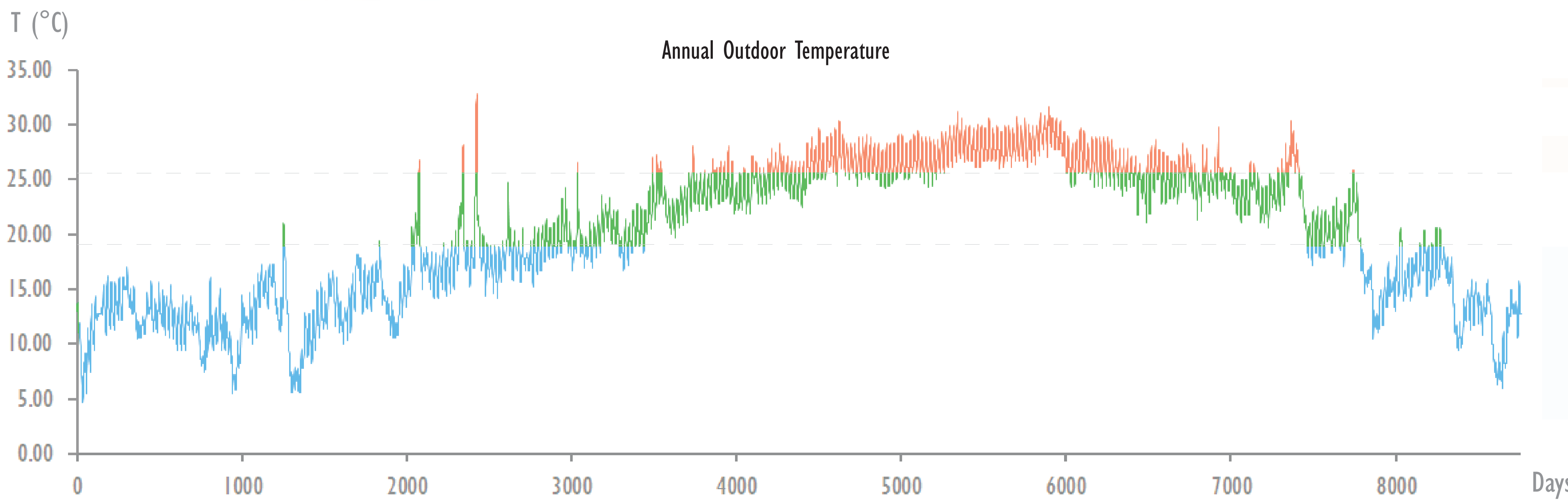
Capital of Lebanon: Beirut

The target of this project is to create a guideline that people can use when evaluating a geothermal system in different locations in Beirut and for different building typologies.

LOCATION & WEATHER







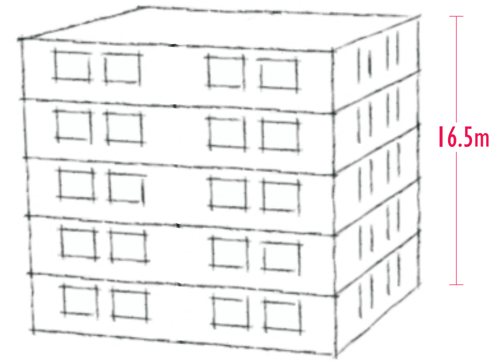
Lebanon is located on the East of the Mediterranean Sea and therefore has a moderate climate.

Outdoor temperatures range from 4°C to 34°C.

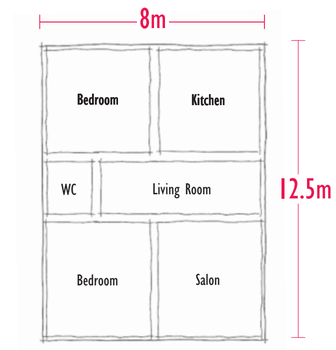
Humidity is generally not a big issue.

BUILDINGS

Four building typologies:



Building



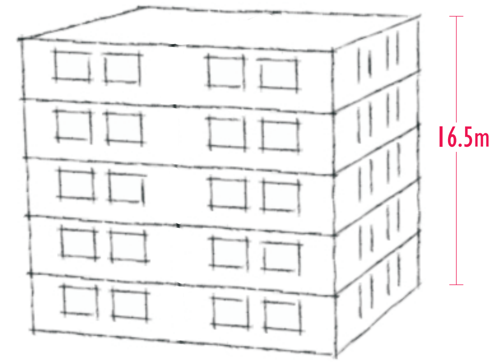
Floor Plan

Due to the diversity of construction methods in Lebanon and the lack of thermal codes, it is hard to generalize and create one builing prototype.

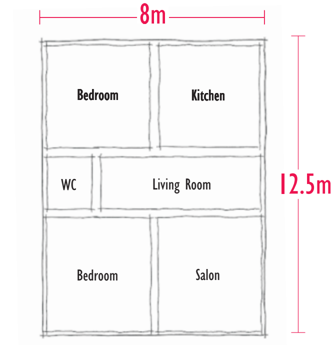
Therefore 4 different building typologies where chosen. All the buildings have the same geometry as shown in the sketches with a total built area of $1000m^2$.

BUILDINGS

Four building typologies:



Building



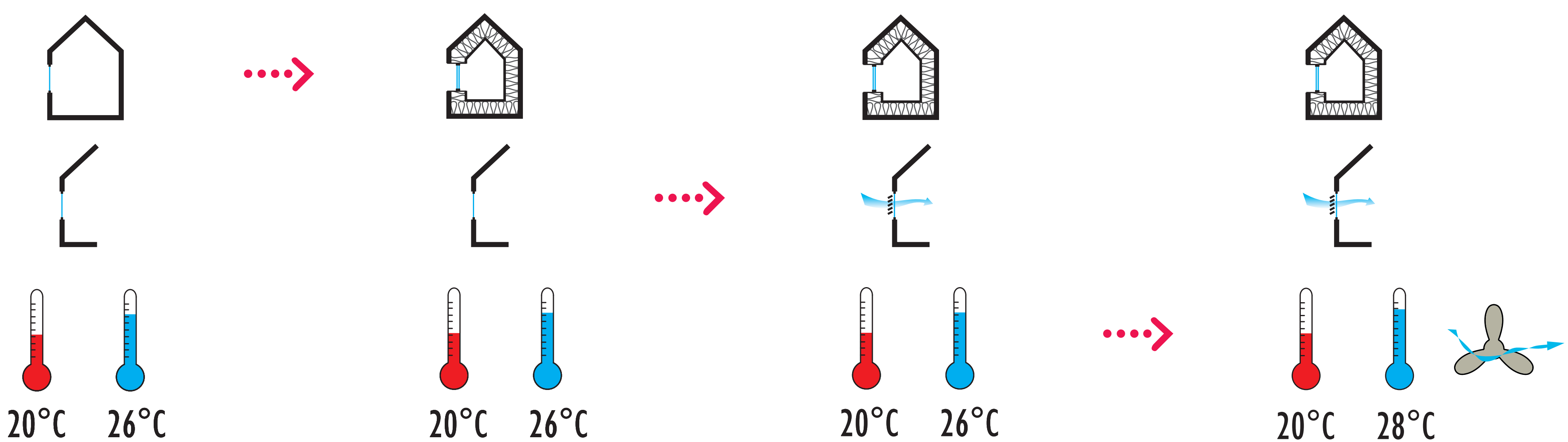
Floor Plan

OLD BUILDING
Past building method

NEW BUILDING
Current building methods

IMPROVED BUILDING
Building with passive approach

ADAPTIVE BUILDING
Building with new user mindset



1. The Old Building: This is the most commonly found building in Beirut. Very bad envelope and no strategies to reduce solar gains.

2. The New Building: Has an improved envelope however still no solar gain reduction.

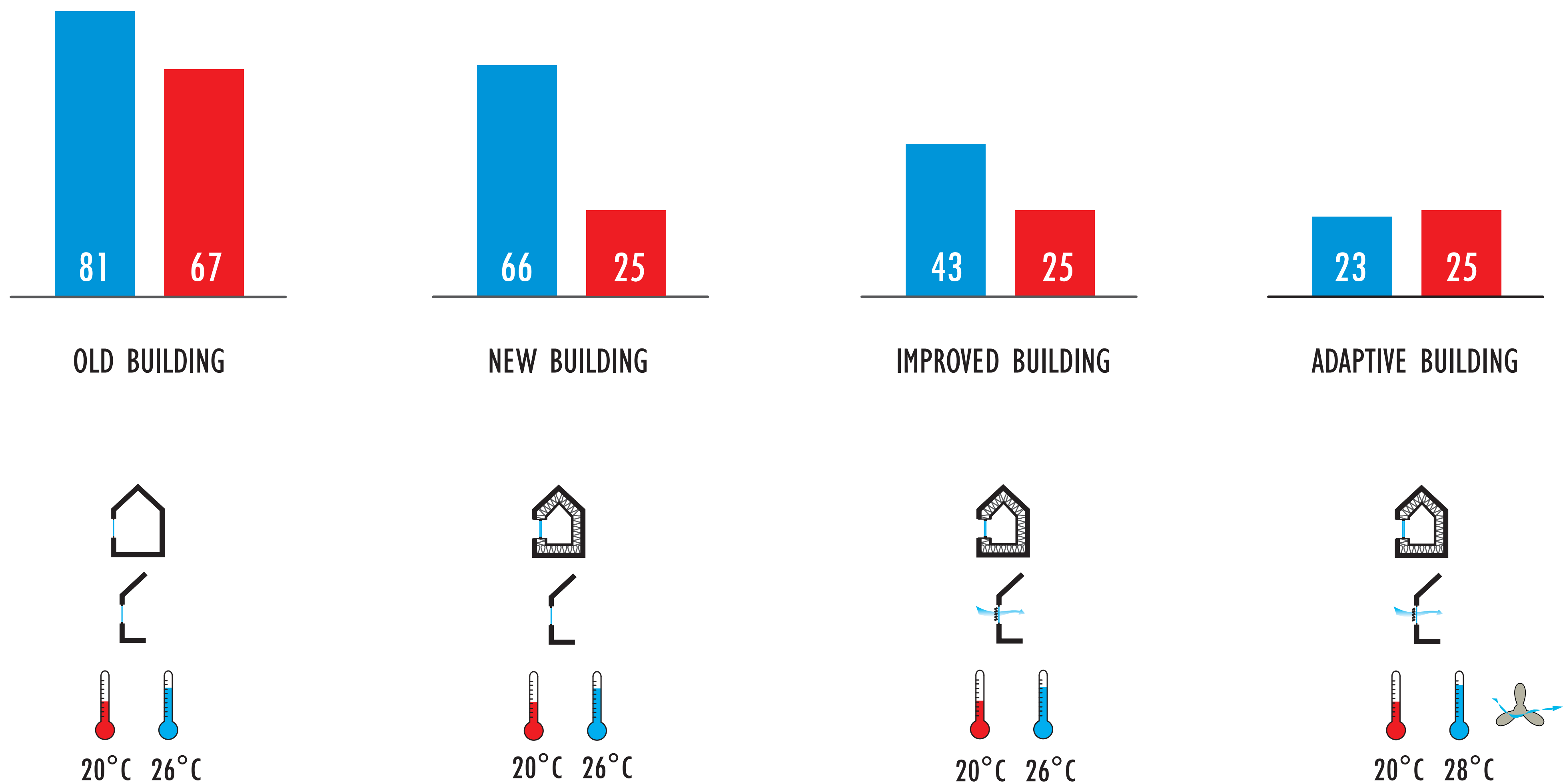
3. The Improved Building: Employs passive strategies such as shading and natural ventilation.

4. The Adaptive Building: Targets the user mindset by increasing the cooling setpoint to 28°C while providing a ceiling fan to maintain constant comfort levels.

BUILDING ENERGY DEMAND

Cooling Demand (kWh/m²/year)

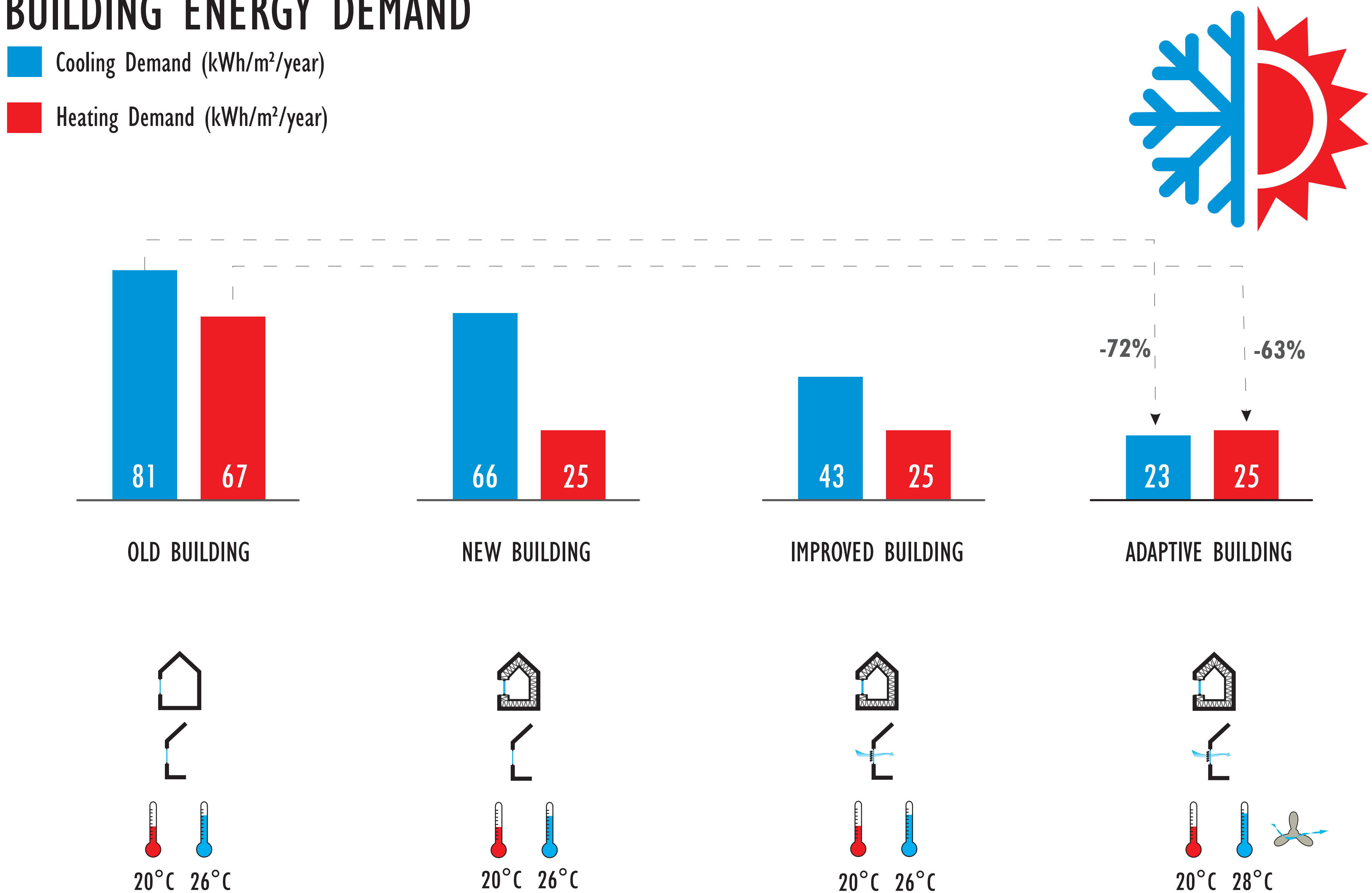
Heating Demand (kWh/m²/year)



Ideal heating and cooling was used to determine the total heating and cooling energy required by each building. The heating loads include domestic hot water demand.

The heating and cooling setpoints for each of the cases are shown. With these setpoints, the following histograms show the energy demand of the buildings in kWh/m²/year.

BUILDING ENERGY DEMAND



Shifting from the old building to the adaptive building reduces 72% of the cooling energy and 63% of the heating energy.

Providing external shading and increasing the cooling setpoint are the two factors which most impact the cooling energy demand.

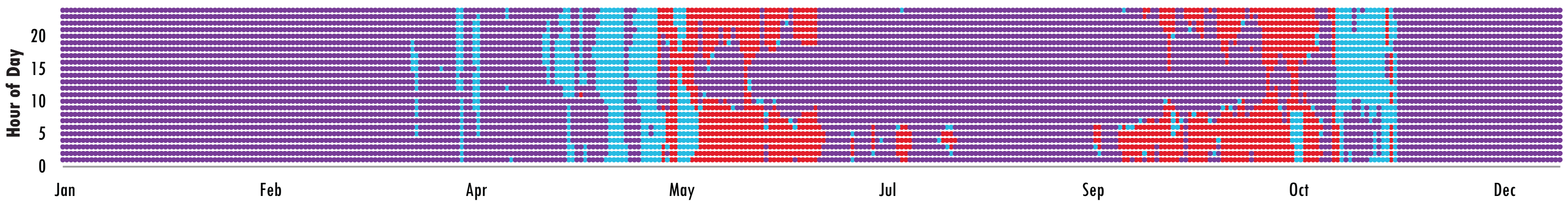
Insulating the building almost cancels the heating demand since 23kWh/m² is the annual energy required to heat water for domestic use.

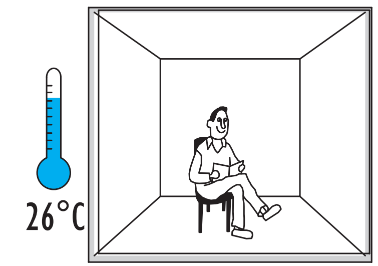
COMFORT

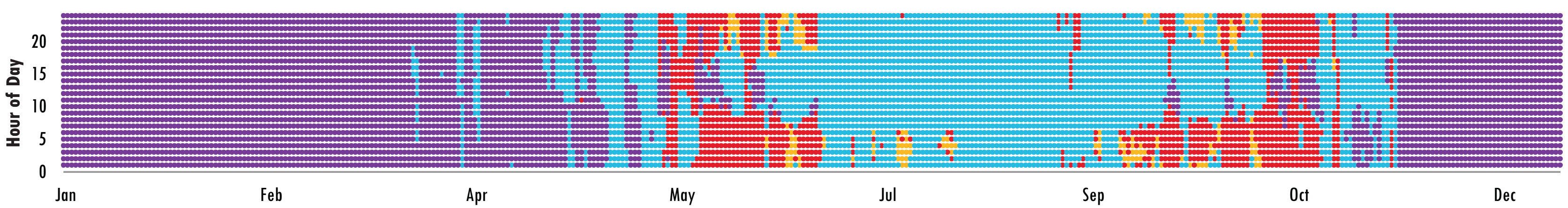
Study the effect of increasing the cooling setpoint and providing air speed.

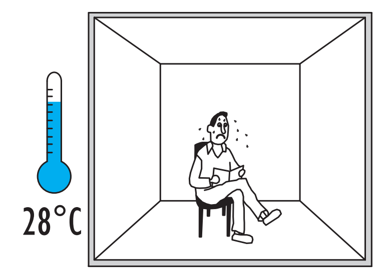
LEGEND

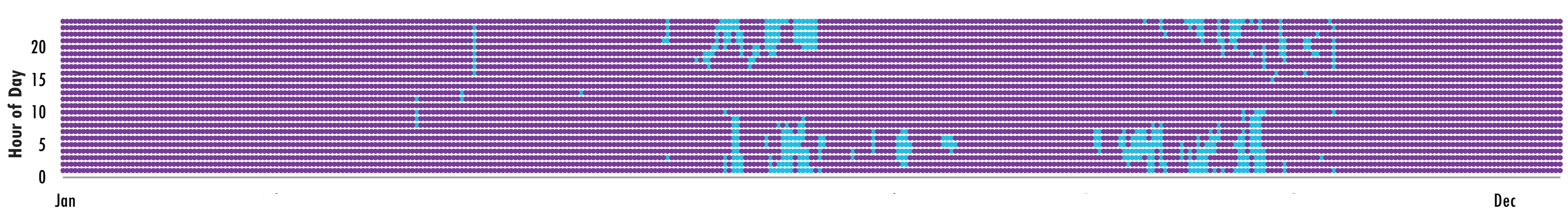
- **Extremely Uncomfortable** PMV<-1.5 and PMV>1.5
- **Uncomfortable** -1.5<PMV<-1 and 1<PMV<1.5
- **Slightly Uncomfortable** -1<PMV<-0.5 and 0.5<PMV<1
- **Comfortable** -0.5<PMV<0.5

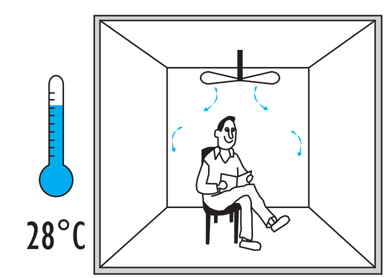












In order to increase the cooling setpoint temperature by 2K when shifting from the Improved to the Adaptive building, an alternative must be provided to maintain the same comfort levels for occupants. The purpose of this is to show people that there are low energy alternatives to providing equal comfort.

The 3 graphs plot yearly PMV values for three scenarios:

1. Cooling set point = 26°C (Improved Building)
2. Cooling set point = 28°C
3. Cooling set point = 28°C + ceiling fan (Adaptive Building)

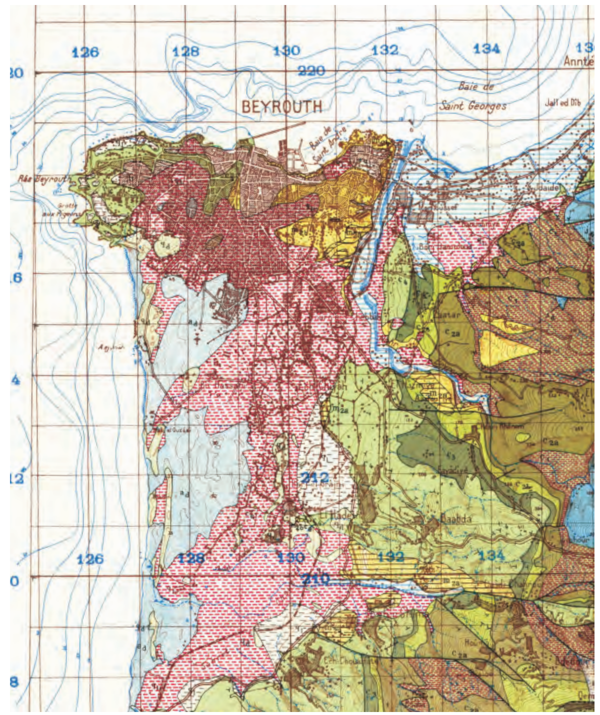
Not only does the Adaptive building have the lowest energy demand, but the best comfort levels!

BEIRUT GEOLOGY

Target Area: Greater Beirut Area

Approximate Area= 65 km^2

Greater Beirut Area (GBA)



Geological Map of GBA

Simplified Geological Map of GBA

10 DIFFERENT SOIL CLASSIFICATIONS → 4 DIFFERENT SOIL CLASSIFICATIONS

The target area for this project is The Greater Beirut area, which includes the city of Beirut and some of its suberbs.

Studing the geological map of this area showed that there are around 10 different soil classifictions. This again makes it very hard to generalize and choose one soil profile.

Therefore the geological map was simplified to include only 4 distinct soil types.

SOIL PROFILES

Soil profiles where chosen based on the following soil properties: Thermal Conductivity (W/m.K)
Volumetric Heat Capacity (MJ/m³.K)

As a result:

- LIMESTONE
- MARLSTONE
- ALLUVIALS
- SAND

Simplified Geological Map of GBA

The resulting 4 soil types are:

1. Limestone
2. Marlstone
3. Alluvials
4. Sands

This simplification was based on 2 soil properties:

1. Thermal conductivity
2. Volumetric heat capacity

These properties show which soils will behave similarly under thermal stress.

SOIL PROFILES

Soil profiles where chosen based on the following soil properties: Thermal Conductivity (W/m.K)
Volumetric Heat Capacity (MJ/m³.K)

As a result:

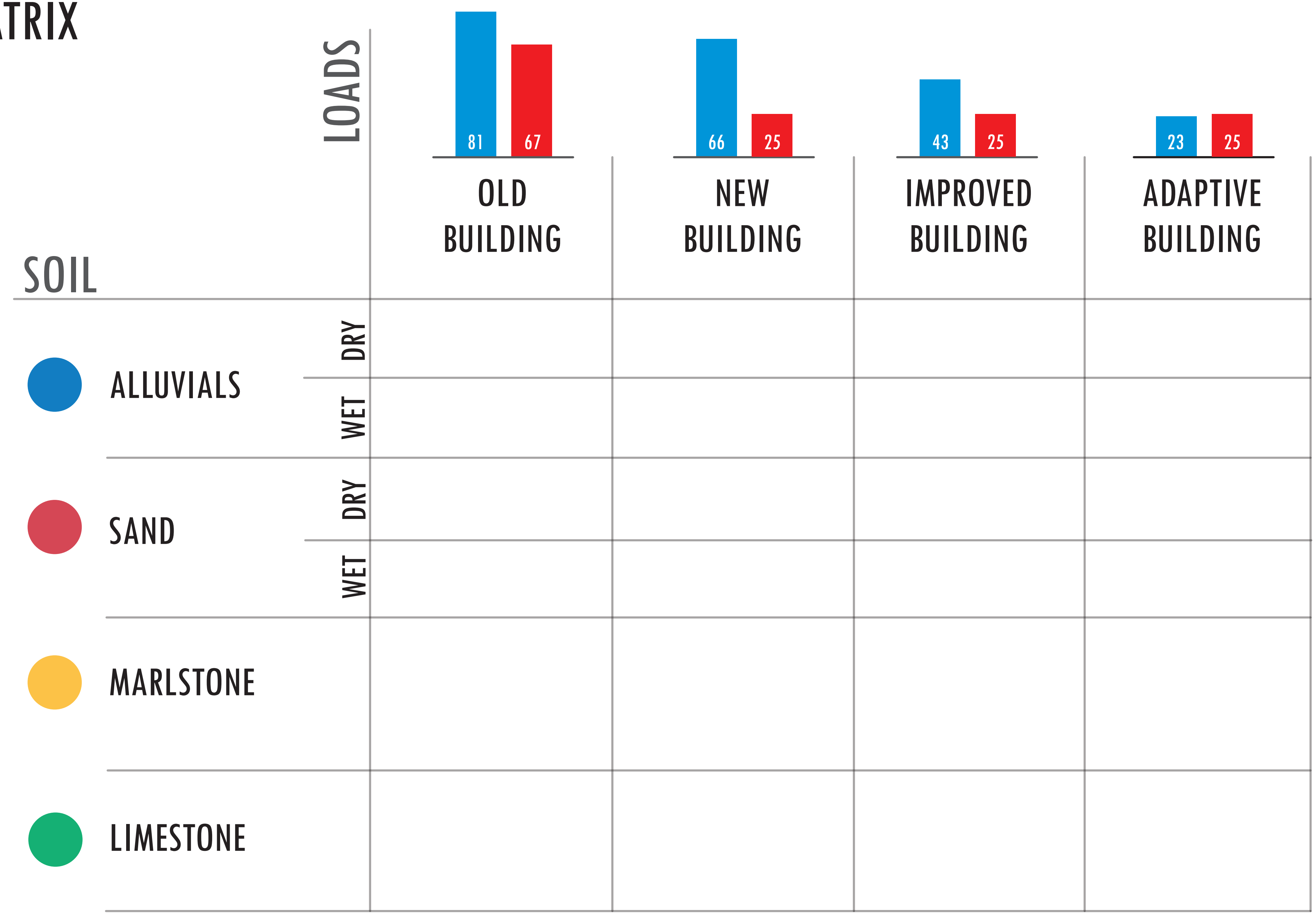
- LIMESTONE
- MARLSTONE
- ALLUVIALS
- SAND

Simplified Geological Map of GBA

However, considering two points within the same zone does not mean that the soil stratification is identical.

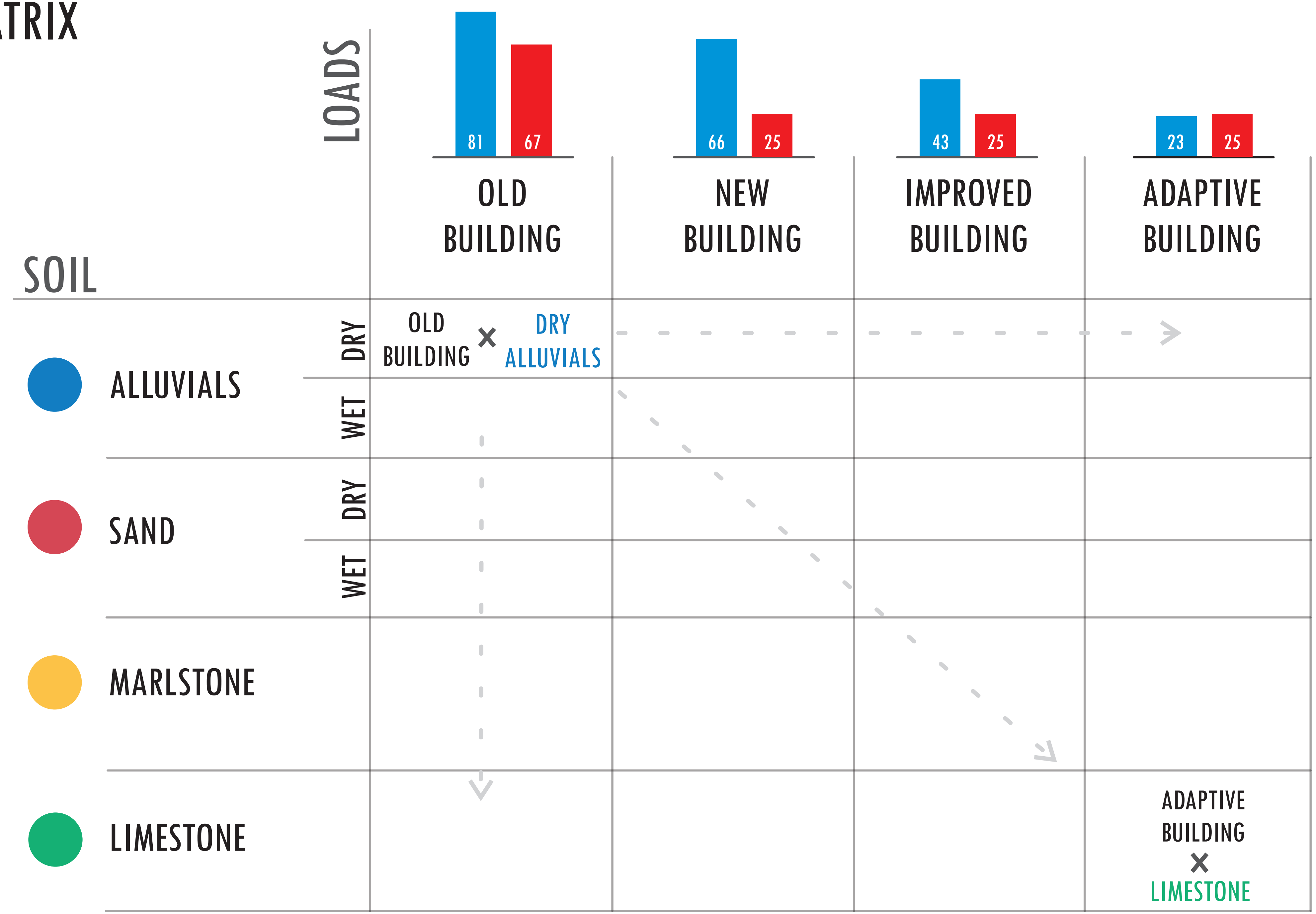
Therefore the worst case (dry soil) and the best case (wet soil) will be considered in the simulations.

MATRIX



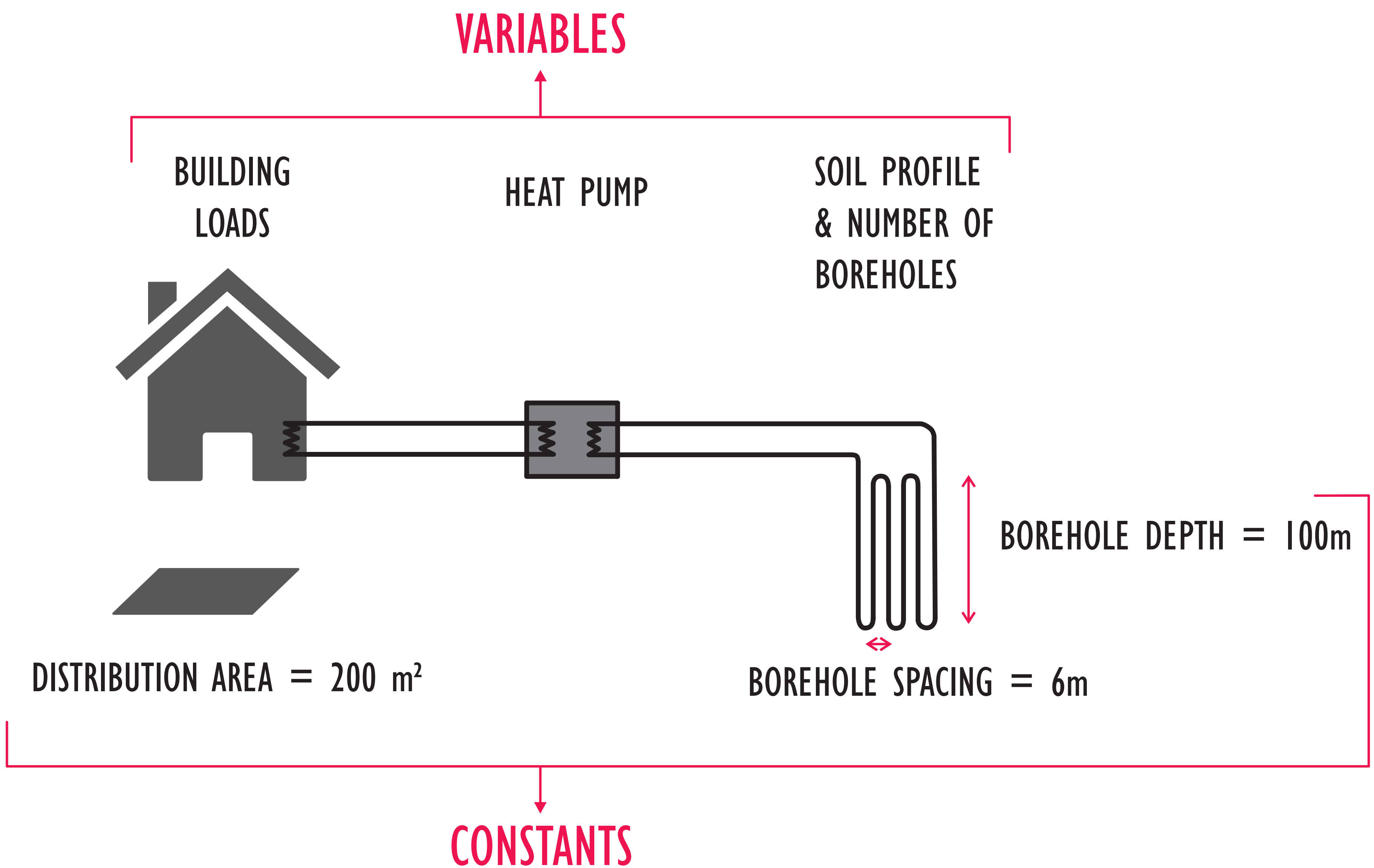
These 4 distinct building typologies and 4 distinct soil profiles lead to a matrix.

MATRIX



This matrix allows people to identify which type of soil and building they are dealing with and evaluate a geothermal system based these 2 properties.

SYSTEM

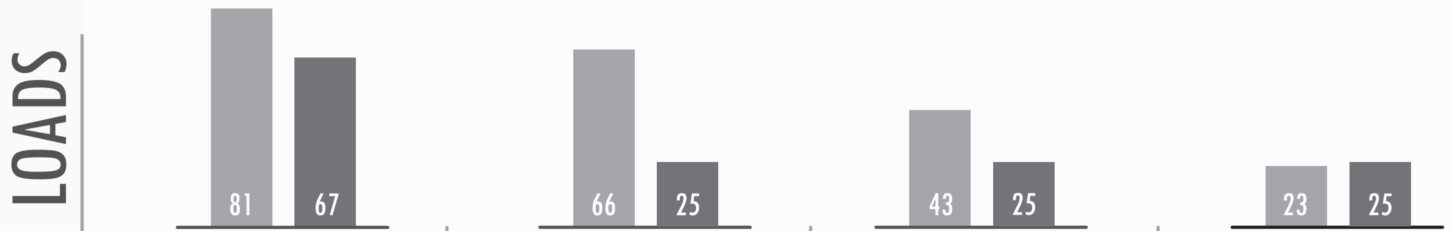


In this project, some factors were fixed between the different cases in order to simplify the work. The constants in the system are:

1. The area where the boreholes are distributed
2. The spacing between one borehole and the other
3. The borehole depth
4. Other specifications such as the thermal properties and dimensions of the plastic tubes, the circulating fluid etc.

The remaining properties as shows in the illustration vary with different building loads and soil profiles.

NUMBER OF BOREHOLES

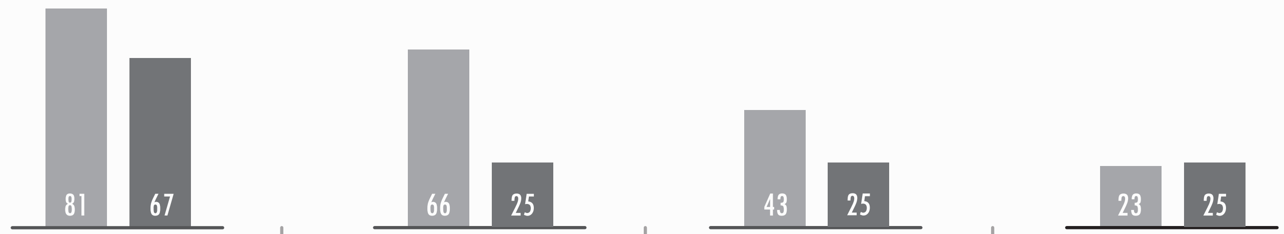


SOIL		OLD BUILDING	NEW BUILDING	IMPROVED BUILDING	ADAPTIVE BUILDING
ALLUVIALS	DRY	28	23	14	11
	WET	9	8	5	4
SAND	DRY	24	20	13	10
	WET	10	8	6	4
MARLSTONE		10	8	6	4
LIMESTONE		8	7	5	3

The following numbers are the number of boreholes required to cover the peak loads of each building within each soil type.

NUMBER OF BOREHOLES

LOADS

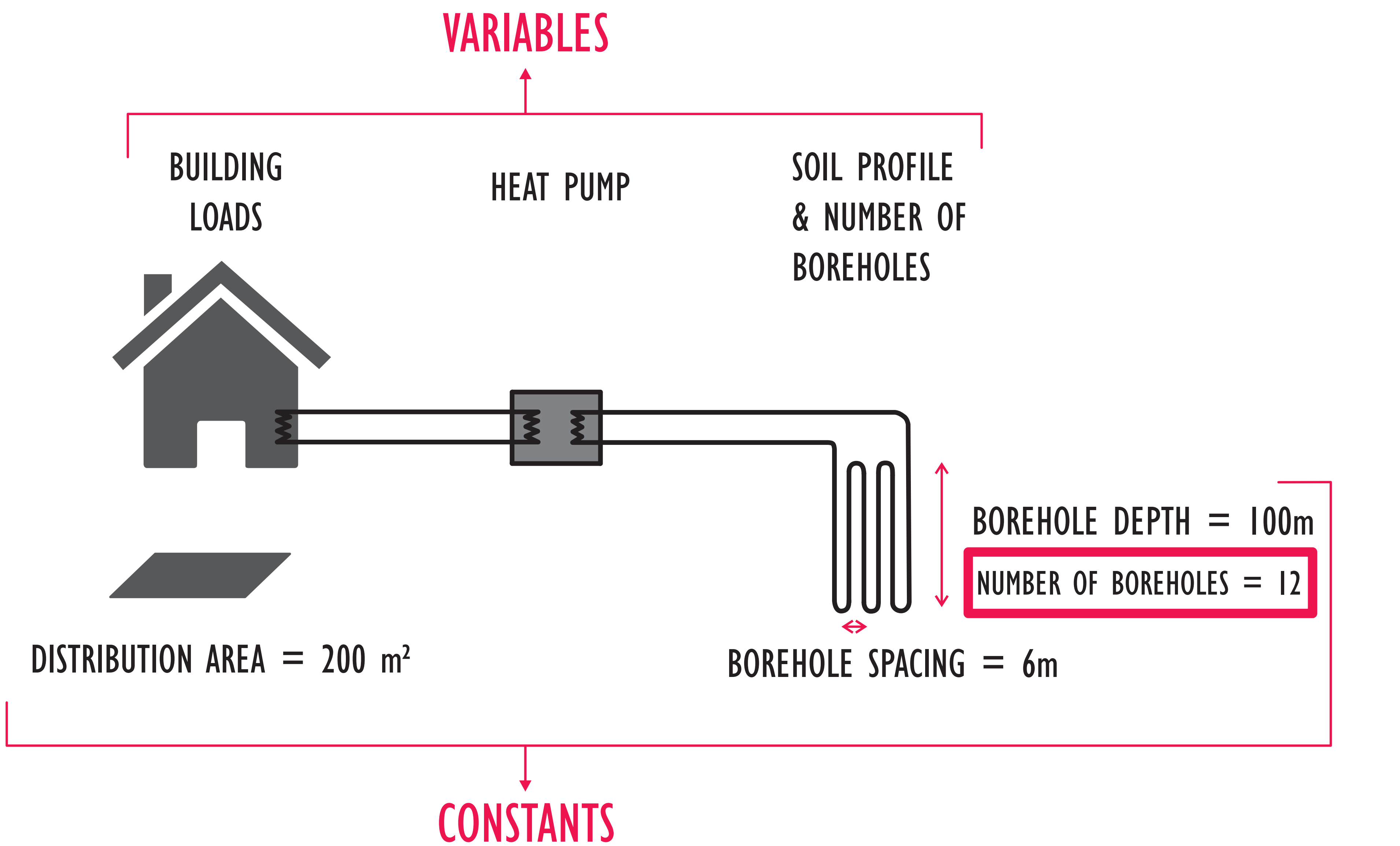


SOIL		OLD BUILDING	NEW BUILDING	IMPROVED BUILDING	ADAPTIVE BUILDING
ALLUVIALS	DRY	12	12	12	12
	WET	12	12	12	12
SAND	DRY	12	12	12	12
	WET	12	12	12	12
MARLSTONE		12	12	12	12
LIMESTONE		12	12	12	12

But having so many different geometries for the ground heat exchangers makes it hard to compare and evaluate the numerous cases in the matrix.

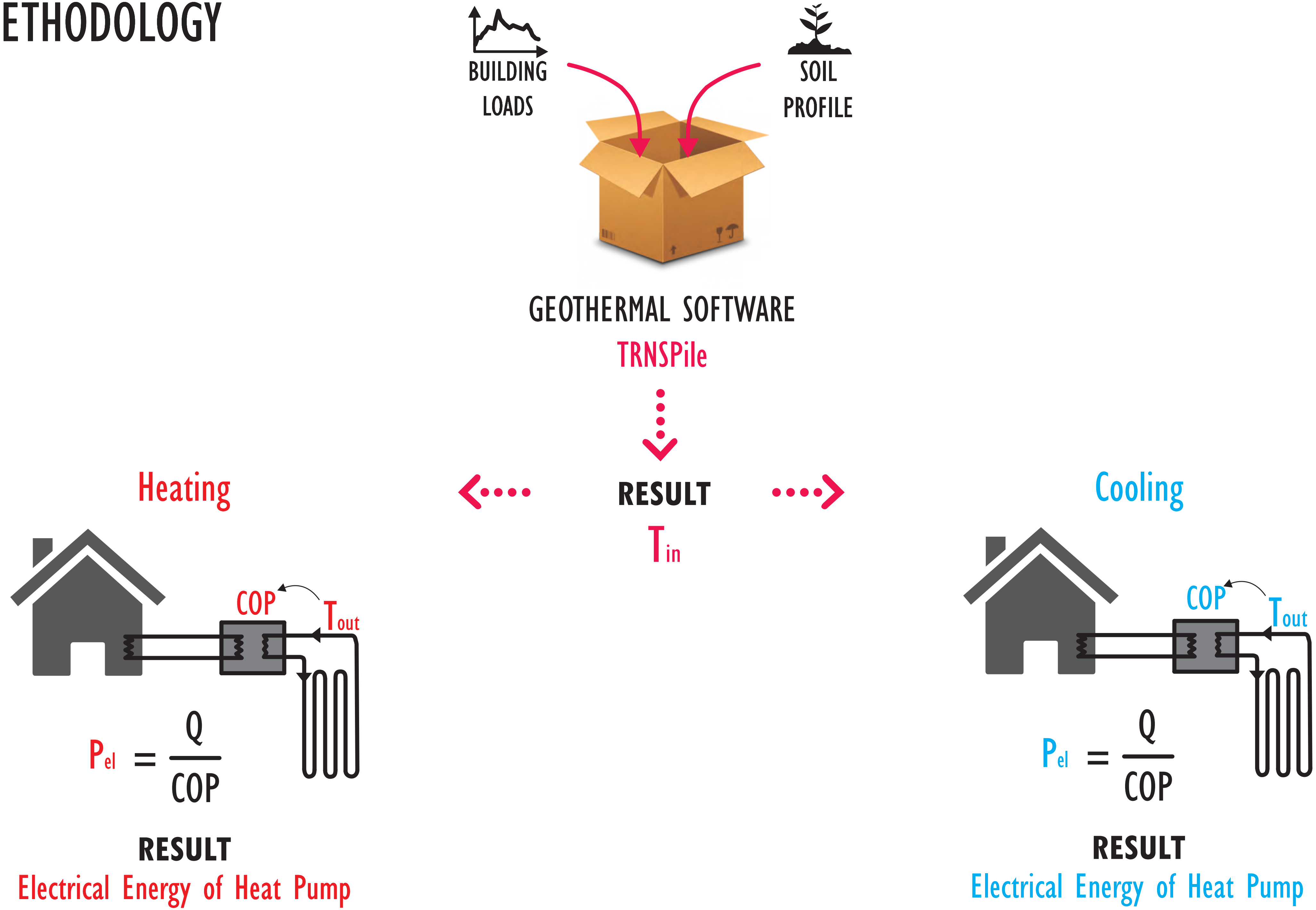
Therefore the number of boreholes was also fixed to 12 in all cases which is the maximum number of boreholes that can fit in the building footprint area of 200m².

SYSTEM



Fixed number of boreholes equal to 12

METHODOLOGY



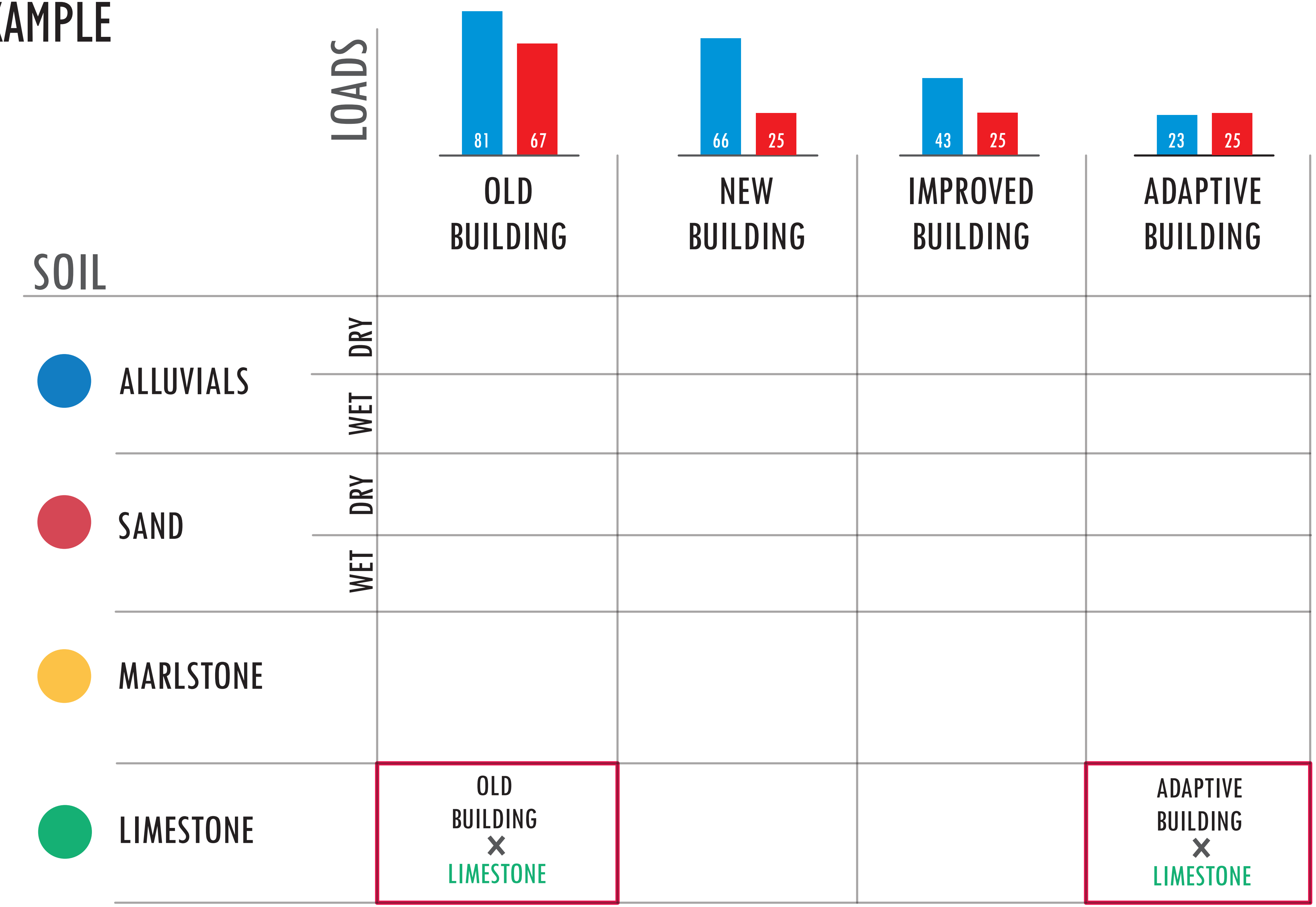
TRNSPile was used to simulate all the geothermal systems.

As shown previously, many of the inputs were fixed for all cases. The variable inputs into the software are the building loads and the soil stratification.

The output of the software that was used for further calculation is the temperature of the fluid returning from the ground.

In heating and cooling this oulet temperature will be used to calculate the temperature dependant COP of the heat pump. The hourly COP and building load will determine the hourly electric energy needed to run the heatpump.

EXAMPLE



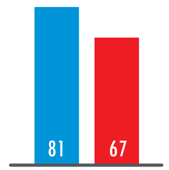
These 2 slots in the matrix will be evaluated in the following example.

EXAMPLE
Year I

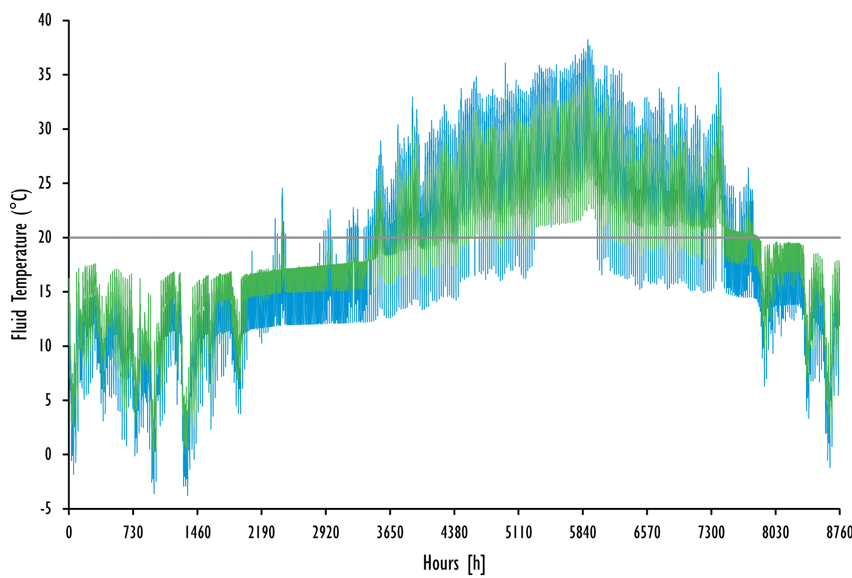
Inlet Temperature to GHE

Outlet Temperature from GHE

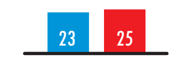
Percent of Free Cooling



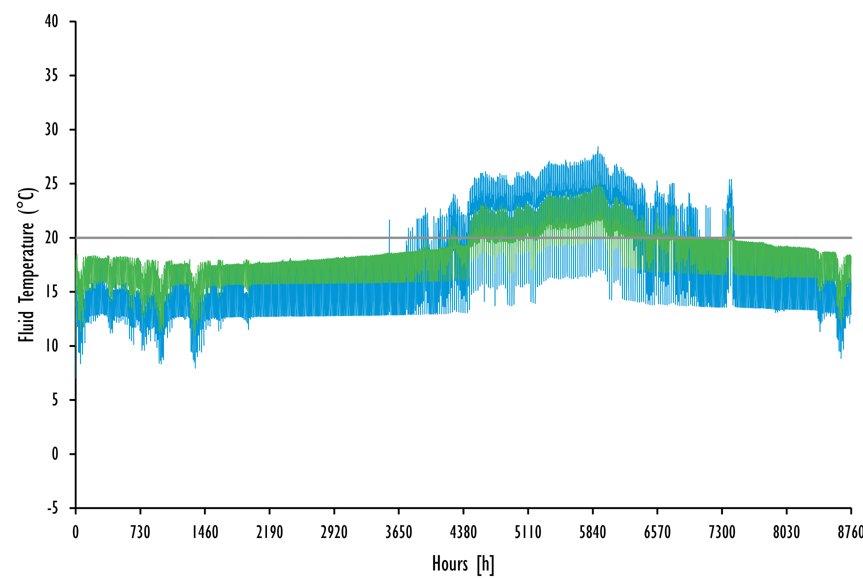
LIMESTONE + OLD BUILDING



13%



LIMESTONE + ADAPTIVE BUILDING



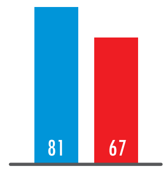
26%

The graphs show the inlet and outlet temperatures of the heat carrying fluid in the ground heat exchangers (GHE) for the 1st year of operation.

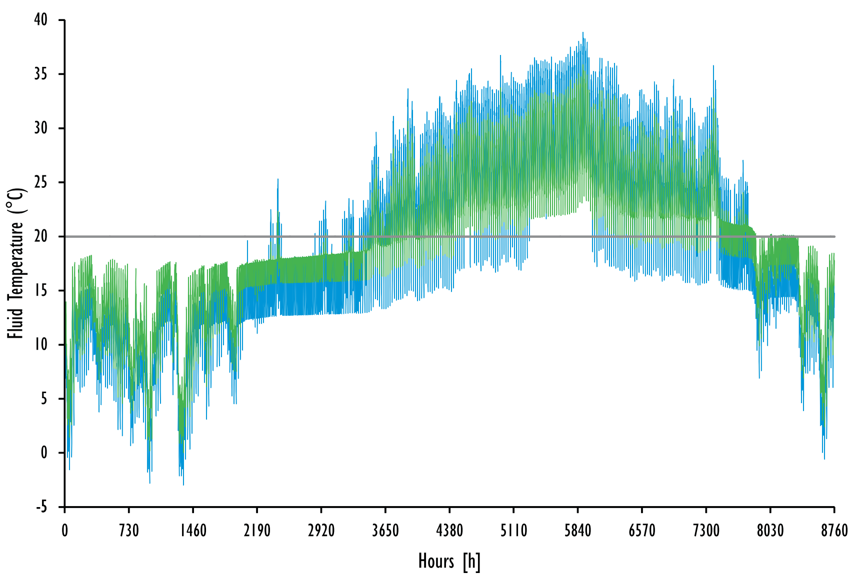
The numbers below show the percent of the cooling load that can be supplied by bypassing the heat pump because the temperatures into the system are adequate.

EXAMPLE
Year 8

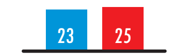
Inlet Temperature to GHE
Outlet Temperature from GHE
Percent of Free Cooling



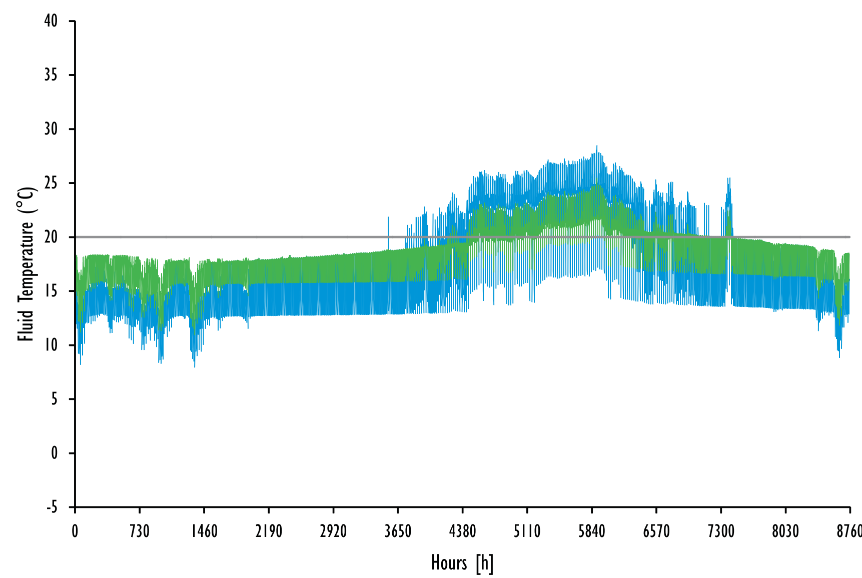
LIMESTONE + OLD BUILDING



9%



LIMESTONE + ADAPTIVE BUILDING



25%

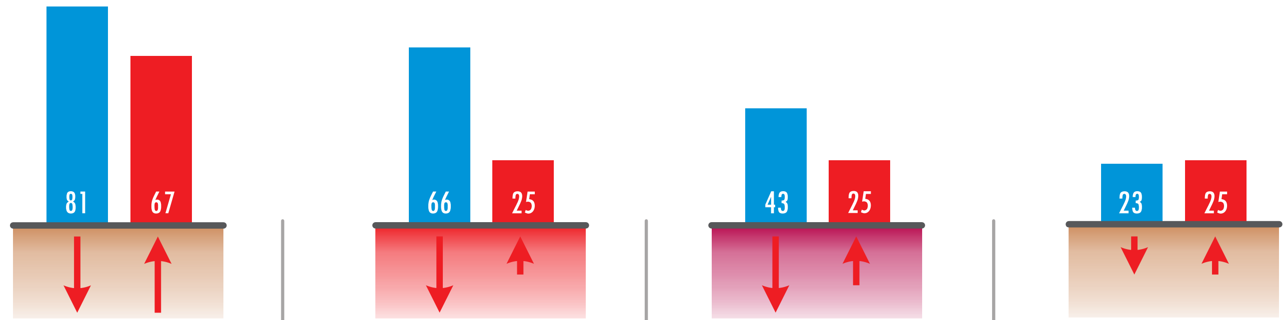
These graphs and numbers are for the 8th year of operation. Shifting between the two years clearly shows the effect of the unbalanced heating and cooling loads of the Old building.

The ground gradually becomes warmer since the cooling demand is greater which means that more heat is being introducted than extracted from the ground. This is most obvious from the reduction in free cooling potential.

RESULTS

ELECTRIC ENERGY
FOR HEATING
kWh/m²/Year

LOADS



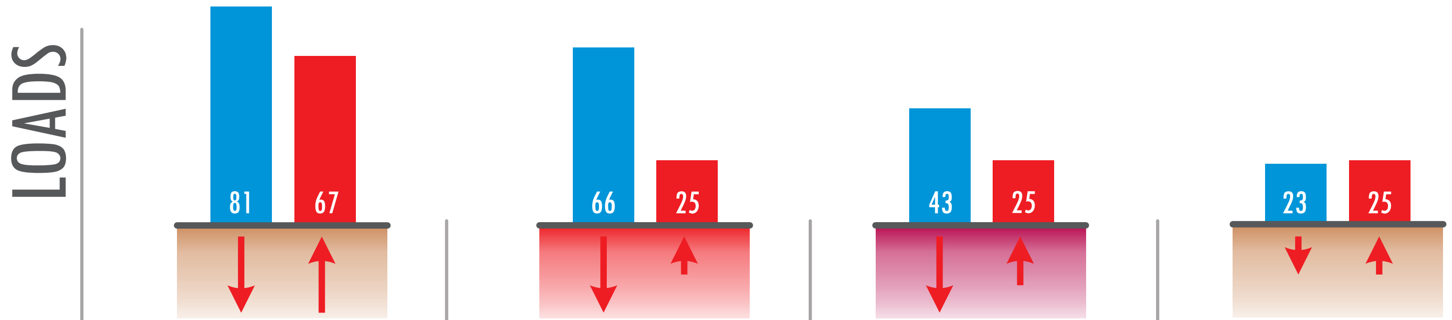
SOIL		OLD BUILDING	NEW BUILDING	IMPROVED BUILDING	ADAPTIVE BUILDING
ALLUVIALS	DRY	18.9	3.5	4.9	5.8
	WET	16.9	3.6	4.8	5.6
SAND	DRY	19.4	3.5	4.9	5.8
	WET	16.7	3.6	4.8	5.6
MARLSTONE		16.8	3.6	4.8	5.6
LIMESTONE		16.6	3.6	4.8	5.6

This matrix shows the electrical energy of the heat pump in kWh/m^2 to supply the yearly heating demand. These values were calculated using the hourly heating demand and temperature dependant COP.

The values shown are for the 3rd year of operation, that is the average time that a geotheraml system needs to stabalize.

RESULTS

ELECTRIC ENERGY FOR COOLING kWh/m²/Year



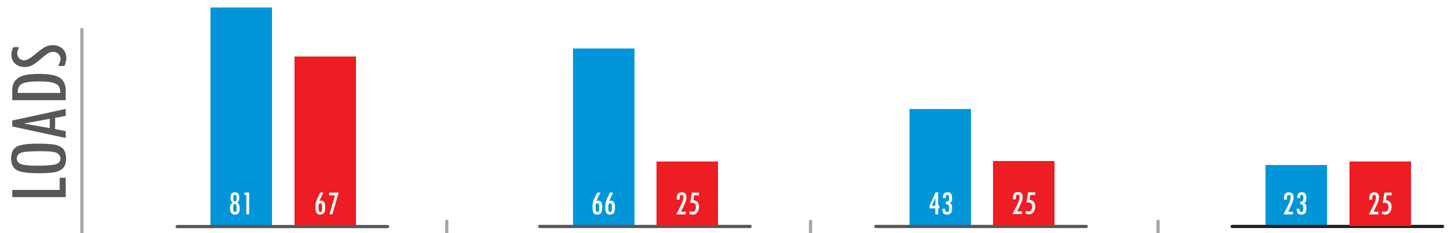
SOIL		OLD BUILDING	NEW BUILDING	IMPROVED BUILDING	ADAPTIVE BUILDING
ALLUVIALS	DRY	14.5	9.9	5.9	2.7
	WET	12.7	8.8	5.5	2.6
SAND	DRY	14.9	10.2	6.1	2.7
	WET	12.5	8.7	5.4	2.6
MARLSTONE		12.6	8.7	5.5	2.6
LIMESTONE		12.5	8.7	5.4	2.6

This matrix shows the electrical energy of the heat pump in kWh/m² to supply the yearly cooling demand. These values were calculated similarly.

These values are also for the 3rd year of operation.

RESULTS

TOTAL
ELECTRIC ENERGY
kWh/m²/Year

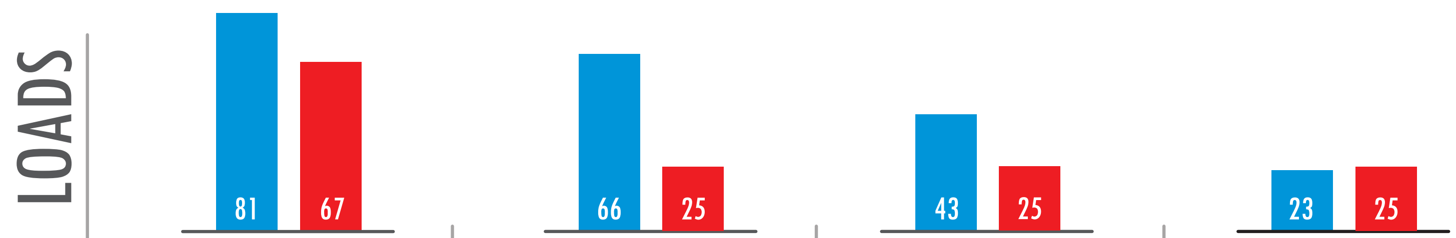


SOIL		OLD BUILDING	NEW BUILDING	IMPROVED BUILDING	ADAPTIVE BUILDING
ALLUVIALS	DRY	33.5	13.4	10.8	8.5
	WET	29.6	12.4	10.4	8.3
SAND	DRY	34.4	13.7	11.0	8.6
	WET	29.2	12.3	10.3	8.2
MARLSTONE		29.3	12.3	10.3	8.2
LIMESTONE		29.1	12.2	10.3	8.2

This matrix shows the total electrical energy of the heat pump in kWh/m² to supply the yearly cooling and heating demand.

RESULTS

TOTAL
ELECTRIC ENERGY
kWh/m²/Year



SOIL		OLD BUILDING	NEW BUILDING	IMPROVED BUILDING	ADAPTIVE BUILDING
ALLUVIALS	DRY	33.5	13.4	10.8	8.5
	WET	29.6	12.4	10.4	8.3
SAND	DRY	34.4	13.7	11.0	8.6
	WET	29.2	12.3	10.3	8.2
MARLSTONE		29.3	12.3	10.3	8.2
LIMESTONE		29.1	12.2	10.3	8.2

The results of the simulations also show that the ground in the case of the New building will be saturated afetr only 6 years and in the case of the Improved building after 13 years. The reason for this is the unbalanced heating and cooling loads. Therefore it is not recommended to use a geothermal system with these 2 building typologies.

A geothermal system in Old and Adaptive buildings function regulary throughout the chosen simulation time of 20 years.

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