Project acronym: GROUND-MED

Project title: Advanced ground source heat pump systems for heating and cooling in Mediterranean climate

Start date of project: 1 January 2009

Duration: 60 months

**Deliverable D5.3: Engineering design of University of Coimbra demo system in Portugal**

Version: Final

Due date of deliverable: 31 October 2010

Actual submission date: 31 October 2010

Organisation name of lead contractor for this deliverable:

**Institute of Systems and Robotics - University of Coimbra**

| Project co-funded by the European Commission within FP7 Programme | | |
|---|---|---|
| Dissemination level | | |
| **PU** | Public | **X** |
| **PP** | Restricted to other programme participants (including the Commission Services) | |
| **RE** | Restricted to a group specified by the Consortium (including the Commission Services) | |
| **CO** | Confidential, only for members of the consortium (including the Commission Services) | |

# GROUND-MED WP5 DELIVERABLE
# DEMO SITE ENGINEERING DESIGN

# D5.3 COIMBRA

# ENGINEERING DESIGN OF THE DEMO SITE

## Chapter I. Air Conditioned Spaces and Building Characteristics

### I.1 Building Location, Type and Use

The GSHP system is located in a public building of the regional government in Coimbra, Portugal.

| | |
|---|---|
| Geographical location: City (Country) | Coimbra(Portugal) |
| Latitude | 40°12'55.97" |
| Longitud | 8°26'18.38"W |
| Altitude | 24 m |
| Building use | Public services |
| Building type | Offices |

### I.2 Building Constructive Data

The spaces to be heated and cooled with the Ground Source Heat Pump (GSHP) are located in level 3 of the building.

The building which is heated and cooled with the ground source heat pump (GSHP), comprises approximately 586m$^2$. The geometrical characteristics of each conditioned area are detailed in the Annex I.

The following table contains the characterization of spaces in level 3.

| BUILDING ZONES | CEILING(m2) | FLOOR(m2) | HEIGHT (m) |
|---|---|---|---|
| 302 | 20,72 | 19,12 | 2,85 |
| 309 | 36,25 | 31,53 | 2,85 |
| 310 | 47,59 | 41,99 | 2,85 |
| 311 | 18,97 | 17,5 | 2,85 |
| 312 | 38,10 | 35,14 | 2,85 |
| 313 | 17,58 | 16,22 | 2,85 |
| 314 | 20,05 | 18,49 | 2,85 |
| 315 | 17,23 | 15,43 | 2,85 |
| 316 | 20,32 | 18,74 | 2,85 |
| 317 | 38,15 | 35,19 | 2,85 |
| 318 | 25,52 | 23,54 | 2,85 |
| 319 | 18,11 | 16,71 | 2,85 |
| 320 | 44,66 | 39,38 | 2,85 |
| 326 | 21,64 | 20,08 | 2,85 |
| 327 | 47,33 | 41,41 | 2,85 |
| 328 | 30,56 | 25,56 | 2,85 |
| 329 | 20,51 | 18,83 | 2,85 |
| 330 | 14,84 | 13,63 | 2,85 |
| 331 | 21,29 | 19,55 | 2,85 |
| 336 | 29,67 | 27,37 | 2,85 |

## I.3 Windows

### *External Windows*

In the tables below the area of the windows and its thermal characteristics are presented for each latitude of the air conditioned spaces. The thermal characteristics are presented in the table bellow. The glass area is composed by a framed windows and a coloured glass panel.

| BUILDING ZONES | YN(m2) | YS (m2) | XE(m2) | XW(m2) |
|---|---|---|---|---|
| 302 | 3,045 | | | |
| 309 | 5,285 | | | |
| 310 | | 6,090 | 3,480 | |
| 311 | | 3,045 | | |
| 312 | | 5,285 | | |
| 313 | | 1,610 | | |
| 314 | | 3,045 | | |
| 315 | | 2,240 | | |
| 316 | | 3,045 | | |
| 317 | | 5,285 | | |
| 318 | | 3,850 | | |
| 319 | | 1,610 | | |
| 320 | | 3,850 | | 6,090 |
| 326 | | | | 3,045 |
| 327 | | | | 6,895 |
| 328 | 3,457 | | 3,850 | |
| 329 | | | 3,850 | |
| 330 | | | 2,240 | |
| 331 | | | 3,850 | |
| 336 | 3,850 | | | |

| THERMAL CHARACTERISTICS | | _____ | |
|---|---|---|---|
| U(WINDOW) | 3,75 | W/m2·K | |
| g(WINDOW) | 0,42 | _____ | |
| U(FRAME) | | W/m2·K | |
| **A (m2)** | **EXTERNAL BLIND** | **INTERNAL BLIND** | **FRAME FRACTION %** |
| 1,75 | No | No | |

## *Indoor Windows*

There are no internal windows considered

## I.4 Walls

In annex 2 are represented the type of walls in level 3 of the building.

### *Outdoor Walls*

External walls area versus orientation:

| ZONES | YN (m2) | YS (m2) | XE(m2) | XW(m2) |
|---|---|---|---|---|
| 302 | 10,95 | | | |
| 309 | 19,24 | | 14,05 | |
| 310 | | 20,02 | 19,28 | |
| 311 | | 10,13 | | |
| 312 | | 19,98 | | |
| 313 | | 9,41 | | |
| 314 | | 10,7 | | |
| 315 | | 8,96 | | |
| 316 | | 10,8 | | |
| 317 | | 19,84 | | |
| 318 | | 13,45 | | |
| 319 | | 9,87 | | |
| 320 | | 14,99 | | 21,87 |
| 326 | | | | 10,51 |
| 327 | 15 | | | 23,61 |
| 328 | 18,68 | | 12,45 | |
| 329 | | | 11,5 | |
| 330 | | | 8,82 | |
| 331 | | | 11,82 | |
| 336 | 15,75 | | | |

| Exterior Wall Level 3 | | | | | |
|---|---|---|---|---|---|
| layer material | Thickness (m) | Conductivity (kJ/hmK) | Density (kg/m3) | Specific heat (kJ/kgK) | Resistance (hm2K/kJ) |
| Gypsum sand render | 0,015 | 2,88 | 1600 | 1 | 0 |
| Cement sand render | 0,05 | 3,6 | 1800 | 1 | 0 |
| Limestone | 0,5 | 6,12 | 2200 | 1 | 0 |
| Cement sand render | 0,05 | 3,6 | 1800 | 1 | 0 |

### *Indoor Walls*

In the annex 2 a plant with the representation of interior walls is presented.

| Interior Walls |
|---|

| layer material | Thickness (m) | Conductivity (kJ/hmK) | Density (kg/m3) | Specific heat (kJ/kgK) | Resistance (hm2K/kJ) |
|---|---|---|---|---|---|
| Gypsum board | 0,013 | 1,08 | 900 | 1 | 0 |
| Rockwool | 0,1 | 0,144 | 12 | 1,03 | 0 |
| Gypsum board | 0,013 | 1,08 | 900 | 1 | 0 |

### *Boundary Condition Walls*

No boundary walls to a conditioned area:

### *Ceiling and Ground*

| Floor wall type | | | | | |
|---|---|---|---|---|---|
| layer material | Thickness (m) | Conductivity (kJ/hmK) | Density (kg/m3) | Specific heat (kJ/kgK) | Resistance (hm2K/kJ) |
| Concrete | 0,2 | 3,32 | 1200 | 1 | Ø |

| Ceiling wall type | | | | | |
|---|---|---|---|---|---|
| layer material | Thickness (m) | Conductivity (kJ/hmK) | Density (kg/m3) | Specific heat (kJ/kgK) | Resistance (hm2K/kJ) |
| Concrete | 0,2 | 3,32 | 1200 | 1 | Ø |

## I.5 Use, Occupancy and Thermal loads calculations

### *I.5.1 Internal gains, ventilation, infiltration, air coupling*

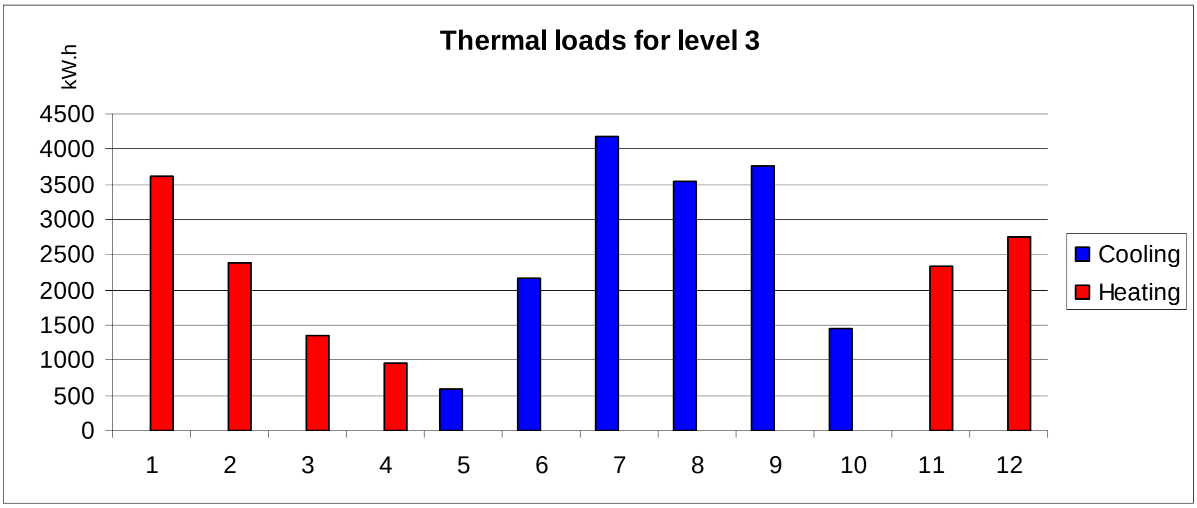
| ZONES | Num. People | Num. Computers | Zone A (m2) | People (W) | Computers (W) | Artificial Lighting (W) |
|---|---|---|---|---|---|---|
| 302 | 2 | 2 | 19,12 | 450 | 360 | 158,696 |
| 309 | 3 | 3 | 31,53 | 750 | 540 | 261,699 |
| 310 | 5 | 5 | 41,99 | 150 | 900 | 348,517 |
| 311 | 1 | 1 | 17,5 | 600 | 180 | 145,25 |
| 312 | 4 | 4 | 35,14 | 150 | 720 | 291,662 |
| 313 | 1 | 1 | 16,22 | 150 | 180 | 134,626 |
| 314 | 1 | 1 | 18,49 | 150 | 180 | 153,467 |
| 315 | 1 | 1 | 15,43 | 150 | 180 | 128,069 |
| 316 | 1 | 1 | 18,74 | 600 | 180 | 155,542 |
| 317 | 4 | 4 | 35,19 | 150 | 720 | 292,077 |
| 318 | 1 | 1 | 23,54 | 150 | 180 | 195,382 |
| 319 | 1 | 1 | 16,71 | 600 | 180 | 138,693 |
| 320 | 4 | 4 | 39,38 | 300 | 720 | 326,854 |
| 326 | 2 | 2 | 20,08 | 750 | 360 | 166,664 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 327 | 5 | 5 | 41,41 | 600 | 900 | 343,703 |
| 328 | 4 | 4 | 25,56 | 300 | 720 | 212,148 |
| 329 | 2 | 2 | 18,83 | 150 | 360 | 156,289 |
| 330 | 1 | 1 | 13,63 | 150 | 180 | 113,129 |
| 331 | 2 | 2 | 19,55 | 300 | 360 | 162,265 |
| 336 | 2 | 2 | 27,37 | 300 | 360 | 227,171 |

| **Ventilation (renovation per hours)** |
|---|
| **outside air** |
| 0,9 |
| **Infiltration (renovation per hours)** |
| **outside air** |
| 0.1 in offices |
| 0.6 in common spaces |
| **Air coupling between zones (renovation per hours)** |
| 0 (between contiguous office rooms) |
| 0.25 (between corridor and office rooms) |

### *I.5.2 Thermal loads results (Peak loads and monthly loads)*

| | PEAK LOAD (kW) | PEAK DAY |
|---|---|---|
| **SUMMER PEAK LOAD (kW)** | 48 | 12 Ago |
| **WINTER PEAK LOAD (kW)** | 34 | 7 Jan |




| Total Loads [kW·h] | Peak Loads [kW] |
|---|---|

| | Heating | Cooling | Heating | Cooling |
|---|---|---|---|---|
| January | 3611,26 | 0,00 | 33,58 | 0,00 |
| February | 2383,57 | 0,00 | 22,30 | 0,00 |
| March | 1355,99 | 0,00 | 29,89 | 0,00 |
| April | 958,18 | 0,00 | 14,94 | 0,00 |
| May | 0,00 | 580,69 | 0,00 | 11,79 |
| June | 0,00 | 2172,51 | 0,00 | 33,90 |
| July | 0,00 | 4178,22 | 0,00 | 44,10 |
| August | 0,00 | 3535,73 | 0,00 | 48,02 |
| September | 0,00 | 3753,07 | 0,00 | 32,08 |
| October | 0,00 | 1455,9 | 0,00 | 23,55 |
| November | 2330,98 | 0,00 | 28,40 | 0,00 |
| December | 2747,79 | 0,00 | 32,00 | 0,00 |

# Chapter II. Climate Description and Geology

## II.1 Demo site Climate Description ( template data)

### *II.1.2 Temperature*

| Weather data | | |
|---|---|---|
| Weather data | Latitude | 40°12'55.97" |
| | Longitud | 8°26'18.38" |
| | Altitude | 24m |
| | Average annual air temperature (ºC) | 15,1 |
| | Average annual air Relative Humidity (%) | 77 |

**INSTITUTO GEOFÍSICO DA UNIVERSIDADE DE COIMBRA**

Valores Climatológicos e Actinométricos Normais (1971/2000)

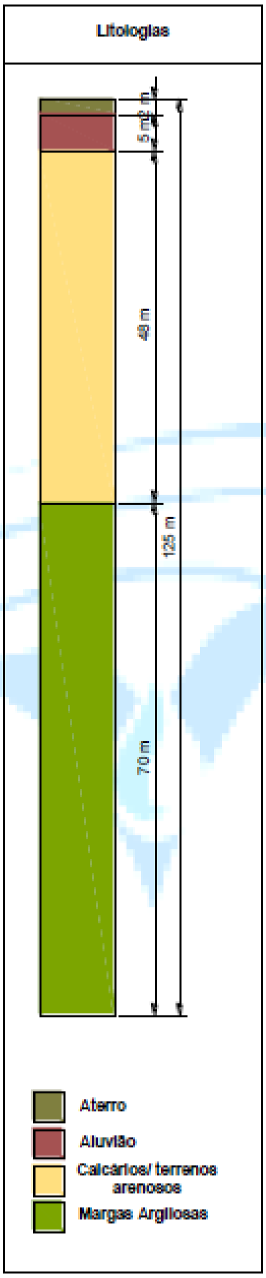
| | | Jan | Fev | Mar | Abr | Mai | Jun | Jul | Ago | Set | Out | Nov | Dez | ANO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Pressão (mb)** | Média | 1004.9 | 1003.6 | 1002.2 | 998.9 | 999.3 | 1001.4 | 1001.0 | 1001.3 | 1001.6 | 1001.5 | 1003.1 | 1003.9 | 1001.9 |
| **Temperatura (°C)** | Média | 9.5 | 10.7 | 12.3 | 13.4 | 15.6 | 18.8 | 20.8 | 20.7 | 19.3 | 16.2 | 12.7 | 10.7 | 15.1 |
| | méd. das máx. | 14.1 | 15.7 | 18.3 | 19.2 | 21.6 | 25.5 | 28.4 | 28.7 | 26.7 | 22.0 | 17.4 | 14.7 | 21.0 |
| | méd. das min. | 5.9 | 7.0 | 7.7 | 8.9 | 11.0 | 13.8 | 15.5 | 15.4 | 14.4 | 12.0 | 9.0 | 7.4 | 10.7 |
| **Humidade Relativa (%)** | | 80 | 78 | 74 | 75 | 77 | 75 | 73 | 73 | 74 | 78 | 80 | 81 | 77 |
| **Evap. Piche 09:00-09:00 (mm)** | | 62.0 | 65.1 | 94.0 | 91.5 | 97.1 | 108.4 | 129.4 | 125.6 | 106.4 | 86.8 | 64.8 | 65.0 | 1092.4 |
| **Nebulosidade (0-10)** | | 5 | 6 | 5 | 6 | 6 | 5 | 4 | 4 | 5 | 6 | 6 | 6 | 5 |
| **Insolação** | Média (h) | 4.9 | 5.1 | 6.4 | 6.6 | 7.3 | 8.6 | 9.6 | 9.4 | 7.4 | 5.7 | 4.8 | 4.1 | 6.7 |
| | % | 49 | 47 | 53 | 50 | 51 | 58 | 65 | 69 | 59 | 51 | 48 | 43 | 54 |
| **Radiação** Global (méd.) (cal.cm2) | | 175 | 240 | 362 | 436 | 492 | 560 | 579 | 527 | 405 | 283 | 193 | 149 | 367 |
| **Precipitação** | 09:00-09:00 (mm) | 121.0 | 115.0 | 72.0 | 91.0 | 85.0 | 44.0 | 15.0 | 15.0 | 55.0 | 108.0 | 116.0 | 139.0 | 975.0 |
| | 00:00-24:00 (mm) | 119.6 | 114.2 | 71.9 | 88.6 | 80.6 | 42.6 | 14.4 | 16.5 | 50.8 | 104.0 | 113.3 | 139.8 | 956.3 |
| | Nº de dias | 15 | 13 | 13 | 15 | 13 | 9 | 5 | 5 | 9 | 14 | 14 | 15 | 138 |
| **Vento** | Vel. média (Km/h) | 9.8 | 9.7 | 9.4 | 9.2 | 8.8 | 8.3 | 8.2 | 8.0 | 7.6 | 8.5 | 9.0 | 10.7 | 8.9 |
| | Direc.predominante | SE | SE | NW | NW | NW | NW | NW | NW | NW | NW/SE | S | SE | |
| | Duração (h) | 138.7 | 107.0 | 126.7 | 138.3 | 177.5 | 178.7 | 257.2 | 233.5 | 157.9 | 101.4/107.0 | 98.2 | 133.3 | |

## II.2 Soil and Geology

### *II.2.1 General Geology*

| | Soil Parameters | |
|---|---|---|
| Location type (rural, build up, field or paved) | field | |
| General soil profile | alluvium granite/shale sediment with 20% quartz, and saturated with water | |
| Estimate of Conductivity | 2 | W/m*K |
| Estimate of Volumetric Heat | 2484 | kJ/K*m3 |
| Ground water flow (qualitative: no, high,low) | low (no current) | |
| Freatic groundwater level | 5 | m |

## II.2.2 Geological Profile



## Chapter III. System Description

### *III.1 Heat Pump Description*


#### *III.1.1 Water temperature conditions considered for the design*

| | | |
|---|---|---|
| User Side Water Temperatures (Cooling) IN/OUT | *[°C]* | 15/10 |
| User Side Water Temperatures (Heating) IN/OUT | *[°C]* | 35 / 40 |

#### *III.1.2 Heat Pump Capacity and nominal flow rate for cooling and heating mode*

Heating Capacity – 74.1 kW
Cooling Capacity – 61.5 kW

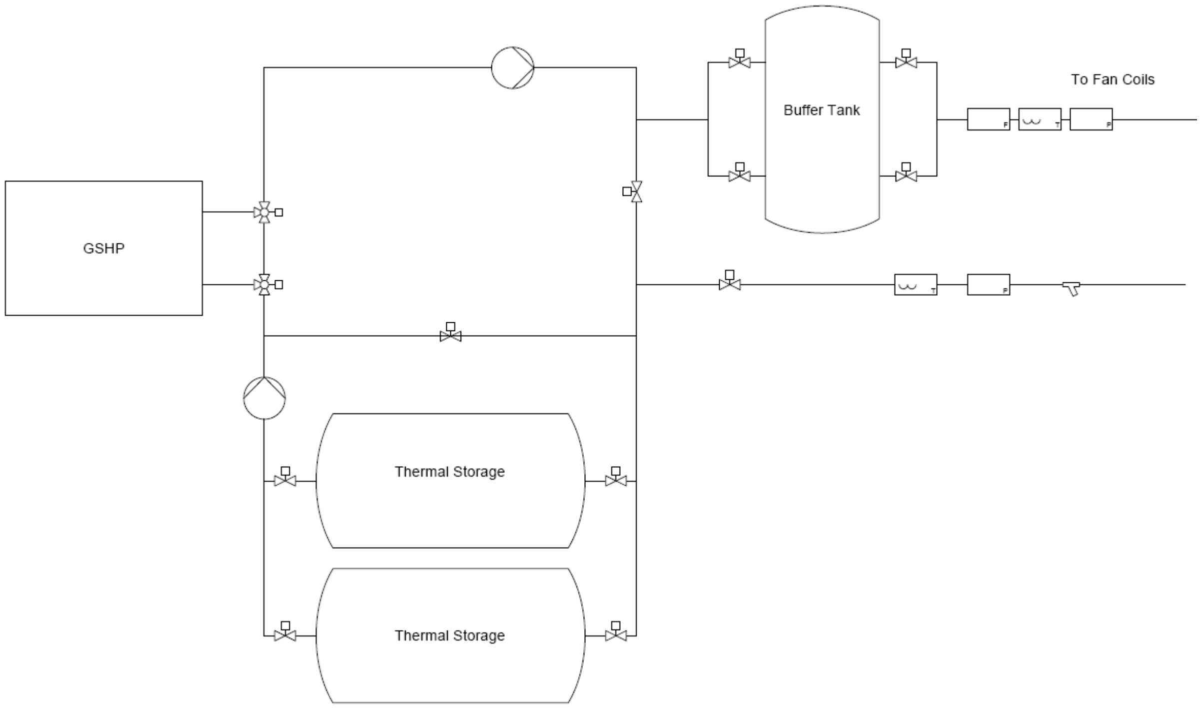
### III. 2 Indoor Loop Description

#### *III.2.1 Hydraulic Loop Description*

This loop pumps the fluid to the fan coil units and comprises the Thermal Energy Storage tanks and hydraulic circuit. It is basically composed by the following elements:

- Circulating pump
- Monitoring elements: flow- , temperature-, pressure – meters
- Thermal storage tanks: Two 3,000 l tanks
- Buffer tank
- Valves, filters, etc.

A simplified schematic of the loop is shown below:




### III.2.2 Internal Tank: volume and position

The tank is located at the outlet of the heat pump on the supply line to fan coils and its volume is 500 l.

### III.2.3 Location of the control temperature sensor for the heat pump

The thermostat control for the heat pump is to be determined at a later stage of design. It will probably be located at the exit of the buffer tank.

### III.2.4 Hydraulic pipes distribution system: schema of the distribution specifying external and internal diameter and flow rate.

This is still an open issue.

### III.2.5 Circulation pump selected:

*Specify the total pressure drop and water flow rate that must be provided by the circulation pump.*

Pressure drop= 20m ; Flow rate=11,037 $m^3/h$

The pressure drop is a preliminary estimate since not all of the inputs are established.

*Manufacturer, model, type (fixed velocity or variable velocity) and catalogue data (performance curves)*

The selection of the circulation pump for the internal circuit is still an open issue. It will be a high efficiency permanent magnet variable speed pump, supplied by Grundfos. The technical advice, from the Portuguese Grundfos representative is also still pending.

### *III.2.3 Fan Coil Technical Description*

#### *Manufacturer & Model selected*

The Fan Coil units will be provided by CIAT. The selection of the units is still dependant on the technical advice of CIAT experts and the approval of the building owner.

However, a preliminary analysis led to the selection of COADIS 2 fancoil units models 235/22 and 235/33. A total of 31 units is to be installed – 23 units of model 235/22 amd 8 units of model 235/33.

#### *Catalogue performance data*

The air flow rate, cooling and heating capacity, and power demand values are shown in the tables below:

235/22

| TEMPERATURES | COOLING COIL | HEATING COIL |
|---|---|---|
| Fluid | Water | Water |
| Fluid inlet temperature | 10 °C | 40 °C |
| Fluid outlet temperature | 15 °C | |
| Recycled air inlet temperature | 26 °C | 22 °C |
| Recycled air inlet humidity | 50 %(RH) | 50 %(RH) |

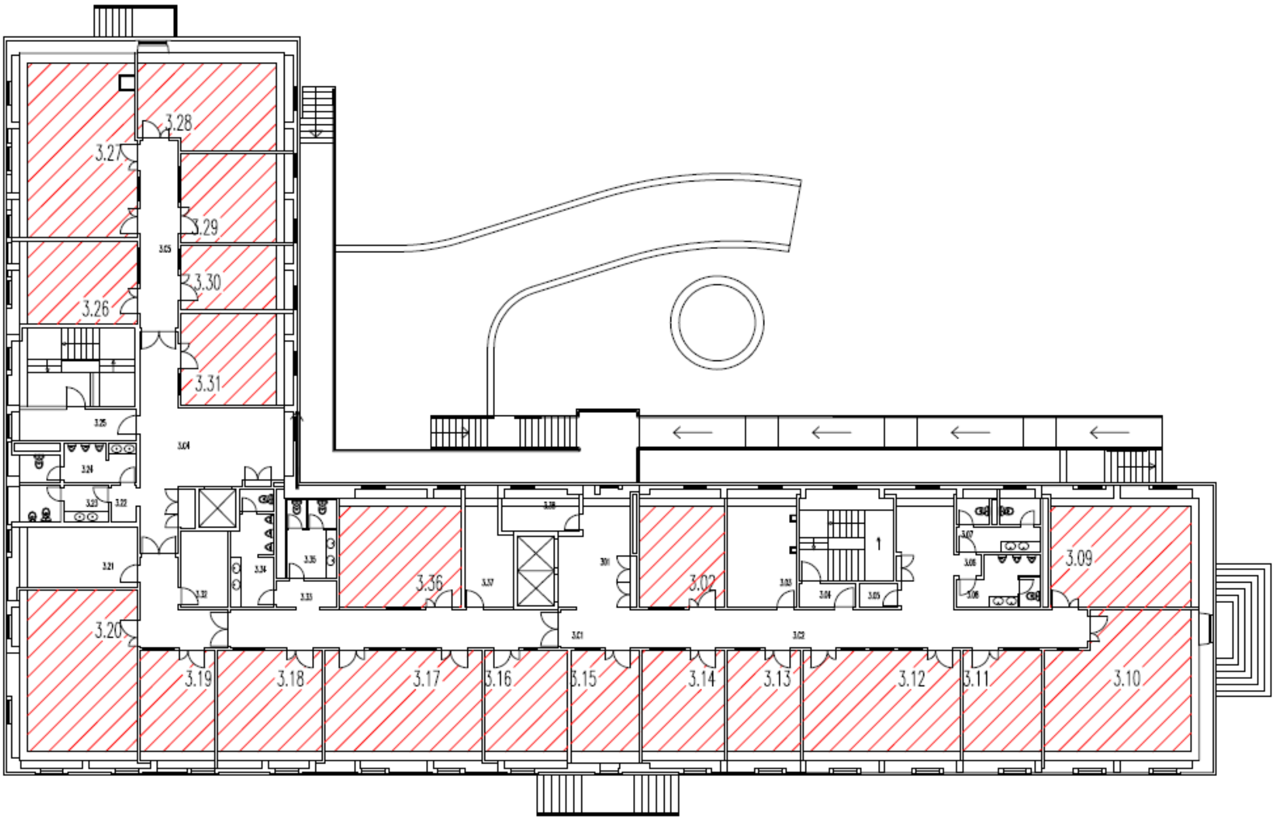
| | | | COOLING COIL | | | | | HEATING COIL | | | | Lp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SERIE Size | R# | Qa m3/h | Pt W | Ps W | Ts °C | Qe m3/h | dP kPa | P W | Ts °C | Qe m3/h | dP kPa | ISO or NR |
| 235 | R2 | 620 | 1.780 | 1.780 | 17,7 | 0,266 | 6,93 | 1.840 | 31,3 | 0,269 | 6,43 | 41 |
| | R4 | 450 | 1.550 | 1.470 | 16,4 | 0,266 | 6,96 | 1.570 | 32,8 | 0,269 | 6,41 | 34 |
| 22 | R6 | 295 | 1.270 | 1.140 | 14,7 | 0,266 | 6,99 | 1.220 | 34,9 | 0,269 | 6,39 | 21 |

235/33

| TEMPERATURES | COOLING COIL | HEATING COIL |
|---|---|---|
| Fluid | Water | Water |
| Fluid inlet temperature | 10 °C | 40 °C |
| Fluid outlet temperature | 15 °C | |
| Recycled air inlet temperature | 26 °C | 22 °C |
| Recycled air inlet humidity | 50 %(RH) | 50 %(RH) |

| | | | COOLING COIL | | | | | HEATING COIL | | | | Lp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SERIE Size | R# | Qa m3/h | Pt W | Ps W | Ts °C | Qe m3/h | dP kPa | P W | Ts °C | Qe m3/h | dP kPa | ISO or NR |
| 235 | R2 | 725 | 2.560 | 2.390 | 16,3 | 0,402 | 15,8 | 2.620 | 33,2 | 0,406 | 14,3 | 38 |
| | R3 | 600 | 2.340 | 2.140 | 15,6 | 0,402 | 15,8 | 2.360 | 34,1 | 0,406 | 14,3 | 35 |
| 33 | R6 | 305 | 1.660 | 1.340 | 13,0 | 0,402 | 15,9 | 1.480 | 37,1 | 0,406 | 14,2 | 16 |

*Location in the building (Schematic Distribution)*




In zones 3.09, 3.12, 3.17, 3.26, 3.28, 3.29, 3.31 and 3.36 – 2 units model 235/22;
In zones 3.10, 3.20, 3.27 – 2 units model 235/33;
In zones 3.02, 3.11, 3.13, 3.14, 3.15, 3.16, 3.19 – 1 unit model 235/22;
In zones 3.18, 3.30 – 1 unit model 235/33.

*Control system*

Each fan coil can be individually regulated by means of a thermostat. Comfort temperature and fan speed can be selected by the user by means of a wall mounted control.

## III.3 Outdoor Loop Description

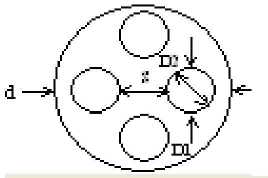
### *III.3.1 Ground Source Heat Exchanger Description*

*Type of configuration (rectangular, line....etc)*

The GSHE consists of seven vertical boreholes connected in a balanced parallel configuration. The six boreholes are arranged in a 5x5 m rectangular grid.

*Single U or Double U (specifying diameters with drawings)*

**DOUBLE U TUBE**




| | | |
|---|---|---|
| Borehole diameter (d) | 110 | mm |
| Pipe internal diameter (D2) | 32 | mm |
| Pipe external diameter (D1) | 35 | mm |
| Shank spacing (s) | 56 | mm |

*Borehole depth*

Each borehole is 125 m deep.

*Borehole spacing*

There is a 5 m separation between boreholes.

*Grout material and conductivity*

The grout material is graded sand and it has a conductivity of 2.4 W/m/k

*Depth below surface*

There is 0.8 m space between the surface and the top of the ground storage.

*Pipe material*

The material used in pipes is high density polyethylene HDPE.

*Working fluid*

Pure water is used as the working fluid.

### *III.3.2 Hydraulic Loop Description*

There are seven boreholes connected in parallel and balanced with several equalising valves. The total external flow rate is 14,9 $m^3$/h.

The outer hydraulic group consists of the following components:

- Manifolds
- A circulating pump (Grundfos)
- A mass flow meter
- Manometers.
- Expansion vessels.
- Regulating and equalising valves.

### *III.3.3 Hydraulic pipes distribution system: schema of the distribution specifying external and internal diameter and flow rate.*

This is an open issue.

### *III.3.4 Circulation pump selected:*

*Total pressure drop and water flow rate that must be provided by the circulation pump.*

Pressure drop= 18.5m ; Flow rate=14,9 $m^3$/h.

*Manufacturer, model, type (fixed velocity or variable velocity) and catalogue data (performance curves)*

The selection of the circulation pump for the outdoor circuit is still an open issue. It will be a high efficiency permanent magnet variable speed pump, supplied by Grundfos. The technical advice, from the Portuguese Grundfos representative is also still pending.

## Chapter IV. OPEN ISSUES (design or construction decisions not solved yet)

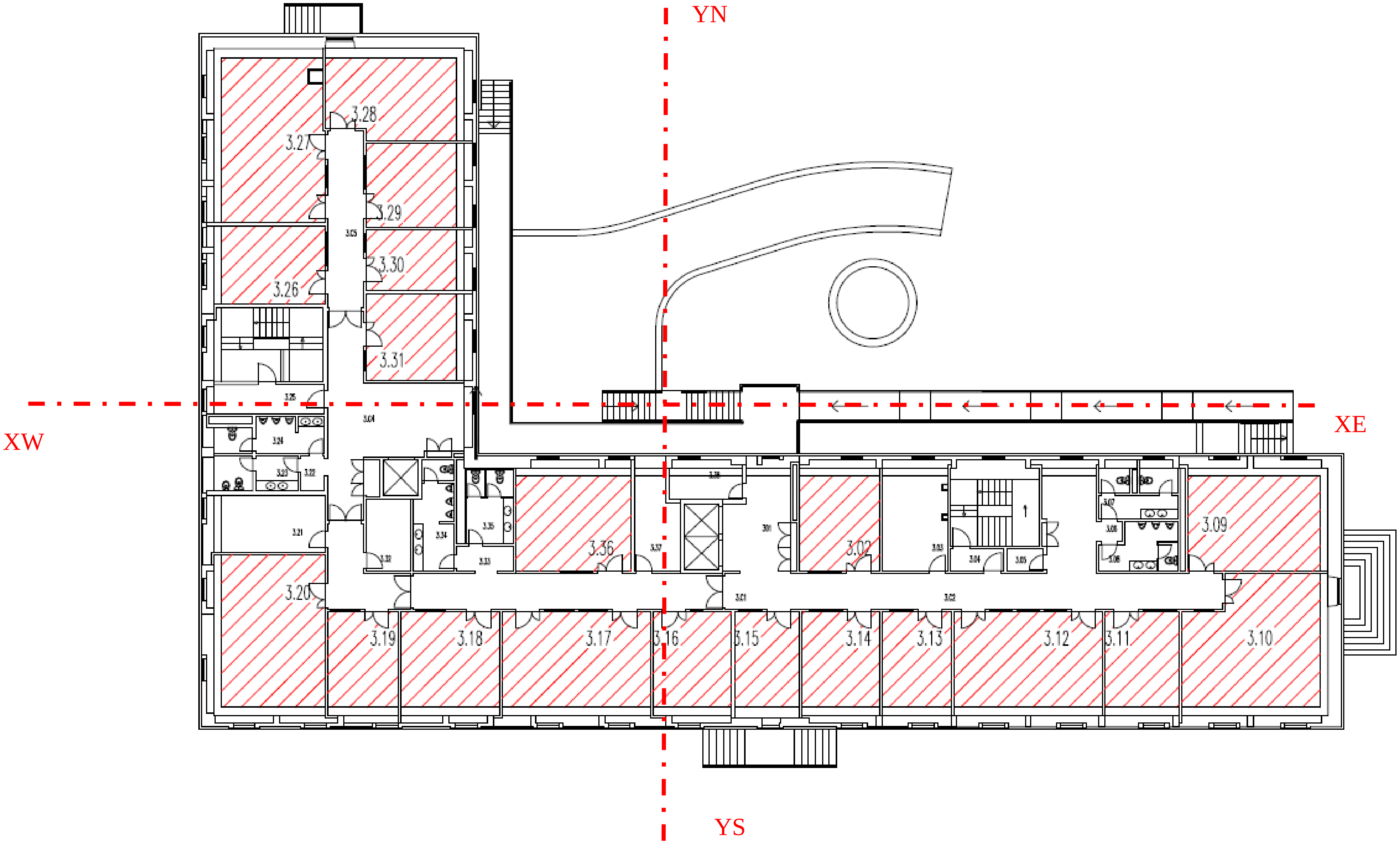
GSHP

There are a number of open issues on the design, mainly caused by the need to minimise intrusion to the regular building's activity during installation, and aesthetics (there is already an air conditioning system installed which doubles the number of terminal units in each room). These concerns considerably delayed decisions regarding the floor in which to undertake the project and the model of fan-coil units to use.

The above mentioned delays caused some setback in the design process which has not yet been finalised. Nevertheless, at this stage, all decisions having major implications in the design have been made leaving only minor details to be handled.

STORAGE SYSTEM

Considering a supply temperature around 40°C and a return temperature of around 35°C for the space heating loop, the PCM manufacturers recommend a PCM with a melting point of 46ºC.
This product has been well tested in installations in UK and Italy.
The Delta Temperature needed to charge and discharge the storage system is around 5ºC. In this way the outlet temperature of GSHP must be around 50ºC during the charge period, which will leads to a lower performance of the HP.
However, the HP will charge the system during the off peak load of electricity, when the prices are lower, which has advantages, namely in the integration of intermittent energy sources.


YN
XW
XE
YS
3.28
3.27
3.29
3.30
3.26
3.31
3.36
3.09
3.02
3.20
3.19
3.18
3.17
3.16
3.15
3.14
3.13
3.12
3.11
3.10

# ANNEX 2