DIRECTION

Demonstration at European Level of Innovative and Replicable Effective Solutions for very Low Energy new Buildings

D1.6: Demonstrators Control Strategies

WP1, Task 1.4

September, 2012 (M9)

(Revised version on M11)

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Demonstration of very low energy new buildings

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[1] PU = Public

PP = Restricted to other programme participants (including the Commission Services).

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0 Abstract

This document serves as first description of the possible control strategies for the demo sites based on the elements and equipment installed on them.

Must be said from the beginning that due to the different stages of the three buildings, the approaches for them can sound not as homogeneous as should be foreseen. In some cases is a more definitive description of a real state, while in other cases is more like a draft. Anyway in all cases the control strategies will surely be readapted along the project duration to include the results obtained on further analysis and simulations. Updated versions for the three buildings will be included on deliverable *D1.7 Building Management System to optimize demonstrators' performance* (M18).

There is a chapter dedicated to each one of the three buildings, CARTIF III (Spanish demo), NuOffice (German demo) and Black Monolith (Italian demo), with a general description of the main elements to be considered previous to the points related to the control system / strategies.

1 Demo 1: CARTIF III

CARTIF III new building will be a very low energy building, which will integrate a lot of solutions for saving energy and to improve the overall energy efficiency; it is located in the centre of Spain, under a Mediterranean Continental Climate. The building has 4.075 m2 of floor space for CARTIF Technology Center research activities, 935 m2 of offices and 3.140 m2 for industrial activities (as test facilities). It has been designed to have a very small heating load and a very low cooling load and other challenge was reducing the electrical consumption. The total foreseen primary energy consumption is 59,97 kWh/m2yr.

This building is composed of six industrial activities zones besides offices and common areas distributed in four levels. The use of the industrial activities zones will be for research and experimental plants mainly. On the basement are located the equipment rooms with the thermal facilities equipment. The air handling units (AHU) will be located on the roof.

1.1 Principal Systems General Description

CARTIF III new building is located in the centre of Spain, under a Mediterranean Continental Climate having 4.075 m^2 of floor space for CARTIF Technology Center research activities, 935 m^2 for offices and 3.140 m^2 for industrial activities (as test facilities).

As mentioned before, it has been planned as a very low energy building, which will integrate a lot of solutions for saving energy and to improve the overall energy efficiency.

The envelope has been designed to minimize thermal energy and light electrical demand through a special concept (glass wall and louvers blinds) that allows an important use of daylight with high solar gain and so to reduce thermal requirements. Also high efficiency lighting equipment will be used on the building.

There will be integrated a polygeneration renewable energy facility, designed as a combination of thermal plants (using a geothermal and biomass integrated systems)that will ensure high efficiency, energy balances between winter and summer periods (by means of the use of the ground storage capacity) and zero CO_2 emissions.

A PV plant will be installed in order to supply an important portion of the total electricity consumption.

And of course there will operate an advanced building management system (BMS) that will optimize energy uses by means of an efficient distribution and final use of the overall energy involved in each system and process.

CARTIF III building was designed to have several industrial activities zones and some offices for R&D tasks of CARTIF Foundation. So, there are four industrial areas of 3100 m^2 and an office area of 935 m^2. The main façade is south oriented, with almost the entire façade and the entire southwest side closed with a glass wall that improves solar gain and a blind with oriented louvers, fixed to optimize the daylight use, avoiding glare.

The building has basement, ground floor and first floor, but not into whole plant as some of the industrial zones were designed as cathedral ceiling or double height.

The building has been designed to have both a very small heating load and a very low cooling load. The building's typology, with a large industrial building surface and smaller offices surface, has allowed selecting solutions that can improve drastically the foreseen consumptions in order to achieve the topic target of the DIRECTION project. Some energy efficiency measures applied are:

- The envelope, designed as a glass wall in the southeast and southwest façade, that will allow reduce heating load due to a very important solar gain.
- A free-cooling system for the entire building that will allow a considerable reduction in cooling requirements; for the industrial zones, combining height, work schedule and, the special Valladolid's climate conditions only free-cooling will be used in summer.
- For the office area there will be a geothermal heat pump with seasonal performance, which will allow to balance the energy absorbed from and dumped to the ground so the annual thermal need to heat this area is null.
- All the necessary thermal energy for the industrial activities areas and the DHW will be provided by a biomass boiler with very high performance (> 90%), with the added value of having zero CO_2 emissions.
- The BMS will allow adjusting comfort conditions with a significant reduction in heating and cooling consumption.

Other challenge is the reduction of the electrical consumption. Equipment with an important electrical consumption are lighting, pumps, HVAC equipment (geothermal heat pump) and the industrial building HVAC system fans. To minimize those contributions have been applied many energy efficient measures like:

- Glass Wall and blind with oriented louvers, fixed to optimize the daylight use, avoiding glare.
- High efficiency lamps throughout the building
- BMS that allows managing the lighting and HVAC systems turning on and turning off, based on occupancy detection, with a big industrial building zoning and with lighting intensity regulation in the offices.
- High efficiency geothermal heat pump, COP 3,18 y EER 3,99
- Ventilation by variable flow in the industrial buildings zone, which involves a change in the air diffuser so that it can be regulated the air duct pressure.

Finally, a 45 kWp Photovoltaic plant will be included. It allows a contribution of 15 kWh/m2yr.

1.1.1 HVAC System

The thermal installation of the new building of Fundación CARTIF is entirely based on the production of the energy to cover all the energy needs of the building using different renewable sources as geothermal and biomass with a considerable decrease of CO2 emissions.

For the offices the main energy source will be the geothermal energy which is based on the exploitation of the natural heat present on the soil to air-condition environmentally. This system works giving or extracting heat from the soil depending on the needs of cooling or heating of the building by means of a set of buried collectors filled with a mix water-glycol circulating. To cool the building during summer the system sends the extra hot of the building inside to the ground. On the opposite, during winter, this equipment allows heating the building with the reverse process, taking hot from the soil through the collectors to send it to the building.

The principal elements of the CARTIF III geothermal installation are:

1. A water-water reversible geothermal heat pump with nominal power of 101.5 kW for heating and 77 kW for cooling, and COP of 4.35 and EER equal to 3.81.

2. A heat exchanger introduces on 100 m deep boreholes consisting of 15 geothermal double U polyethylene collectors of high resistance and long life with a mix water-glycol inside. Using double U collectors a 30-40% higher performance is obtained as there is a double flow circulating with the same length of borehole.

3. A hydraulic pump, for the water-glycol solution flowing through the geothermal collectors.

The geothermal pump, as well as the rest of elements of this system, is placed on a technical room located on the basement.

To cover the heat needs of the industrial areas in winter as well as for the production of DHW of the whole building a 220kW biomass boiler fed with pellets and kindling wood will be used. For the boiler there will be power modulation from25% to 100% so as to adapt the installation to a changing power demand for partial loads with no problem, avoiding thus unnecessary stops/starts of the installation and achieving then simultaneously a lower energy consumption and a longer useful life.

Apart from that there will be an intermediate inertial tank for the biomass boiler to guarantee a constant flow through the boiler and a better performance when the installation starts working. As for the geothermal system there will be a dedicated technical room located on the basement for this installation, containing the biomass boiler as well as the 3500l inertial storage tank.

From the collectors located on the technical rooms depart distribution circuits to each terminal unit which have been grouped according to the characteristics of consumptions, to create the zoning of the building.

- Industrial areas circuits: these circuits feed the air conditioning units located on the roof of each of the industrial areas and the offices, to heat and ventilate these areas.
- Offices circuit: to feed the radiant floor both for heating and cooling installed in these areas.
- DHW Circuit: To cover the domestic hot water needs of the building.

The **air conditioning of the industrial areas** will be done by air units. Each industrial area will have one AHU except the Ind. Area 1, which for its dimensions have two units. Each equipment will be located on the roof of the building, driving the air through circular ducts and making the air diffusion through thermoregulable nozzles which are oriented depending on air temperature. The air conditioning units of the industrial areas have adequate filters, free cooling, adiabatic humidification, cold (pre-installed) and heat batteries.

The **air conditioning in the offices** will be through radiant floor, heating to heat and cool to cold. In a system of this type heat is uniform and pleasant whenever is maintained a suitable soil surface temperature, because it produces no airflows and is completely silent. Is achieved a feeling of comfort and well-being leading to significant energy savings. Each radiant floor circuit will be regulated by the temperature sensor of each room. The areas have been defined according to their orientation.

To ensure the required ventilation within the offices is installed an air conditioning unit equipped with hot and cold battery, free cooling, mixing box, energy recovery, adiabatic cooling, filters, and desiccant systems preinstallation. Both the AHU and the ductwork is sized to complement the installation of radiant floor both for heating and cooling covering a percentage of the thermal needs of each office area.

In addition for **the room of DPC** (data processing center) will be installed an air handling unit with condensation control, humidity control, filtration and temperature control, with nominal power of 5kW to cover the required indoor conditions of 18 ° C.

The **heat production for DHW** will be obtained through the biomass boiler. The installation system for domestic hot water is designed by accumulation, with automatic regulation system, and will have a thermostatic valve for its distribution.

The facility for DHW is intended to heat the water on the general distribution network at temperatures suitable for consumption. It will control water features, such as flow, temperature and hygienic quality.

HVAC CARTIF 3			
Generation		*Mode*	*Location*
GEOTHERMAL Heat Pump	RADIANT FLOOR	**HEAT**	OFFICES
	RADIANT FLOOR	**COOL**	CORRIDORS
	AHU in office	**COOL**	OFFICES
			CORRIDORS
BIOMASS Boiler	DHW	**HEAT**	All CARTIF
	AHU (Climate Unit)	**HEAT**	Industrial Area 1
			Industrial Area 2
			Industrial Area 3
			Industrial Area 4
			Industrial Area 5
			Industrial Area 6
			OFFICES
			CORRIDORS
Freecooling	AHU (Climate Unit)	**COOL**	Industrial Area 1
			Industrial Area 2
			Industrial Area 3
			Industrial Area 4
			Industrial Area 5
			Industrial Area 6
			OFFICES
			CORRIDORS

1.1.2 Lighting system

Regarding the lighting system, this facility involves a high consumption in all the buildings. Therefore to achieve a low-energy building it is important to take measures in order to obtain as much saving as possible in this point. To do it, lighting of both offices and industrial areas are high efficiency lights. For example, on the Industrial zones, the lights used are sodium vapour ones.

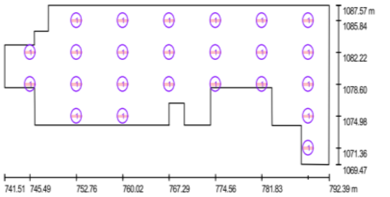
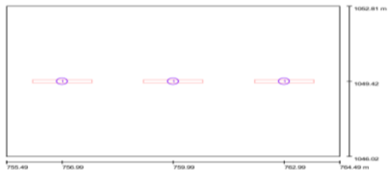
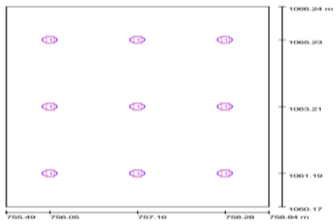
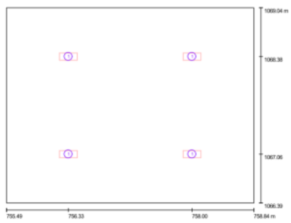
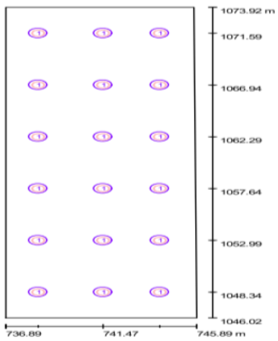
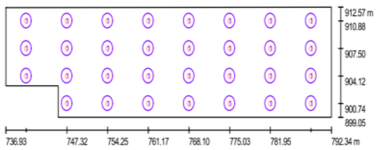
This type of lighting has a much lower consumption relative to other luminaires on the market. In addition to selecting low consumption lights, there are also installed control devices that will allow variations on the intensity depending on the daylight values and users' needs.

Also to allow future control, lamps are grouped by area of use and proximity to windows, so the light can vary in intensity depending on the natural light entering the offices and industrial areas.

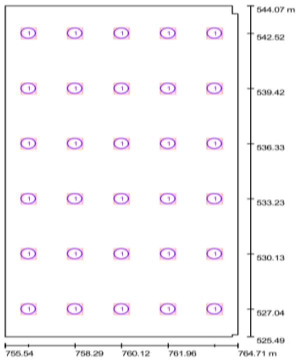
Of course all lighting devices have been selected complying all national rules and legislation for Spain.

For the lighting inside the building a general subdivision has been made depending mainly on the kind of use of the areas. Main types used are industrial areas, offices, technical rooms, toilets, corridors, cars park area, etc.

Using this zonal distribution, the next table shows the selected luminaires for each type of space:

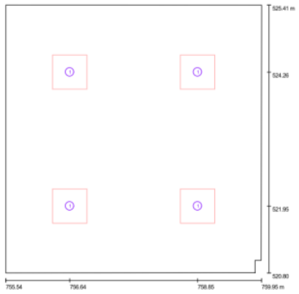
Basement Floor		Disano 921 Hydro T8 El Disano 921 2*58 CELF-D grey
Technical rooms		Disano 921 Hydro T8 El Disano 921 2*58 CELF-D grey
Changing rooms		Disano Shell 1 IP44 Fosnova SHELL 1 FCLC2*26 CNRL silver
Toilets		Disano Shell 1 IP44 Fosnova SHELL 1 FCLC2*26 CNRL silver
Industrial area 2 inf.		Disano 1116 Quark – Disano 1116 SAP-E 250 CNRL-EM black
Industrial area 1		Disano 1116 Quark – Disano 1116 JM-E 400 CNRL- black

Industrial area 3



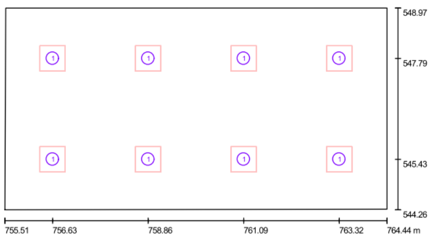
Disano 864 Comforlight T8
Disano 864*18 CELL white

Office 1



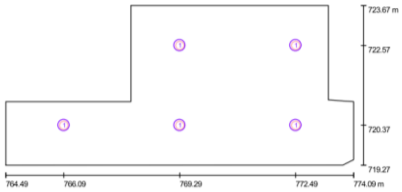
Disano 864 Comforlight T8
Disano 864*18 CELL white

Office 2



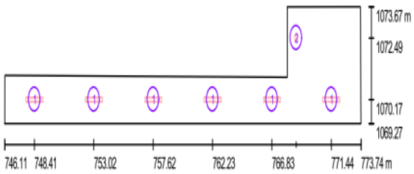
Disano 864 Comforlight T8
Disano 864*18 CELL white

Corridor



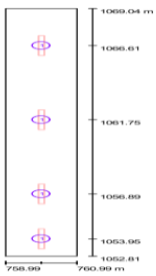
Disano Energy 2000 Fonova ENERGY 2000 FLC 2X26D 4K CELL aluminium+ anillo prismatizado Energy 2000 + pantalla energy 2000

Basement corridor 1

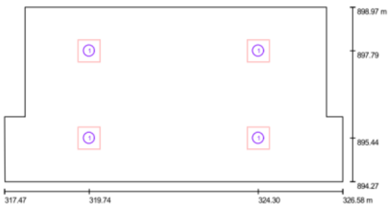
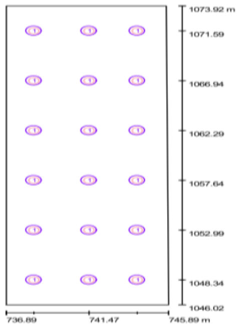
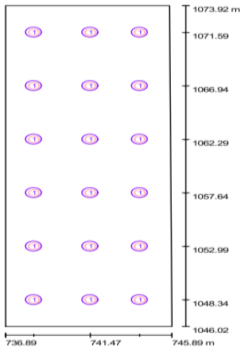


Disano Energy 2000 Fonova ENERGY 2000 FLC 2X26D 4K CELL aluminium+ anillo prismatizado Energy 2000 + pantalla energy 2000
Disano 921 Hydro T8 EL
DIsano 921 2*36 CEL-F grey

Basement corridor 2



Disano 921 Hydro T8 EL
DIsano 921 2*36 CEL-F grey

Ground floor rest room		Disano 864 Comforlight T8 Disano 864*18 CELL white
Industrial area 4 inf.		Disano 1116 Quark – Disano 1116 SAP-E 250 CNRL-EM black
Industrial area 3 inf.		Disano 1116 Quark – Disano 1116 SAP-E 250 CNRL-EM black
Basement cars park area		Luminaire: Disano 921 Hydro T8 EL Disano 921 2*36 CEL-F grey Lamps: 2 x FL36/4/3B

1.2 Control Elements

The size of the control system can vary between one unique device, having only one action, to wide systems able to control all equipment and devices of the whole installation. The different elements of a control system can be classified as:

Controllers: Controllers are the brain of the control system, devices able to manage the installation through the program generated on them and the information they receive form the system. There can be a unique controller or a set of them distributed all over the system.

Sensors: Sensors are the elements that monitor the environment taking information of the installation and sending it to the controller (water, gas or smoke presence, temperature, flow meters, humidity, light intensity, etc.).

Actuators: Actuators are those devices that carry out the orders generated on the controller acting over other elements of the installation (turn on/off, lower/raise, open/close, etc.).

Network: The network is the transmission medium that carries the information between devices via its own wiring or by other systems one (grid, telephone network, data network) or wirelessly.

Control and technical management software & Interface: The interface is as can be imagined is the way how the users can interact with the control system. It shows the information of the system and allows the user to give set point or act on specific devices of the installation modifying if wanted the performance of the system.

Let's say that it is not necessary that all those elements described have to be independent devices. On the opposite some of them can be combined in one same device. For example a central control equipment can integrate at the same time a controller, actuators, sensors and various different interfaces.

The control systems act on, and interact with, the equipment and the electrical systems of the installation according to:

- The user program and the configuration of the equipment.
- The information gathered by the sensors of the system.
- The information provided by other interconnected systems
- The direct user interaction with the system.

Following this scheme, on CARTIF III building the structure and elements that are installed (or are foreseen to be installed) are mainly the following.

Controllers

Fort the HVAC system control the devices used are TAC Xenta programmable / configurable modules (Schneider). Those modules allow programming the different control functions for the installation (automation and control of Fan-Coils, VAV boxes, air conditioning units, etc.). Currently a basic control is implemented, but it is open for a more complex and advanced one that will be implemented during the project duration. The set points and other feedbacks for those controllers can come from the users, any sensor or even other controller at the same or higher level.

For the lighting, the elements controlling are at the same time actuators so will be described in this point.

Sensors

Along CARTIF III building there are installed a variety of sensors, as presence or light intensity sensors for the lighting installation and temperature sensors (environment and pipes), pressure sensors, flow meters (Kamstrup), etc. for the HVAC system.

Actuators

Actuators on CARTIF III are for instance the water pumps and valves (2 ways or 3 ways).

Must be highlighted among actuators the engines installed on the set of oriented louvers installed in the main office windows. These engines allow varying the degree of inclination of the louvers in order to modify the outside light coming into these offices as well as to avoid glare.

In the particular case of lighting, the actuators/controllers used to control luminosity are Dimmer devices 3DIM DR-N (Schneider). These elements allow both turning on and off the illumination of a certain area, as well as the regulation of its light intensity. To do this, the control system has a device (dimmer) which is capable of performing this regulation based on a given set point, usually expressed as a percentage of the total. This set point can be specified by a user, by a device (sensor) or calculated by a controller depending on certain conditions.

A possible installation scheme of such equipment may be seen below on Figure 1.

The dimmers are associated in this case, to electronic ballasts placed on the luminaires which are responsible for acting directly on them varying the intensity of light depending on the regulation carried out by the dimmer.

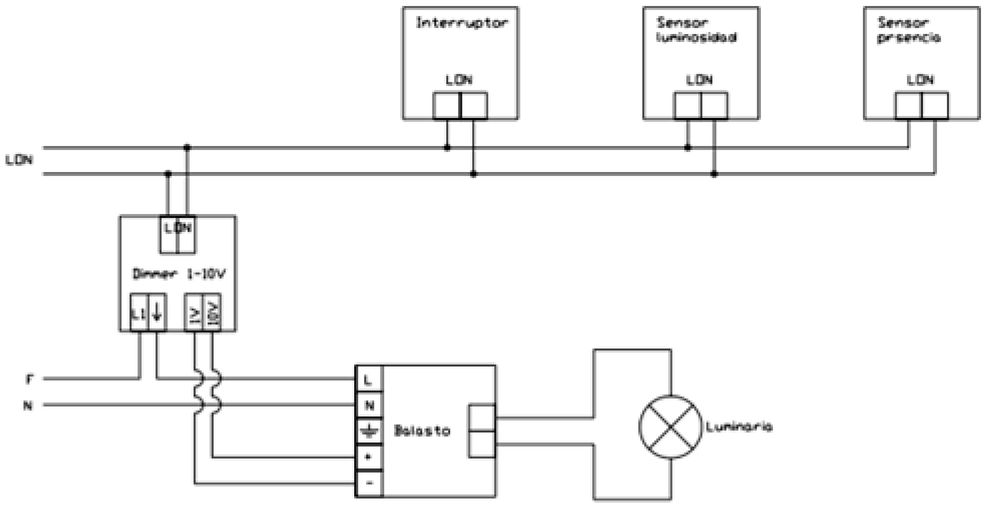


Figure 1 Dimmer connection scheme

These dimmers as are also programmable / configurable so can be considered as controllers and actuators at the same time.

Another type of lighting controllers that can be considered also actuators ON / OFF are the input and output modules SVEA 8I 8O (Schneider). In this kind of ON / OFF regulation, the devices are only able to activate or deactivate the illumination of an area based on the set point, which in this case will be turn on or off. This set point as in the previous case may be determined by a user, by a sensor, or by a controller.

A possible installation scheme of such equipment may be seen below on Figure 2.

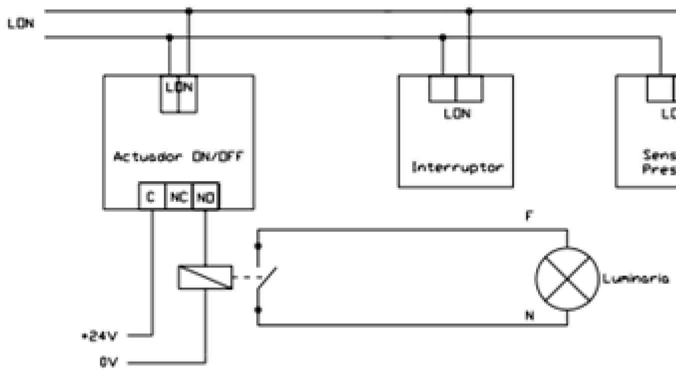


Figure 2 ON/OFF actuator connection scheme

Network

Both for the HVAC installation as for the lighting one LONWORKS has been selected as control and monitoring network. This network is compatible with all devices that have been installed, (sensors, actuators, controllers, etc.) as they have been selected for this purpose. The network has been built with the Echelon LonMaker software which is used to design the control network and communications between the different control equipment, as well as common variables, etc. It is an autonomous distributed control network.

Control and technical management software & Interface

The selected interface for control and monitoring is a SCADA system called TAC Vista (Schneider) which is totally compatible with the network chosen and all controllers and other devices used on the installation like the different versions of TAC Xenta and SVEA modules.

There will be a personal computer (PC) workstation programmed for BMS. TAC Vista IV Workstation Manager. That is, possibility for monitoring and management of any element governed by the system as well as reporting, control of events, alarms, etc.. In the same computer will be installed the application Management Database (TAC Vista Server).

For the integration of third party systems, is foreseen to have a TAC Vista OPC Client license which allows the integration of the system through communication, transfer and update of information among systems.

Also will be available a Web server (TAC Vista Webstation) to allow remote access to the facilities management system from any computer connected to the network (Ethernet / Internet) using different passwords and accessibility categories.

Considering the location and use of the controllers and other control system devices, there may be several classifications for the structure of the system. Those below are the ones that come closest to the reality of CARTIF III.

Decentralized Architecture

In a control system with decentralized architecture, "intelligence" is distributed among different controllers, interconnected by a bus that will support the exchange of information between them and the actuators and interfaces connected to the controllers:

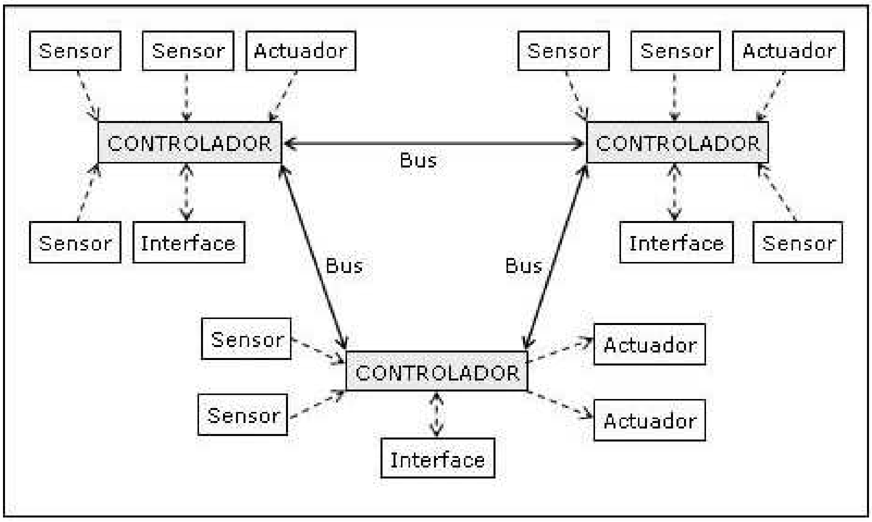


Figure 3 Scheme for Decentralized architecture

Hybrid / Mixed Architecture

In a control system with hybrid architecture are combined different types of architectures such as centralized, decentralized and distributed. In a system of this type can be found a central controller, various decentralized controllers and interfaces, sensors and actuators which are also controllers.

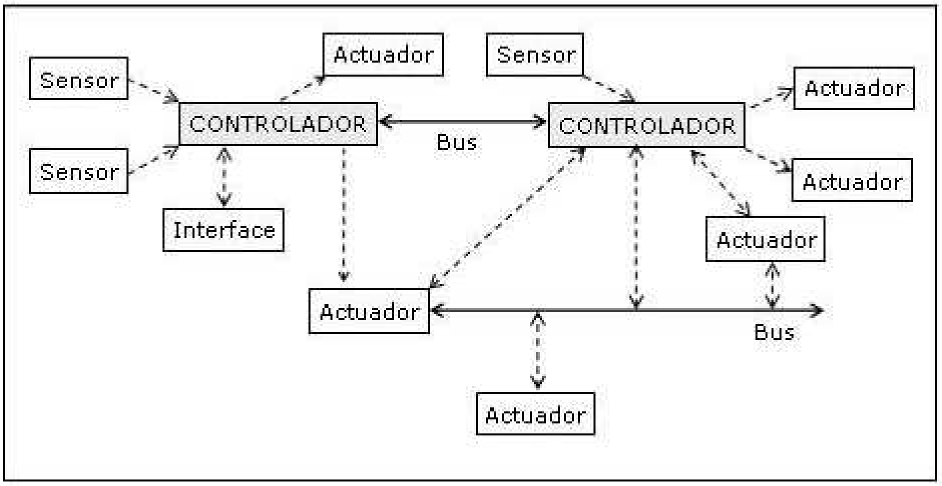


Figure 4 Scheme for Hybrid/Mixed architecture

For CARTIF III main criteria under which it will be designed the architecture are reliability and flexibility of the management system.

A high reliability must be associated to all elements of the management system. A reliable system should prevent that the failure of one of its parts could produce the collapse of the entire system.

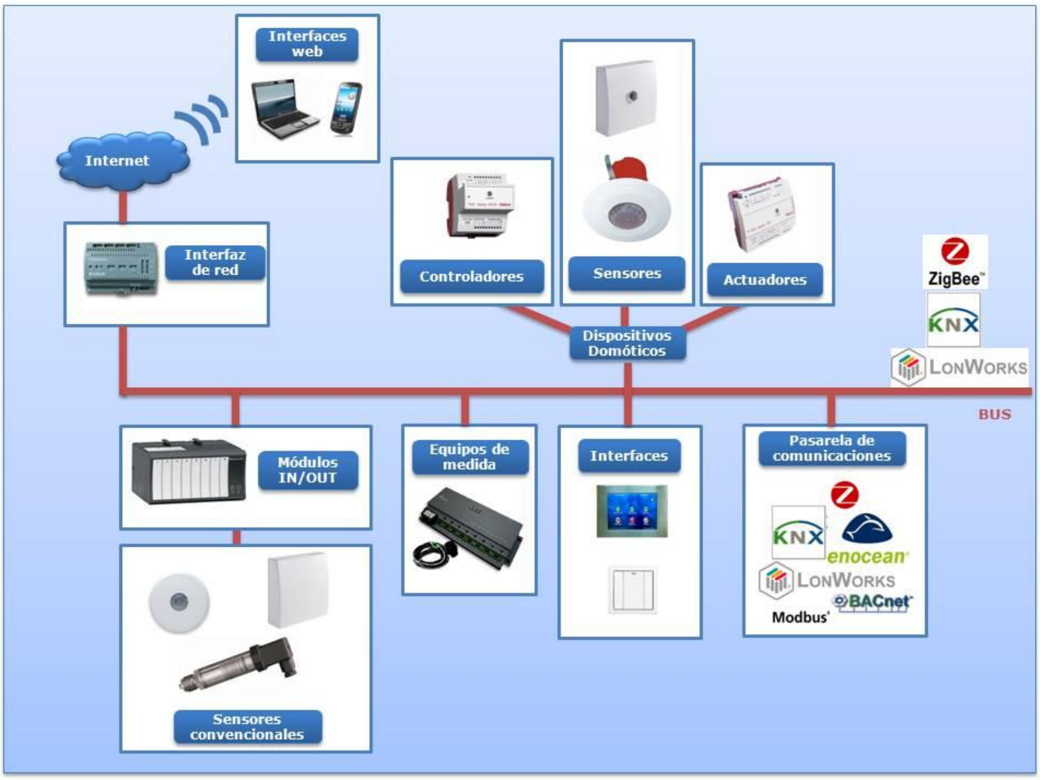


Figure 5 Foreseen scheme of the management system

An architecture that is adapted to these conditions is shown below. Systems that have this hierarchical architecture are highly flexible and provide a high level of reliability.

LEVEL 1

Consisting of the field elements located at the facilities (sensors and actuators), which will collect the measures and digital inputs to be sent to the second level. This level will act directly on the facility according to the orders received from higher level.

LEVEL 2

This level consists of distributed control processors open programming (Xenta/SVEA modules) to which will be assigned regulatory functions, control and monitoring of the production of heating and cooling, air conditioning and power control.

They may work independently from the rest of the controllers that are connected to the same bus as well as from the central control system, while they receive and send information to the control center via the system bus.

These controllers also manage the production and distribution of energy for air conditioning as well as the treatment of air made on the AHUs.

Controllers send to the central control point information about:

- Environment temperature of each area
- Current Set Points
- Deviations with respect to the set points.
- Heating and cooling demand.
- Energy consumption
- Etc.

LEVEL 3

Level 3 is formed by the Building Control Centre. Composed of a Management Central Computer, will have the mission of coordinating and monitoring the the building installations acting through the elements of the lower levels. This level will have a user interface to facilitate the control of the building installations.

From the General Control Center will be possible to act on the various facilities so that, automatically or manually, orders can be given for activation or deactivation and change the operating parameters of the facility (temperature set points of the different dependencies, lighting schedules, etc.).

Some features of the system are:

- Monitoring the status of all facilities, by displaying synoptic diagrams of each facility monitored.
- The reception of any alarm produced.
- Equipment start and stop automation.
- Graphical and numerical recorders to track the historical evolution of the signals of the installation.
- Event Logging of alarms of the different installations and user commands.
- Access Control System, through a system of user configurable passwords.

1.3 Kind of Areas & Uses

In order to implement the management of the building it is necessary to differentiate the kind of areas that will be controlled. Three are the elements that have been considered to make this characterisation: the lighting control elements available, the HVAC ones, and the foreseen use of the areas.

If we look for the kind of areas based on the lighting we have to focus on the type of available elements on the circuits of each zone, which in CARTIF III are basically two: those that allow variable intensity (with dimmer) and those for on/off control exclusively.

Taking this aspect into account, we can differentiate the zones of the building where dimmers are installed, which are the main offices on the upper floor. The rest of the spaces on CARTIF III, that is rest of offices, corridors, industrial areas, technical rooms, toilets, etc. have so far ON/OFF actuators (although the switching can be made manually or by automatic control based on different programmed strategies).

We can arrange the areas also depending on the HVAC. Using this criterion we have three groups of areas.

First we have to consider those areas where the air conditioning is done with air heater units, AHU, (forced convection air heater) exclusively. Those areas correspond with the spaces where is foreseen to have lower level of occupancy which are the industrial areas of the building.

There are other areas where there are both radiant floor and AHU. Those are the main offices located on the upper floor.

Finally we can consider those areas supplied only by radiant floor, which correspond to halls, corridors, toilets, administrative areas, etc.

As a final point, if we consider the foreseen use of the area to make the classification, we can find there are mainly two kinds of spaces, those for standard and fix use which are mainly the offices areas (apart from technical rooms and similar ones), and on the other hand those with variable use mainly represented by the industrial areas which will adapt their use depending on the different test facilities installed inside on different moments on the future (also should be considered here areas initially defined as corridors, rest halls or meeting rooms that can be reconfigured to act as offices or other kind of area).

1.4 Control Strategies

An important part of the energy used in a building goes to heating and cooling. Thus, apart from selecting the most efficient technologies is so important to implement also a smart and global control to guarantee as much energy saving as possible, maintaining at the same time an adequate comfort level for the users.

Also, a correct management of the lighting can lead us to savings up to 80% on energy consumption compared to a traditional installation. It has been studied that controlling the switching (on/off) on walkways and common use zones depending on the presence can provide savings around 20%. Also regulation of the artificial lighting depending on the use of the room or the natural supply and even not allowing levels on the dimmers of 100% (the difference between a lamp at 80% and another with 100% is negligible), can lead to a saving up to 40%.

For both systems, HVAC and lighting, different kind of controls can be applied depending on the point of view. Also different approaches can be done. A first factor that is going to be considered is the kind of user interacting the control system. So we are going to make difference between a normal user or a high level user (or administrator). Following point describes the modes of operation wanted for CARTIF III following this approach.

1.4.1 Modes of operation wanted

Final User Mode

The control system must provide end users with an interface which displays the different areas in which he can interact with the system, and for each of these areas, must have accessible information of those variables that are to be modified, controlled, etc.

In the case of the lighting control the system should therefore show the user information about the lighting circuits that are activated or deactivated and a possible interface for the user to activate, deactivate, or even change the light intensity (in those cases where possible) the wanted lighting circuit.

Figure 6 below shows an example of interface through website that offers these features and allows adjusting the intensity as well as controlling the switching on or off different lighting circuits that are installed on the area dedicated to the main offices.

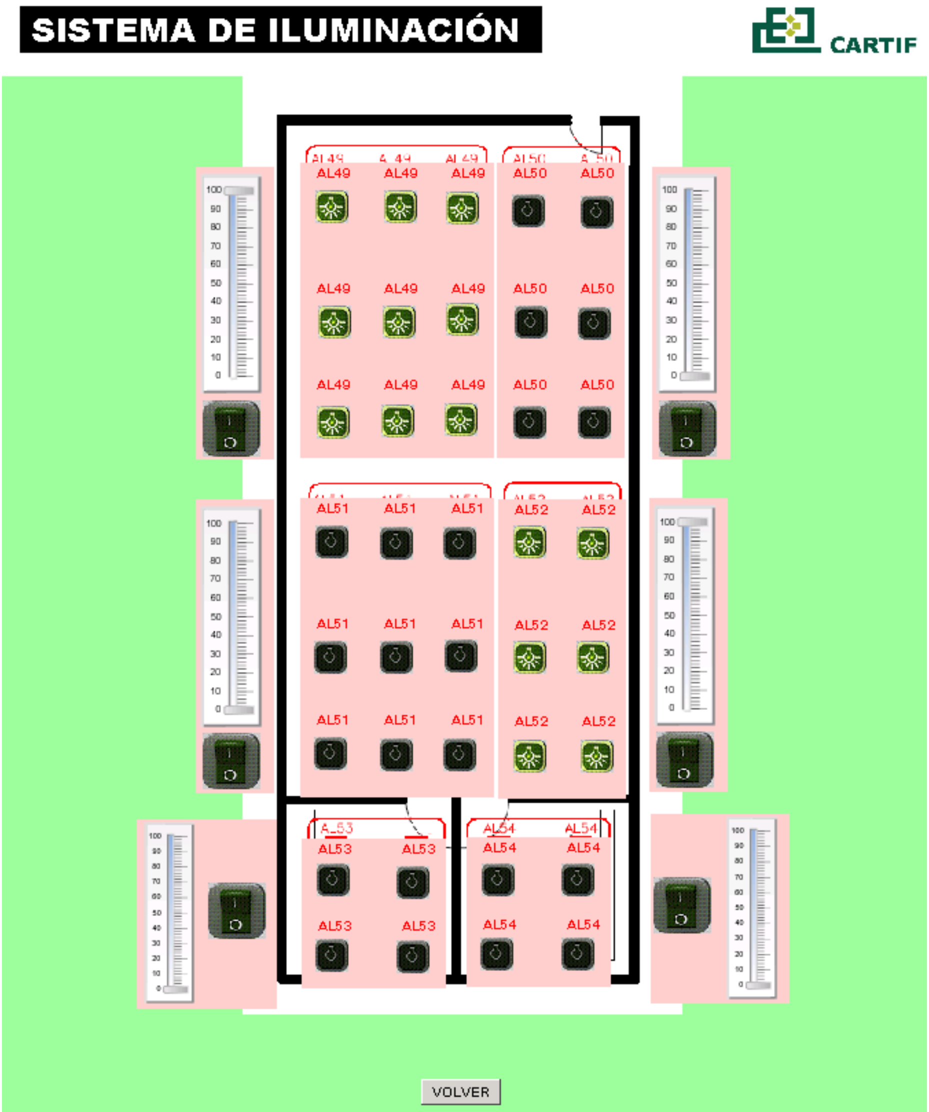


Figure 6 Example of user interface for lighting control in CARTIF III

In addition to the above, in the building have been installed in the windows of the south side, adjustable louvers. Through these louvers the interior lighting can be changed to higher or lower depending on the inclination of them, apart from avoid glare. Logically it also influence on the temperature inside the room. In the main offices those louvers are motorized and currently their control is manual, but is intended to be part of the automatic control of the building.

- Regarding the HVAC systems, as happens on the previous case, the system must offer the user a number of features and information among which can be showed each one of the with different areas which can be manipulated and for each area should be available among others: Current temperature
- Temperature set point for winter (21º – 24ºC aprox.)

- Temperature set point for summer (22ºC – 25ºC aprox.)
- Timetable (Calendar) if any
- Etc.

Figure 6Figure 7 below shows an example of interface for the heating and cooling system on the area dedicated to the main offices of CARTIF III.

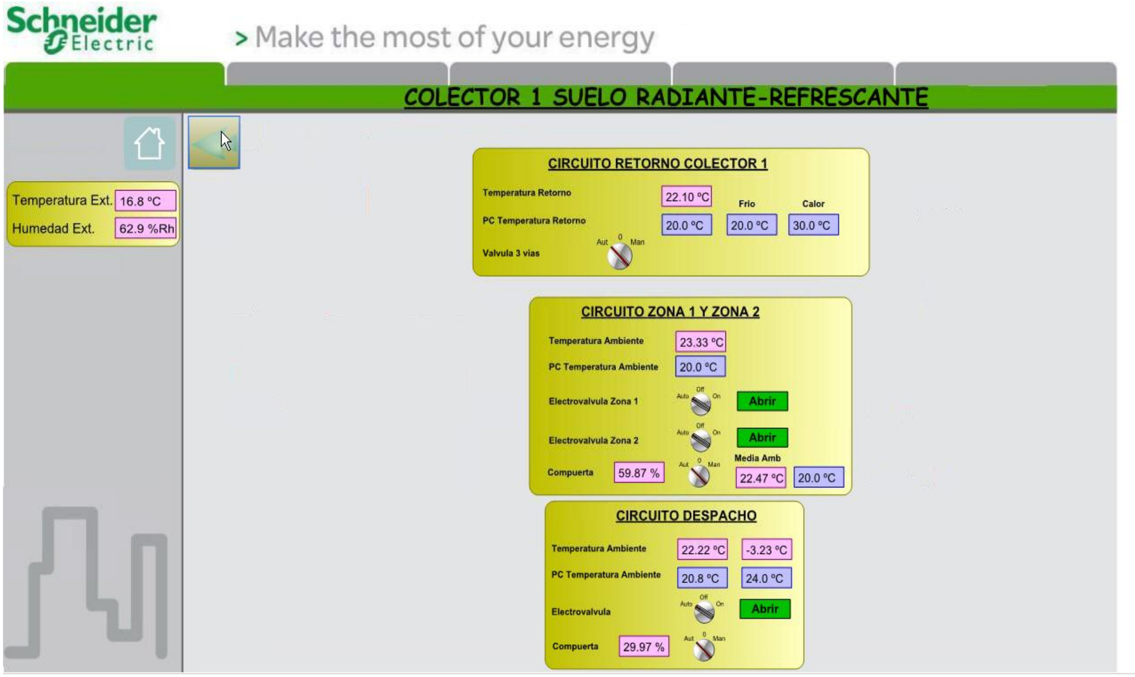


Figure 7 Example of user interface for heating-cooling control in CARTIF III

Administrator Mode

Apart from having all functionality available for a final user, the control system in administrator mode will offer at least the following features:

- One section showing the general status:
  - All temperatures (table)
  - All set points
  - Status of all equipment (table) (ON/OFF/..)
- General information of operation of each equipment:
  - List of HVAC equipment:
    - Status
    - Temperature set point to be applied
    - Temperature of its influence area
    - Deactivation/activation/maximum
    - Location (link to its area)
  - Lighting:

- List of luminaires
  - ON/OFF
  - Status
  - Base timetable / alternative timetable
- ON/OFF general (top priority)
- Presence:
  - Status
  - Temporization
- Brightness:
  - Status
  - Calibration

o Temperature sensors:
- Current values
- Calibration

In the particular case of CARTIF III building, the software also displays this information on the user mode although does not allow modifications. When entering the management software, this discriminates between standard user and administrator user, offering this last the capabilities to modify, alter or delete certain parameters or variables that in user mode are not available, such as the programming by schedule. In this case the standard user can see what schedule has been programmed, but cannot modify it, something the user with Administrator role can do.

1.4.2 Variables to be controlled

Regarding the lighting in the cases where the system does not allow adjustment of light intensity, the controlled variable is reduced to one, which will be the activation or deactivation state of the respective lighting circuit.

Furthermore, in cases where the system does allow dimming lighting (main offices), we can consider two variables to control, lighting intensity and state of activation or deactivation of the corresponding circuits (although this second one can be integrated on the first one as cero intensity).

As already mentioned, through the oriented louvers installed in the windows of the main offices, can also be changed the interior lighting.

For HVAC systems, the control variables will be essentially the room temperatures of each one of the spaces, but also can be controlled other variables such as temperature flow supplied and on return of the different radiant floor circuits, set point temperatures for air conditioners, their air output pressure, manual or automatic operation of the equipment, water temperature of the boiler pump, DHW temperature, etc..

1.4.3 Possible strategies

Here are described some of the control strategies that will be considered for the different systems.

Control strategies for operation based on LIGHTING

A first selection is to have manual control or automatic one.

For manual control the strategy is simple, but can be divided into two cases, that will be the on/off mode and the dimmers mode

- Manual
  - ON/OFF. In this mode, the user only has the possibility to turn on or off the lighting according to their need to use or not.
  - Dimmer. In this case the system allows intensity regulation of lighting. In this situation, the user has authority to turn on or off the light, and being able to vary the intensity of it.

- Automatic. In case the lighting control is performed automatically, various scenarios can be distinguished:
  - Timetable + constant control. In this case, the activation or deactivation of the lighting will be conditioned by a time schedule that will determine when turn it on or off. Besides the light intensity will vary depending, for example on set point and external light conditions.
  - Timetable + ON/OFF. In this case, the illumination is activated based on a time schedule, but also responds to commands given by a user or a controller depending on information gathered from different sensors.
  - Timetable and presence. This is a special case of the previous one, in which the sensor that indicates whether to turn on or off the light to the controller is a presence sensor. This is for example a typical control applied on bathrooms.
  - Presence. This control is similar to the previous one but simpler, without time schedule and taking into account only the presence sensors. So, if the sensor detects presence in their area of influence then the lighting is activated. If in some programmed time there is no presence detected, the light is turned off.
  - Light intensity + presence + timetable + on/off. This control is a combination of all the previous ones. Lighting intensity varies depending on the luminosity set point on the other hand, the lighting turns on or off, whenever it is within the time

scheduled and has presence detection or in case any user indicates activation or deactivation explicitly.

Control strategies for operation based on HVAC

Similar to what happens with the lighting system, the HVAC can be controlled manually or automatically. In this case, it should be noted that because the equipment of the various rooms are different, a division is made on the control based on which of these elements are installed in the area to be conditioned.

In areas where both systems are available (radiant floor + AHU) the central control will decide how to proceed depending on the temperature set point. At the same time temperature flow supplied and on return of the different circuits will be also controlled to maintain them on the adequate ranges. This will depend on the time of year. The regulation of the installation based on time schedules also depends directly on the station. For example temperature set points of 24 °C in summer can be 22 °C in winter.

HVAC based in generation sources

- **GEOTERMAL** Heat Pump: for radiant floor heating and radiant floor cooling, in offices and corridors and also we use the geothermal heat pump as source for Air Handling Unit in cool mode in office and corridors.

- **BIOMASS** Boiler: is used for Domestic Hot Water and as hot source for Air Handling Unit in Industrial Areas and Offices and Corridors.

- **Free-Cooling:** is used in summer for giving air cooling to Industrial Areas through Air Handling Unit

HVAC based in the season, we have three operation modes:

- **Winter** for heating:
  - In the office we have the base with radiant floor, and if it's necessary an extra heating we have an AHU
  - Industrial Area we only have AHU

- **Summer** for cooling:
  - In the office we have a radiant floor, and if it's necessary an extra cooling we have an AHU it's the same operation as in winter
  - Industrial Area we only have free-cooling

- **Autumn/Spring** It's maybe necessary heating and cooling:
  - In the Office we have Radiant Floor for heating and AHU for cooling

- Industrial Area we have AHU for heating and cooling with free-cooling

HVAC based in Operation Mode

- **Manual:** It makes a start or stop of each equipment depending on whether is desired its use or not, and the regulation of their different set points. This case is independent of the area to control, is directly controlled the equipment one or more of each zone, whatever they are.
  At the moment there is any system that it is works in manual mode because we are optimising the control program

- **Automatic:** The user will determine the set point and will select Heat mode or Cool Mode, and the system must be able to get the set point.

  For this scenario, climate control responds mainly to a time schedule, as in the previous case, in which discriminates mainly when using equipment based on the season, and the set point or set points fixed for that season.

Other control strategies

The aim of all control strategies described before is of course to obtain as much energy efficiency as possible of each system, maintaining at the same time user comfort. Said that, we can see that all strategies proposed so far treat each system (HVAC and lighting) independently.
Another approach that will be studied is an overall one taking into account all installations simultaneously and stating as objective to maximize the energy efficiency of the whole building, maximizing also energy savings.

2 Demo 2: NuOffice

The Domagk-Gewerbepark GmbH & Co. KG as an affiliated company of the Hubert Haupt Immobilien Holding has built an office building in Munich with a very high energy efficiency standard and maximum comfort requirements. Hereby, Domagk - Gewerbepark is client and building owner of an ensemble of office buildings, of which the current building will be the first property.

Essential concept components are targeted on use of environmentally compatible building material, high quality of ambient air, maximum flexibility of occupancy and high energy efficiency for heating, cooling, ventilating and lightening. This includes excellent heat insulation, innovative systems engineering, use of renewable energy, passive heating and cooling concepts as well as optimized daylight concepts and artificial light.

2.1 Principal Systems General Description

2.1.1 HVAC System

Heating and cooling

The core of the heating system is the application of an absorption heat pump, operated by district heat having a certified and extremely advantageous primary energy factor of 0.122. As low-temperature heat source, heat is extracted from ground water using an adaptor to a ground water well. Because of limitations on the part of the energy provider it's not allowed to exceed the return temperature over 50°C. For this reason a heat exchanger is installed, where district heat can be used directly for heating purposes. With this concept, the use of district heat in Munich will be further optimized.

The building is equipped for all occupied zones with a surface heating and cooling system designed for thermal activated building constructions (TABS). During the heating period, energy supplied by the absorption heat pump will be used, whereas for cooling a passive cooling system using ground water will be realised. In addition to that a compression chiller is used for covering peak loads and the basic loads for the IT-systems.

Ventilation

The building comes with four central air handling units (AHU) which are placed at the main distribution axes in the basement. The AHU's are equipped with rotary heat exchangers for heat recovery which ensure a thermal efficiency of 75 up to 80%. Supply air is preconditioned via heating and cooling coils, which are supplied by district heat (winter) or ground water (summer). Mechanical ventilation is only used in winter and summer with an air change rate according to DIN EN 15251 for the following categories:

Thermal winter conditions	Cat. II	Design:	20 – 24 °C
Thermal summer conditions	Cat. II - III	Design:	22 – 27 °C

Selected for CO_2 air quality indicator Category II (500 ppm above outside air) with a ventilation rate of 40 m³/(h*person); 0.93 l/s.m². The air change per hour is set to ACH=1,12 h^{-1}.

During the transitional period (April-May; September-October) tenants are asked to use natural ventilation by opening windows.

2.1.2 Lighting system

The main zones (offices, lecture rooms, playschool and gym) are equipped with ceiling-mounted pendant lighting with a high ratio of direct light by using T5 fluorescent tubes. This System is appropriate for basic lighting. In addition to that, LED desk-lamps provide the rest of the demanded illuminance. Differing from this concept, tenants are allowed to modify the additional devices for their own needs.

Lighting of common areas like staircases and circulation areas is realised by using high efficient LED-bulbs mounted on the ceiling or walls.

2.1.3 Sun protection

Every window in the main façade has an external shading device. For this, all windows which are oriented to the south, west and east are provided with venetian blinds. In addition to that a solitary part of the building positioned at the south, so called 'Bubble' is equipped with electrochrome switchable glazing.

The shading device is assumed to reduce the transmittance of the glass to 0.7 (i.e. 70 % of the incident light is transmitted through the glass). The control of the shading device is programmed within the control system.

2.2 Control Elements

The control system for the building is realised by a direct digital control (DDC) which features the programming of set points, schedules, timers, trend logs, alarms, visualisation and alarm handling. The data acquisition programme is also implemented in this automation system.

The following table gives an overview on mainly used sensors, actuators and control devices:

Table 1 Main sensors and actuators for the control system

control section	type	used sensor	actuator
lighting	presence of daylight	photosensor (integrated)	dimmer
lighting	presence	passive infrared sensor	switch

heating	room temperature	PT100 temperature sensor	digital processing
heating	flow temperature	PT100 temperature sensor	3-way valves
heating	precontrol weather-forecast	wind force and direction	
heating	precontrol weather-forecast	global radiation	
heating	precontrol weather-forecast	precipitation	
heating	precontrol weather-forecast	hours of sunshine	
heating	precontrol weather-forecast	humidity	
heating	precontrol weather-forecast	ext. temperature	
heating	precontrol flow-temperature	PT1000 ext. temperature	3-way valves
ventilation	air quality	Co_2-sensor	frequency converter
ventilation	volume flow	pressure sensor	frequency converter
ventilation	supply air temperature	PT1000 temperature sensor	flaps
cooling	volume flow	flow-meter	valves
cooling	flow temperature	PT100 within flow-meter	
shading	venetian blinds	global radiation	motor
shading	electrochrome glazing	global radiation	control voltage

2.3 Kind of Areas & Uses

The building 'NuOffice' is divided into ten zones which have different usages. As to be seen the predominant zone consists of offices accompanied by a playschool (placed at the west side of the ground floor) and the lecture rooms which can be found at the fourth floor. Additionally a gym can be found on the third floor. Table 1 gives an overview on the different types of usable space including the control strategies for heating, cooling and lighting.

Table 2: Used areas of NU-office

Zone name	Area m²	heating/cooling control	light control
playschool	282,02	TABS precontrol weather-forecast; zone-control	manual ON/OFF
staircase	654,97	none	presence
WC	414,82	TABS precontrol weather-forecast; zone-control	presence
office	4783,082	TABS precontrol weather-forecast; zone-control	daylight dependent, presence
traffic zone	1911,6	passive heated	presence
storage area	118,77	none	manual ON/OFF
kitchen	36,12	TABS precontrol weather-forecast; zone-control	manual ON/OFF
gym	455,1	TABS precontrol weather-forecast; zone-control	daylight dependent, presence
lecture room	609,08	TABS precontrol weather-forecast; zone-control	daylight dependent, presence
showroom	812,102	TABS precontrol weather-forecast; zone-control	daylight dependent, presence

2.4 Control Strategies

2.4.1 Possible strategies

Lighting

In all permanent occupied zones except the zone playschool the artificial lighting is regulated according to the amount of the natural day lighting. A lamp integrated control system dims the lights if sufficient daylight is available. The light control system has to be activated by users. Therefor a regular light switch has to be actuated. In order to avoid stand by losses, the control system is additionally equipped with presence detectors which switch off the lights when users had left the zone.

Traffic zones, staircases and toilets are equipped with presence detectors (infrared-sensors) which switch on the light by detecting people.

Some special zones have no control system for lighting like playschool, where tenants don't wanted such a system or storage rooms where light control have no benefit for energy savings.

Sun protection systems

The position of all external sun blinds are controlled by one central switch. Hereby the signal to shut or open the blinds depends on the azimuth of the sun. So in summer the blinds on the eastern facades will be shut down first.

Ventilation system

The ventilation system maintains air quality in the different usage areas. The purpose of the heating and cooling functions of the fresh air devices is to support the base load heating and cooling system which is predicated on concrete core activation (TABS). Fresh air supply for the whole building is conducted at an air exchange rate of 1.12 times.

The ventilation system can be driven by using a software-switch for the operating modes 'ON', 'OFF' and 'AUTOMATIC'. Normal operating modes are scheduled as shown in table XX. The ventilation system will only be operated in winter and summer. The equipment will be active during the main usage times (timer and operation panel according to ventilation zone).

Table 3 Operation time for the ventilation system

Ventilation zone timer	Value	Setting
Normal operation (day) - daytime set point	Mon - Fri	7:00 a.m. – 7:00 p.m.
Normal operation (day) - daytime set point	Sat - Sun	

Wintertime operation: Outside temperature < 15 °C

Transition period: Outside temperature 15 - 22°C

Summertime operation: Outside temperature > 22°C

During the transition period, users can manually regulate the indoor air quality by opening windows. This is to optimize the energy usage of the ventilation system as well as to improve the users' comfort by giving them the option of opening the windows.

On hot summer days fresh air can be cooled to improve users' comfort in office zones. This is to be done using well water. Since TABS bases on stored cooling energy, TABS and the ventilation system can be operated alternatively. Concrete surfaces will be cooled down during the night and the stored energy can be used for cooling purposes via the ventilation system during the day.

Ventilation zone control

Motor-driven flow controllers allow individual limitation and complete shutoff of air flow for each usage area. The flow temperature cannot be regulated separately for each ventilation zone. CO_2-Sensors which are placed in every main exhaust duct will be used to analyse the effectiveness of the adjusted flow rates.

Office room ventilation

An air change rate of 1.12 times is set for all areas of utilization. Therefor fresh air is induced via controllable fresh air nozzles (3cm in diameter) placed at every center panel, allowing any desired room layout in the grid.

- 3 fresh air nozzles at 7.5 m3/h D = 30 mm

Overflow boxes with integrated cross-talk sound attenuators, which are fitted into partition walls, provide for the exhaust air to flow from office areas into the corridor zones. All exhaust air flows to the corridor area and is redirected to the central system. During the transition period, office ventilation is turned off completely using the flow controllers

WC exhaust air

The exhaust air is extracted via the exhaust air ventilator of the office ventilation system, thus using the heat recovery system and making the ventilation system more energy efficient. Pursuant to German workplace regulation ASR 37/1, the air exchange rate will be set to 5 times.

In case of fire or unusual behaviour of the system the following shutdown criteria are defined:

- Motor malfunction (fresh air ventilator / exhaust air ventilator)
- Malfunction of a frequency changer (fresh air ventilator / exhaust air ventilator)
- Actuation of an isolation switch (fresh air ventilator / exhaust air ventilator)

- Triggering of fire dampers in the main duct
- Triggering of the flow monitor (fresh air / exhaust air)
- Triggering of the damper runtime monitor (outside air damper / exhaust air damper)
- Malfunction of the heat pump
- Triggering of the air-side frost protection monitor
- Signal from the smoke detector
- Fire alarm shutdown (connected to fire alarm system)

Overview control functions

Table 4 Overview on control functions

Summer compensation pursuant to German regulation DIN1946 T2	**Value**	**Setting**	
Proportional set point increase	x_S	4	K
Outside temperature (OT) range	X_{OT}	26-32	°C
Free exterior cooling	**Value**	**Setting**	
Temperature difference between room temperature (RT) and calculated room temperature set point	$\Delta T_{RT-RTxsc}$	2	K
Temperature difference between outside temperature and room temperature	ΔT_{OT-RT}	4	K
Switch-back hysteresis	HY_{OT-RT}	2	K
Starting logic	**Value**	**Setting**	
OT threshold	TH_{OT}	12	°C
Increase of fresh air (FR) temperature set point	$\Delta x_{S,FR}$	10	K
Time slope for set point decrease	t_{slope}	15	Min
Idleness control	**Value**	**Setting**	
OT threshold	TH_{OT}	12	°C
Return temperature set point	$x_{S,RE}$	25	°C

Constant control of pressure difference (fresh air+exhaust air)	Value	Setting	
Fresh air set point (daytime operation)	$x_{S,FR}$	300	Pa
Exhaust air set point (daytime operation)	$x_{S,EX}$	300	Pa
Temperature cascade control (exhaust air/fresh air)	**Value**	**Setting**	
Exhaust air set point	$x_{S,EX}$	22	°C
Fresh air set point	$x_{S,FR}$	18	°C
Fresh air set point adjustment	$\Delta x_{S,FR}$	3	K
Minimum air inlet temperature	$x_{S,FRmin}$	16	°C
Maximum air intake temperature	$x_{S,FRmax}$	32	°C
Summertime (SU) heat recovery threshold	TH_{SU}	3	K
Heat recovery frost protection (exhaust air temperature)		5	°C
Activate cooling	TH_C	18	°C
Activate heating	TH_H	25	°C

Description of control functions:

Summer compensation pursuant to German norm DIN1946 Part 2

During summertime, extreme differences between outside and inside temperatures may cause uncomfortable room conditions. Thus, in case of high outside temperatures in the outside temperature zone XOT, a proportional set point increase ΔxS of the room and fresh air temperature set points is set (e.g. pursuant to German norm DIN1946 Part 2: XOT = 26-32°C; ΔxS = 0-4K).

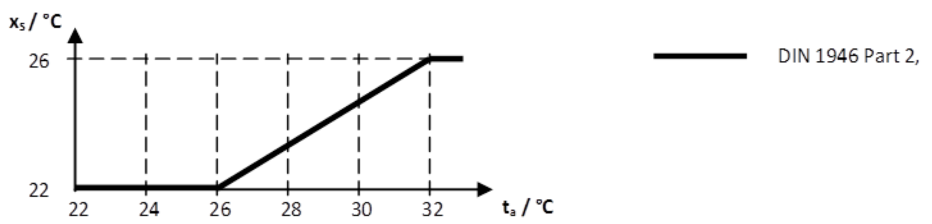


Figure 8 Summer compensation

Free exterior cooling

During summertime the ventilation system can be turned on at night in order to decrease room temperatures by using outside air. Free cooling operation of the ventilation system is activated if:

a) The room temperature exceeds the calculated room temperature set point at least by the difference ∆TRT-RTxsc ("i.e. the room temperature is at least 2K higher than the calculated set point"),

b) and the room temperature is not below the calculated room temperature set point ("i.e. the room temperature is not below the calculated room set point or the air in the room is getting too cold"),

c) and the room temperature exceeds the outside temperature at least by the difference ∆TOT-RT ("i.e. the outside air is at least 4K colder than the air inside a room")

Switch-back hysteresis: HYOT-RT,

d) and the outside temperature exceeds the threshold THOT ("i.e. the outside air is not too cold either").

In case of free cooling mode the system is turned on, temperature controls are disabled, the air heating/cooling vents are closed and the exhaust air dampers are open.

Weather forecast data (free cooling)

For energy-saving purposes it’s possible to use weather forecast data, which are collected by the system and used as an additional criterion for activating the free cooling mode. In case of low predicted outside temperatures for the next day, the night cooling system may be switched off.

The starting logic reduces the risk of malfunction caused by frost when starting the ventilation system. The adjusted set point will be decreased continuously using a time slope t-slope until it reaches the initial set point.

Temperature cascade control (exhaust air /fresh air; heating - heat recovery (SU) - cooling)

The exhaust air temperature is controlled via an exhaust air / fresh air cascade. The cascade circuit consists of a main loop (exhaust air temperature controller) and an auxiliary loop (regulated fresh air temperature range). If the main control variable (exhaust air temperature) differs from the exhaust air set point $x_{S,EX}$ the fresh air set point will be increased or decreased by $\Delta x_{S,FR}$ per K of deviation. The fresh air temperature is limited to a minimum inlet temperature $x_{S,FRmin}$ and a maximum inlet temperature $x_{S,FRmax}$.

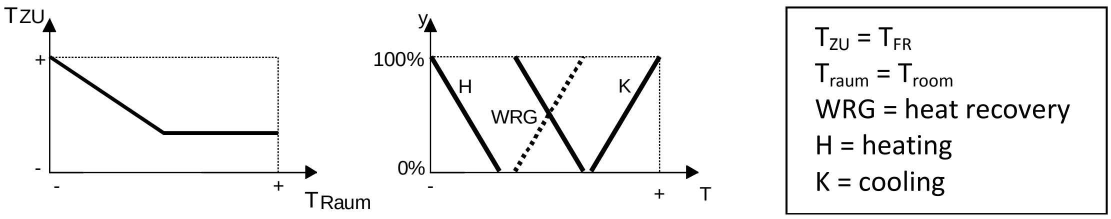


Figure 9 Temperature cascade control

The corrective signal of the auxiliary controller sequentially affects the air heater, heat recovery and the air cooler. When the difference between outside temperature minus exhaust air temperature exceeds the threshold TH_{SU}, the heat recovery sequence is switched to summertime operation mode (dotted line). When the difference falls below the threshold, the sequence is switched back again. Activation of the sequence is based on the criteria described in the system overview.

Constant pressure control (fresh air - exhaust air)

Fresh air and exhaust air pressures are independently adjusted to constant set points $x_{S,FR}$ and $x_{S,RE}$.

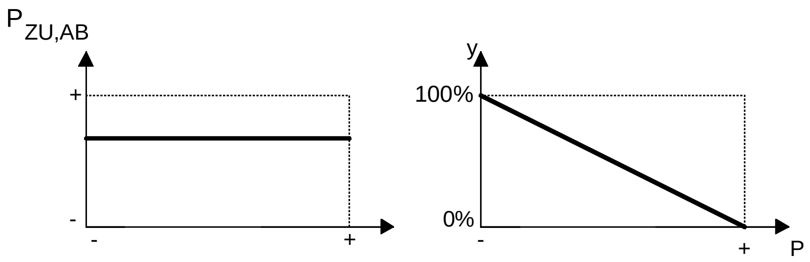


Figure 10 Pressure control of fans

The corrective signal of the controller affects the frequency changers. Activation is based on the criteria described in the system overview.

Heating and cooling system

Pre-control

Concrete core activation is designed to function as an independent hydraulic heating / cooling cycle. The following heat exchangers provide energy input to this cycle

- heating via absorption heat pumps
- heating via district heat
- passive cooling by ground water
- backup cooling via air cooled chiller

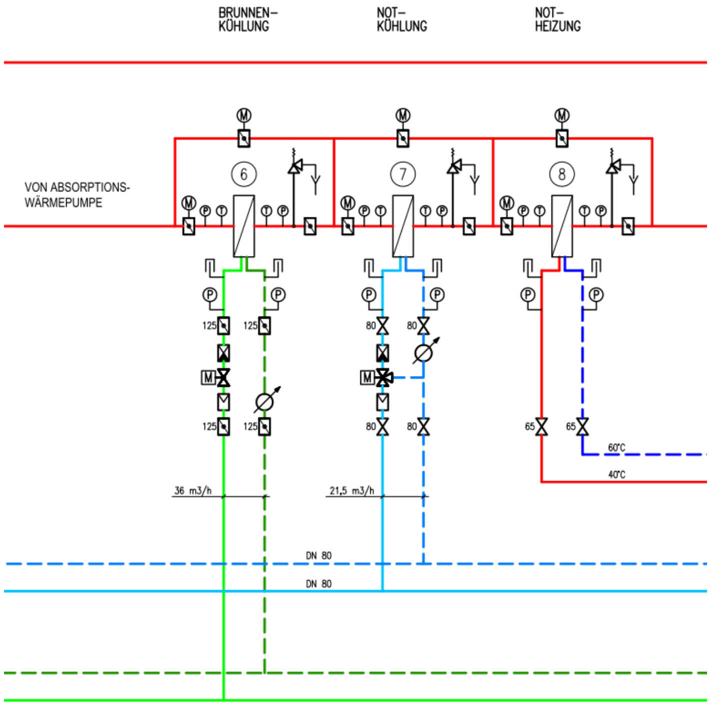


Figure 11 Precontrol for the heating system (hydraulic scheme)

Weather forecast (METEO data)

Due to the fact, that TABS comes with high thermal masses and high inertia predicted weather data can help to decide which operation mode is ideal for the following day. The average external temperature of the following day is used in an algorithm to calculate the best operation mode. The following aspects are fundamental for TABS:

- Consideration of the high inertia of the thermal mass of the concrete elements (reaction times of 10-12 hours).
- Consider the relatively low power input and output (cooling, heating)
- Determine the ideal schedule for heating and cooling cycles
- Consider the crucial impact of the internal thermal load and of the solar input on the system performance.
- Use weather data to make the right decision - 12 hours in advance!

Decision criteria concerning heating / cooling operation (TABS pre-control circuit)

The activation of the systems is mainly based on the predicted weather conditions of the following day provided by the weather module. In case of unavailable data (network malfunction, malfunction of the internet connection/etc.), the control strategy is switching to real-time data use via the DDC (outside temperature).

The current operation mode (heating / oFF / cooling) is transmitted to the TABS-zone controllers.

Possible operation modes are:

- AUTO based on weather forecast
- AUTO based on weather forecast and emergency switching via real external temperature.
- AUTO only based on the real external temperature sensor
- Manual heating operation
- Manual cooling operation
- OFF

Activation of the TABS is only possible during following defined times (alternating operation of concrete core activation / ventilation system)

Table 5 Operation time for the heating and cooling system

TABS operation timer	Value	Setting	Changed
Activation - Activation set point	Sunday	10 pm – 07 am	
Activation - Activation set point	Mon - Thu	10 pm – 07 am	
Activation - Activation set point	Sat		

Switching (heating / cooling) is based on the average outside temperature for the following day (6 am to 10 pm) as forecast by the weather forecast module (METEO).

predicted external temperature for next day (METEO)

basic setpoint

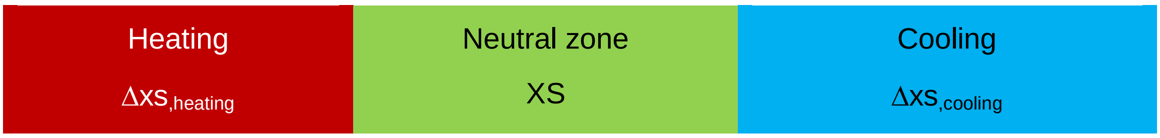


Table 6 Set point for operation mode changeover

METEO switching (heating/cooling) set point	Value	Setting	
Basic set point for switching	$x_{S,}$	21	°C
Neutral zone (heating)	$\Delta xs_{,heating}$	0.5	K

Neutral zone (cooling)	$\Delta xs_{,cooling}$	0.5	K

4.4.1.3 Switching based on outside temperature (internal)

The real outside temperature is used for emergency switching between heating and cooling operation.

Table 7 Set point for operation mode changeover by ext. temperature

Set points for switching (heating/cooling) based on OT 24h internal	**Value**	**Setting**	
Average outside temperature set point for heating operation	$xs_{,heating}$	12	°C
Average outside temperature set point for cooling operation	$xs_{,cooling}$	20	°C

Zone automation / room controller

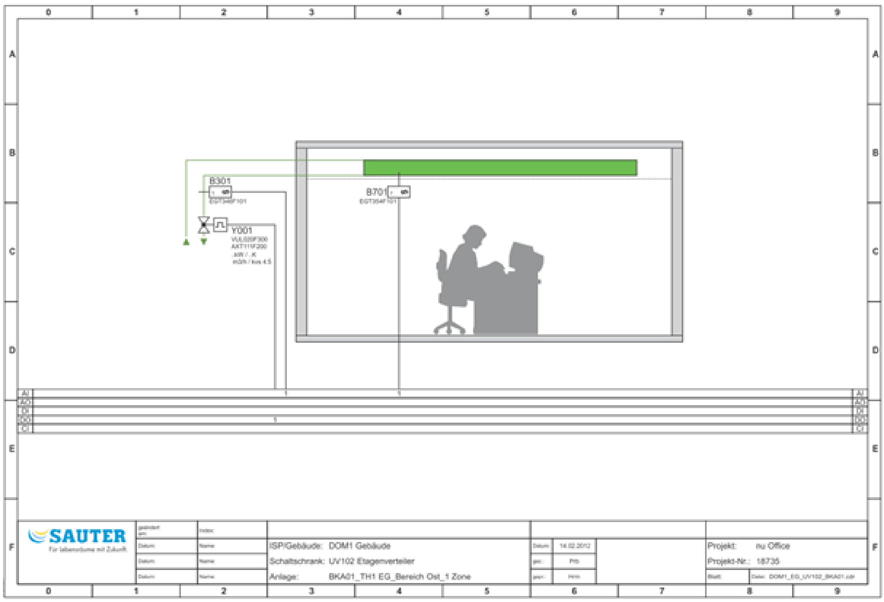


Figure 12 Components of room controlling

The system consists of the following components:

- Floor distributor with integrated DDC controller (FDxxx)
- Zone shut-off valve TABS
- Exhaust air temperature sensor TABS

- Ceiling temperature sensor TABS
- Manual set point adjustment

Every zone within NU-office has an independent room controller. Basically every system is connected to all sensors and actuators of field components (e.g. sensors, monitors, control valves, etc.).

Operation and turn-on criteria

- Software switch "On - Off - Auto" for DDC/BCS (TABS zone)
- Manual set point adjustment (+/- 1.5K)

Weather forecast for defining the TABS temperature.

The predicted external temperature for the next day, as well as the difference between maximum and average outside temperature will be used to calculate the flow temperature for the TABS.

The following parameters have an effect to the TABS temperature:

1. Average outside temperature for the following day
2. Difference between maximum and average outside temperature on the following day
3. Global radiation on the following day

Identification of the TABS basic set point:

Defining the basic TABS temperature set point (ceiling sensor / return temperature sensor) for deactivation of the TABS cycle:

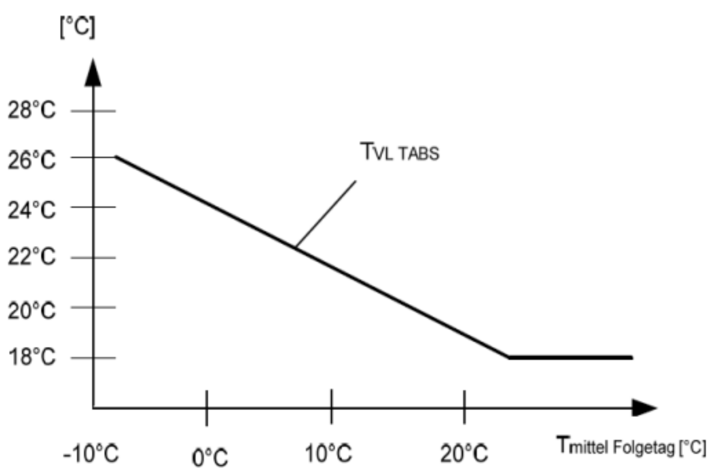


Figure 13 Set temperature for TABS

Table 8 Set temperatures for TABS calculated

Basic set point for TABS deactivation temperature	**Value**	**Setting**	
TABS temperature (-10°C OT)	$TABS_{-10OT}$	26	°C
TABS temperature (20 °C OT)	$TABS_{20OT}$	18	°C

Manual user adjustment of TABS set point:

One control panel per usage area allows users to adjust the concrete core temperature. Users can adjust the set point by (+/- 1.5 K) via a potentiometer.

Figure 14 User control panel

The following figure shows the calculated set point depending on the difference between the predicted outside temperature and maximum temperature on the following day

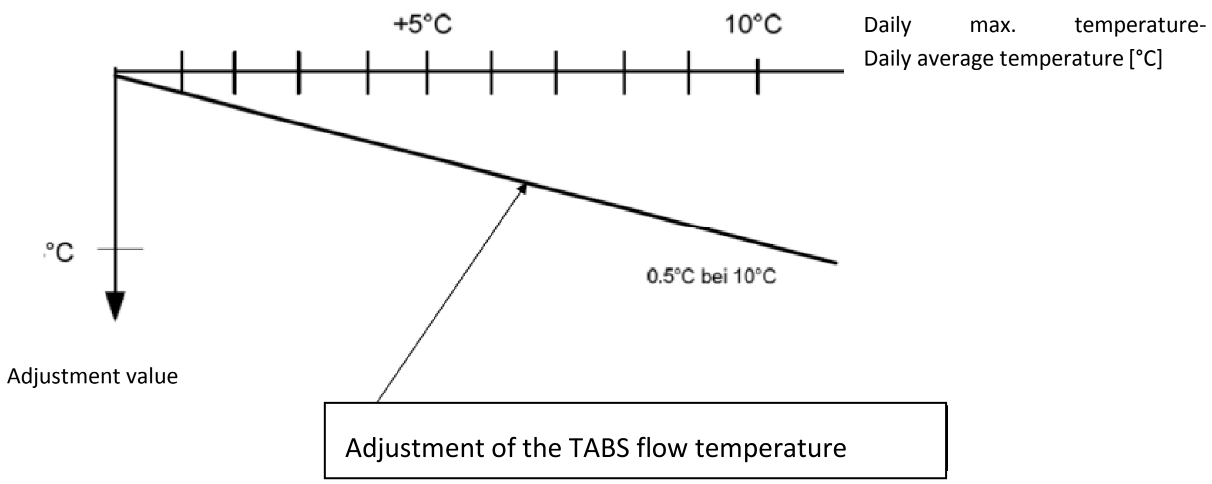


Figure 15 Adjustment by predicted temperature difference

Table 9 Values for TABS adjustment

TABS adjustment value (correction)	**Value**	**Setting**		**Changed**
TABS adjustment value (0 K)	$TABS_{0K}$	0	K	
TABS adjustment value (10 K)	$TABS_{10K}$	2	K	

The calculation of the basic set point based on the global radiation on the following day can be seen in Figure 8.

Despite only short periods of sunshine in wintertime, the amount of heat gained through window surfaces is considerable due to the low position of the sun. It covers the heating load during the period of additional solar radiation especially in new buildings with upgraded insulation and windows with thermal coating.

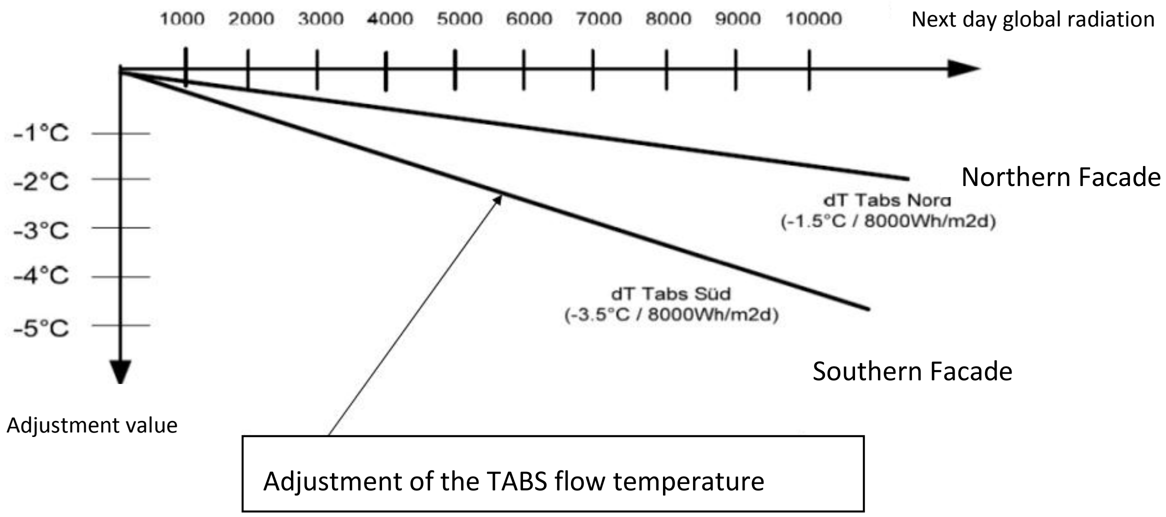


Figure 16 Calculation for TABS set point depending on solar radiation

Table 10 Values for TABS adjustment (solar radiation)

TABS adjustment value based on global radiation	**Value**	**Setting**	
TABS adjustment value (0 Wh/m²d) North	$TABS_{0Wh\ North}$	0	K
TABS Adjustment (10000 Wh/m²d) North	$TABS_{10kWh\ North}$	-2	K
TABS Adjustment (0 Wh/m²d) South	$TABS_{0Wh\ Süd}$	0	K
TABS Adjustment (10000 Wh/m2d) South	$TABS_{10kWh\ South}$	-5	K

Shut-off conditions for TABS per zone

The current operating mode (heating / OFF / cooling) of the pre-control circuit is transmitted to the individual zones. The activation of the shut-off valve **Y001** for the TABS ceiling zone is based on the TABS ceiling temperature and the TABS return temperature setting.

As soon as the calculated set point has reached this condition (ceiling sensor **B7xx** and return sensor **B301**) the zone is shut down.

3 Demo 3: Black Monolith

Figure 17: Rendering of Black Monolith

The Black Monolith will be built on the New Technology Park area in the industrial zone of Bolzano in northern Italy. It will host non-profit research institutes, public authorities, and SMEs. The building is L-shaped (see Figure 17**¡Error! No se encuentra el origen de la eferencia.** and Figure 18) and consists of five floors and a basement. The ground floor contains the main entrance and an expo area. The upper floors will host offices, meeting rooms, and service rooms. On the basement there will be conference rooms and the cafeteria. In the centre of the building, a green patio connected to outdoors and with top openings cuts through all storeys to control natural ventilation and provide natural lighting also to the offices on the first floor.

Figure 18: New Technology Park area with the existing buildings shaded in blue (BZ1, BZ2, and BZ3), and the L-shaped Black Monolith shaded in red

Owner and designer aspire the following energy targets:

- Net Zero Energy Building (NZEB)
- Total primary energy consumption lower than 60 kWh/m^2/a

To reach these targets, the following list of energy efficiency measures was identified through an integrated design process accompanied by dynamic simulations and parametric studies:

- Low shape ratio (S/V)
- Optimized transparent/opaque surfaces ratio
- High envelope insulation
- Exploitation of thermal mass
- Natural ventilation
- Exploitation of daylight through vertical cut and patio
- Efficient and controlled artificial lighting and electrical equipment
- Advanced Building Management system (BMS)

To reduce the HVAC consumption:

- Exploitation of ground water heated up during an industrial process
- Ground water source (open loop) heat pump system
- Absorption machine coupled with solar thermal plant
- Heat recovery of server room's rejected heat

RES integration to cover the energy demand:

- Building-integrated solar thermal system (BIST)
- Building-integrated photovoltaic system (BIPV)

3.1 Principal Systems General Description

To unleash the full energy saving potential of the combined energy efficiency measures, an optimal control of all systems has to be sought. The main controllable systems of the Black Monolith include HVAC and lighting. HVAC comprises active building elements (radiant ceiling panels) and energy generation (solar-thermal panels).

3.1.1 HVAC System

In the municipality of Bolzano, deep well and ground water geothermal plants are prohibited by law. Considering the size and importance of the project, it was asked for a special permission to build an open loop ground water geothermal plant with two heat pumps, but the application was rejected. As an alternative, a concession was obtained to use the ground water of the aluminium extrusion industrial plant of the company SAPA which is adjacent to the Black Monolith. The ground water supplied to the building is in series with their industrial process. Ideally, the ground water would be extracted before the industrial process in summer and after it in winter, but the company requested total control on the ground water temperature, making a ground water use for the Black Monolith possible only after the industrial use of SAPA.

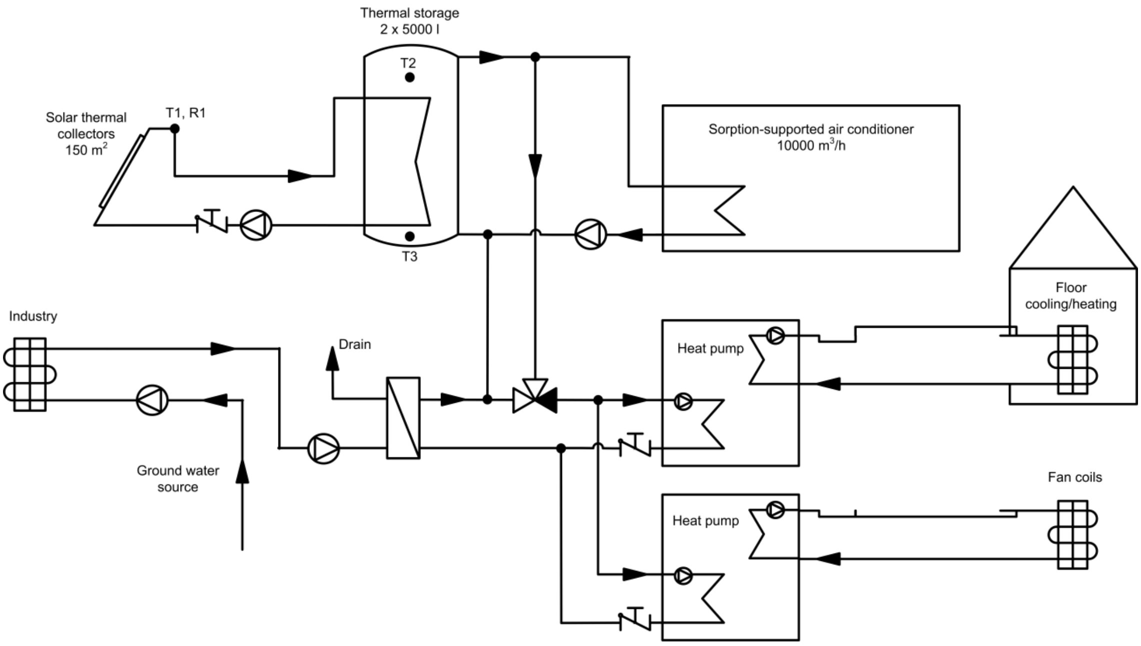


Figure 19: Heating/cooling scheme

To satisfy peak loads, an existing water storage tank serves as thermal storage. A solar thermal vacuum tube field consisting of a surface of 150 m² and two heat pumps will allow an increase of the ground water temperature to heat the building in winter. During summer, the heat produced by the solar thermal collectors will be advantageously used in a desiccant cooling cycle. It was decided to maintain three back-up boilers supporting the heat pumps in case of peak loads.

The heat is distributed by a carrier fluid. The ratios between the electricity consumption of the distributing heat pumps and the heat transported are shown in Table 11.

Table 11: Pump consumptions

Circuit	Pump power [kW] / heat transported [kW]
Primary	0.103 in heating mode 0.108 in cooling mode
Secondary	0.066

HVAC equipment is located on the basements of the BZ1 building and the Black Monolith:

- On the basement of BZ1: central cooling and heating system, AHU, pumping station, and central hydraulic system;

- On the basement of the Black Monolith: AHU for expo area and entrance hall, ground water pumping station, ground water storage tank.

The HVAC distribution system comprises primarily the following components:

- Distribution channels, piping, and ductwork installed on the ceiling (both visible and/or above dropped ceilings) of each floor;
- Air vents on the roof for air change in offices and conference halls.

For AC equipment rating, the following reference conditions were used:

- Outdoor hydrothermal conditions:
  - In summer, 35°C/32°C and 50% RH to rate the AHUs, and 31.5°C and 45% RH to rate the cooling equipment;
  - In winter, 15°C and 60% RH.
- Indoor hydrothermal conditions (n.c. = not controlled):
  - Cooling mode: 26°C, RH n.c.;
  - Heating mode: 20°C, RH n.c.
- Air change rates:
  - Offices: 11 l/s per person;
  - Meeting rooms: 2 V/h;
  - Entrance, foyer, and conference halls: 5.5 l/s per person;
  - Expo area: 8.5 l/s per person.
- Tolerances:
  - Temperature: ±1°C;
  - RH: ±10%;
  - ACH: ±5%.
- Maximum noise level of equipment (reference regarding terminology and compliance: UNI 8199:1998):
  - Offices, meeting rooms: 45 dB(A);
  - Conference halls: 40 dB(A).
- Occupancies in air-conditioned zones where the inlet air volume is proportional to the occupancy:
  - Offices: 0.12 persons/m^2;
  - Meeting rooms, entrance, foyer: 0.2 persons/m^2;
  - Expo area: 0.3 persons/m^2.
- Internal gains due to lighting and electromotive force (specified only for the air-conditioned zones):
  - Offices, meeting rooms, conference halls, expo area: 25 W/m^2;
  - Entrance, foyer: 15 W/m^2;
- Thermal transmittances:
  - External wall: 0.2 W/m^2/K;
  - Wall towards existing building: 0.3 W/m^2/K;
  - Wall towards ground: 0.2 W/m^2/K;
  - Slab to the outside: 0.2 W/m^2/K;

  - Slab towards ground: 0.2 W/m^2/K;
  - Roof: 0.2 W/m^2/K;
  - Glazing: 0.8 W/m^2/K;
  - Fenestration frame: 1.9 W/m^2/K.
- g value: less than 0.4.
- Maximum air velocity (inside an occupied air volume as defined by UNI 10339:1995):
  - Heating mode: 0.15 m/s;
  - Cooling mode: 0.2 m/s.
- Outdoor air filtration: two-stage (G4 plus F8).

A static heating/cooling load calculation yielded the following power ratings:

- Warm water for heating:
  - Losses: 170 kW;
  - Intermittence: 20 kW;
  - Outdoor air: 540 kW;
  - Heat recovery: -200 kW;
  - **Total with recovery: 530 kW;**
  - **Total without recovery: 730 kW.**
- Cooled water:
  - Gains: 195 kW;
  - Outdoor air: 340 kW;
  - Sensible load persons: 85 kW;
  - Latent load persons: 90 kW;
  - Electric rooms: 26 kW;
  - Lighting and electromotive force: 140 kW;
  - Passive losses: 50 kW;
  - **Total: 926 kW.**

A summary of AHU ratings and usages is given in Table 12.

Table 12: Summary AHU ratings and usages

AHU code	Usage	Hygrothermal outdoor reference conditions in summer	Heating power [kW]	Cooling power [kW]
Basement & ground floor				
AHU A1	Auditorium	35°C; 50% RH	42.700	107.000
AHU A2	Auditorium	35°C; 50% RH	26.000	66.100
AHU A3	Auditorium	35°C; 50% RH	54.000	106.800
AHU A4	Auditorium	35°C; 50% RH	20.200	50.800
AHU I1	Entrance	35°C; 50% RH	13.300	37.700
AHU E1	Expo	32°C; 40% RH	N/A	N/A

Terminals			7.394	1.391
Radiant panels			28.500	44.000
First to fourth floor				
AHU U2	Offices	32°C; 50% RH	117.130	179.700
AHU U3	Offices	32°C; 50% RH	87.555	134.400
Electric rooms				26.000
Radiant panels			135.000	166.117

Ground water use has some advantages and disadvantages with respect to a traditional system composed of boilers and chillers.

Main advantages are:

- The water temperature is constant over the year, allowing to run the heat pumps with high COPs;
- Almost zero local atmospheric pollution;
- Low noise;
- Low energy cost.

Of course there are also some disadvantages:

- Higher initial investment cost compared to a traditional system;
- More involved maintenance;
- Higher need for roofed space for the technical facilities.

SAPA activates the groundwater reservoir pumps to either direct the groundwater to its industrial process or fill the surge tank.

The integration of the Black Monolith in the groundwater cycle consists of:

- Preferentially using the groundwater before the discharge of SAPA;
- Alternatively by creating a branch that fills the Technology Park storage tank.

The water accumulated in the Technology Park storage tank is then extracted by the electric pumps and pumped to the heat exchangers.

In the winter period, the SAPA discharge tank is essential because the groundwater itself is too cold to directly drive the heat pumps. The SAPA wastewater is used to heat up the groundwater rendering the latter useable.

The groundwater loop is open: after use, the groundwater is drained through the SAPA discharge piping.

Winter operating mode: the water is extracted from the SAPA discharge tank if available and with higher temperature than the extracted groundwater. Otherwise, the groundwater is extracted from the subsoil at a temperature of 10-15°C with variable flow rate immersion pumps depending on the energy demand. Next, the water is filtered, pumped through a heat exchanger and discharged at a lower temperature (about 5 K temperature difference).

Summer operating mode: during summer, the cycle is inverted. The groundwater becomes a source of chilled water to offset the cooling load.

There are two hot water sources: if the accumulated water temperature is higher than 10°C (in the mid seasons), the two heat pumps can be used. The thermal power of each heat pump is equal to 1,100 kWt. The pumps produce water at a temperature of 45°C. In winter, if the outdoor temperature reaches minimum values, the water supplied to the terminals must have a temperature equal to 55°C. The condensing boilers intervene. Three condensing boilers with a thermal power of 950 kWt each are foreseen. The supply temperature to the terminals is a function of the outdoor temperature.

SAPA reported the following data on the groundwater well:

- Water extraction depth: 8 m;
- Peak extraction rate: approx. 125 l/s
- Water temperature in winter: 8/10°C;
- Water temperature in summer: 12/14°C.

Hot/chilled water production systems: both hot water production systems are located in a technical room on the basement of the existing BZ1 building. The chilled water is either produced by the heat pumps or by two back-up chillers on the basement of the existing BZ1 building. The chillers are of the water to water type with compressors with inverter. Each chiller has a refrigeration power of 1,050 kWt.

Equipment typologies:

- Conference halls, entrance, foyer: all-air (external and circulation component);
- Offices, expo: air-water type with terminal radiant ceiling panels.

AHU types (see Table 12):

- AHU A1-A4: heat exchanger of counterflow type with mixing chamber, double-stage filter, and coils with hot and chilled water. Supply and return ducts are equipped with silencers. The quantity of air is regulated by an air quality sensor on the return duct. The air is used to control ventilation, humidity, and temperature. In winter, free-cooling is used if the enthalpy of the outdoor air is lower than the circulated air. In the conference halls, the air is injected by nozzles and sucked in through grilles in the ceiling. In the foyer zone, the air is injected through nozzles where there is no suspended ceiling, otherwise through outlet vents in the ceiling. The return air is sucked in at the wall;
- AHU I1 is analogous to AHU A1-A4, the air injection occurs through outlet vents;
- AHU E1 is for the expo area. It uses the energy accumulated by the solar-thermal equipment to cool and dry the air. Radiant ceiling panels perform the temperature control. The air is injected through linear outlet vents;

- The central unit of AHU U2 and AHU U3 is equal to that of the other AHUs. The air is for ventilation purposes, while the radiant ceiling panels control the temperature. In summer, the flow rate guarantees humidity control. In winter, that flow rate is reduced to the minimum foreseen by law. Every zone is equipped with a temperature and humidity sensor. In summer, when humidity rises over a threshold, before closing the chilled water supply valves, the system verifies that all temperature set points are maintained and changes the chilled water supply temperature by at most 2 K. If afterwards some zones cannot satisfy the sensible load, that temperature is brought back to design conditions, and only then the chilled water supply valves are closed in the zones where the humidity has reached the threshold.
- The air in the facilities of the conference halls in the basement of the Black Monolith is injected and extracted through local heat recovery units of counterflow type equipped with a heating unit that ensures 20°C ambient temperature in winter.

3.1.2 Lighting System

The lighting in the offices and conference rooms must satisfy three needs:

- Ensure safety and comfort for users and visitors;
- Ensure appropriate and uniform light in the working areas;
- Ensure contained energy consumption; this can be achieved for example by exploiting daylight.

Table 13 shows the illumination values for indoor lighting required by the German standard DIN 5034-1:1999 "Tageslicht in Innenräumen: Allgemeine Anforderungen" (Daylight in interiors – General requirements).

Table 13: Illumination required by DIN 5034-1:1999 for different room types

Room type	Illuminance [lux]
Corridors / Stairs	150
Foyer	350
Reception area	300
Desks	500
Expo area	500
Conference hall	500

The natural lighting system is considered an important part of the building. Ideally, it should reduce the direct sunlight by redirecting it appropriately, while simultaneously capturing the diffuse light. The natural light allows a continuous perception of the external environmental conditions and reduces the need for artificial illumination.

The building is rather compact, requiring numerous solutions to increase the amount of natural lighting.

The South façade is fully glazed and characterized by shading elements like opaque glass, following the trend of the opaque ribbons in the other façades.

In the East, West, and North façades, at least two sets of ribbon windows on each floor have been included:

- Ribbon windows at a height of at least 180 cm from the floor, to send the light deep into the room;
- Ribbon windows at a height of about 120 cm from the floor enabling to look outside.

Figure 20 shows the dimensions of the ribbon windows in the North, East, and West façades.

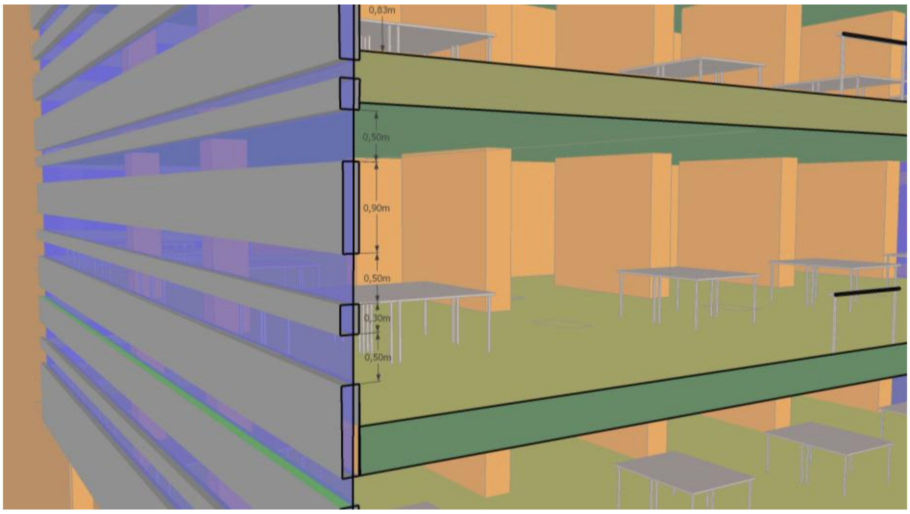


Figure 20: Perspective view of the building with the dimensions of the ribbon windows installed in the North, East, and West façades

The building features an internal garden and a vertical cut to allow a better distribution of the sunlight to all the floors, especially the lower ones. The roof of the garden is higher than that of the building and has lateral openings that facilitate the natural ventilation. The walls limiting the vertical cut are covered with white plaster with a reflectance of 85% in order to scatter the natural light and send it to the ground floor.

For more light in the rooms, the internal walls are mainly glazed. Only some parts are opaque in order to ensure privacy in the offices.

3.2 Control Elements

3.2.1 BMS

The BMS (and its subsystem, the BEMS), controls all technical services equipment of the building, in particular:

- HVAC, DHW, sanitary, and fire protection equipment;
- Control cabinets;
- Heat meters;
- Low- and medium-voltage switchgear;
- Multimeters.

The hardware configuration of the BMS foresees the use of DDC (Digital Direct Control) peripheral units located within the control cabinets. These peripheral units connect the local equipment and communicate with it as well as with the control room via Ethernet TCP/IP. The heat meters are connected via M-bus to a gateway that connects to the Ethernet TCP/IP network. The ambient control is done by microprocessors in serial communication with the regulating equipment (like radiant panels). The microprocessors of the heavy HVAC equipment (heat pumps, boilers, and chillers), electric meters, and main control switches are connected via Modbus to a gateway that connects to the Ethernet TCP/IP network.

The BMS architecture contains a central node installed in the control room on the basement of the existing BZ1 building containing the rack with the switch and the gateways. The following equipment will be connected to the switch:

- Net server;
- Two workstations for the operators: one for security alarms and BMS, and one for the CCTV employed in the video surveillance system;
- Fire alarm system;
- Intruder alarm system;
- Access control system;
- Video surveillance system;
- DDCs for the control of HVAC, DHW, sanitary, and fire protection equipment;
- DDCs for the control of electrical equipment;
- Multicontrollers controlling the microprocessors at the terminal units;
- Gateways connecting third-party processors used in:
    - Chillers;
    - AHU E1;
    - Energy meters;
    - UPS.

The bus of the BMS has to ensure a data transfer of at least 9600 baud. The structure of the BMS is hierarchical, that is, each component equipped with a CPU reports to a parent node situated one level above. However, it is capable to operate autonomously in case the parent node should be offline or out of service. The peripheral system is controlled from the central unit equipped with a FEP (front end processor) or a net of FEPs. Due to the distributed nature of the system, to guarantee continuity in the functioning of the single machines, the applications reside on the peripheral units.

The peripheral units have to be equipped with:

- A CPU;
- An operating system on a permanent storage medium and the application software installed on a permanent storage medium or running in the RAM. In the latter case, the RAM has to have appropriate size, and batteries have to ensure an autonomy of at least one year. The same autonomy is required for maintaining the RTC (real time clock). An EPROM, programmed with the appropriate application software, will permit an automatic reload in case of abnormal conditions or a program crash. A manual command from the peripheral unit or the BMS will permit a reset followed by a reload of the application software and the last saved data on the EPROM;
- Hardware and software for self-diagnosis;
- Signal exchange cards for analogical and digital signals;
- Communication software for data transfer based on proven standard protocols;
- Memory buffer to ensure the storage of state changes and alarms of the equipment, together with time stamps, for a time period of at least one hour in case of disconnection with the BMS;
- Terminal with LCD and keyboard to permit operators, via a two level password (users and admin), to visualize the state of the machine, modify the visualized parameters, and issue commands to all nodes controlled by the peripheral unit and to all adjacent nodes that are part of the same system bus;
- At least one port for communication with the central unit and interface with other peripheral units;
- At least one port for local connection to a data terminal;
- Power supply and recharge unit.

In addition, they have to:

- Handle the equipment also in case of disconnection with the central unit;
- Communicate, transfer, and share data between other peripheral units connected by the same system bus, also in case of disconnection with the central unit;
- Allow modular and flexible reconfiguration, both on hardware and software level.

The peripheral units have to be distributed and dimensioned in such a way that one single CPU controls only a limited number of AHUs or limited parts of the equipment in order to avoid total systems' failure. Full CPUs can be substituted with PLCs (Programmable Logic Controllers) if the peripheral unit performs only monitoring tasks.

The executable operations at the data terminal accessible to the operator will be at least:

- On/off (start/shutdown) of the equipment;
- Modification of set points;
- Change of PID (proportional-integral-derivative) controller parameters;

- Change/setting of RTC;
- Addition and change of daily and weekly on/off schedules;
- Addition and change of daily and weekly set point schedules;
- Setup of holiday/exceptional days on/off/set point schedules;
- Visualisation of limits and setup of limit values for pre-alarm and alarm signals;
- Visualisation of data history.

The connection to the data terminal must not interfere or interrupt the functioning of the equipment.

The application software programming language of the peripheral units has to be freely programmable by operators to permit the integration of new programs. The DDC algorithms (PID, on/off, by steps) acting on the actuators (servo motors for valves, louvers, contactors, etc.) reside on the peripheral unit and are processed by its CPU. In case of particular, abnormal events, the system has to react in less than 2 seconds between generation of cause and activation of reaction. Such causes include, but are not limited to:

- Stop of fans in case of fire alarm;
- Lights switched on after an intrusion alarm or video-camera activation;
- Return of elevators to a default floor in case of fire alarm;
- Activation of emergency equipment (pumps, fans, back-up HVAC equipment) in case of primary equipment malfunctioning;
- Etc.

In special cases, for some controlled nodes, the BMS has to delay the reaction to an abnormal event: flow or pressure sensors for example have to be filtered during the start-up/shutdown of equipment to avoid wrong signalling in case of abnormal functioning.

For maintenance purposes, and to guarantee a smooth functioning of the equipment, it will be possible to setup deadlines or running time limits. If the deadline or limit is exceeded, a signal will be sent to the BMS. If available, the emergency equipment will turn on. The operator can then print out a summary sheet from the BMS detailing the state of the equipment that exceeded the deadline or limit.

Limit values: in every connected node it must be possible to set an upper and/or lower limit value. If these limits are exceeded, alarm signals will be sent and reaction programs, if any, activated.

DAQ (data acquisition): the operator can select quantities and the sampling frequency with which they will be stored. These quantities are then available for post-processing and evaluation. A laptop is used to program the peripheral units and put them to service. It is equipped with the necessary interface cards, operating system, and specific software. Data downloads/uploads are also performed from here.

Sensors (codes and numbers of sensors subject to change):

- Electric meters:

- El_1-4: Electric pumps P09A-C (that is, pumps P09A, P09B, and P09C), P08 upstream of groundwater heat exchanger;
- El_5-10: Electric pumps P01A-C, P10A-C downstream of groundwater heat exchanger;
- El_11-12: Chillers electrical consumption;
- El_13-14: Heat pumps electrical consumption;
- El_15-17: Boilers electrical consumption;
- El_18: PV plant electricity production;
- El_19-20: Electric pumps P12A-B for warm water flow to radiant ceiling panels;
- El_22-23: Electric pumps P14A-B for warm water flow to AHUs;
- El_21: Electric pump P06 for chilled water flow to AHUs;
- El_24: Electric pump P07 for chilled water flow to radiant ceiling panels;
- El_25-26: Electric pumps P21A-B downstream of chillers;
- El_27: Electric pumps P11A-C (total consumption of all three pumps) downstream of boilers;
- El_28-29: Electric pumps PS1, PS2 upstream and downstream of solar thermal collectors;
- El_30-37: AHUs electrical consumption;
- El_38-92: Electric meters for air-conditioned indoor spaces (conference halls, atriums, technical rooms, expo, offices); for each space, one meter is for appliances and one for lighting electricity consumption. In some spaces, one or more electric meters are metering DHW use;

- Temperature and humidity sensors TH_1-TH_32 for the AHU ducts: for each AHU, one for fresh air, heated fluid, conditioned air, return air, exhaust air, and cooled fluid where applicable;
- Room temperature and humidity sensors T1-T22, H1-H22 for the air-conditioned indoor spaces;
- Heat meters:
    - Hm_1: Downstream of solar thermal collectors;
    - Hm_2-3: Downstream of chillers;
    - Hm_4-7: Downstream of heat pumps; for each heat pump, one heat meter is foreseen for heating energy and one for cooling energy;
    - Hm_8-10: Downstream of boilers;
    - Hm_11: Downstream of heat storage;
    - Hm_12-13: Heat meters for warm and chilled water directed to the AHUs;
    - Hm_14-15: Heat meters for warm and chilled water directed to the air-conditioned indoor spaces;
- Gas meters Gm_1-3 for the boilers;
- Water temperature sensors Tw_1-3 for the groundwater heat exchanger;
- Opening windows sensors for:
    - Ground floor: atrium;
    - First floor: southern offices;
    - Second floor: southern, central, and northern offices;

- Third floor: southern, central, and northern offices;
- Fourth floor: atrium, southern, central, and northern offices;

- Weather station: wind speed and direction sensor, external temperature and humidity sensor, pyranometer for solar irradiation, and a rain sensor.

For the sensors, the following technical specifications are given (non-exhaustive list):

- Temperature sensors: minimum measuring range -40°C to +130°C;
- Humidity sensors: capacitive, minimum precision 5%, minimum measuring range 10% to 90% RH;
- Flow rate sensors: of turbine type with horizontal axis for diameters less than or equal to DN 50, with vertical axis for diameters less than or equal to DN 200, and of magnetic type for larger diameters. The sensors are suitable for fluid temperatures below 100°C and are equipped with a digital pulse output;
- Thermal energy meters: the measurement of thermal energy is performed using the following set of elements:
  - Water flow rate meter;
  - Resistance temperature detector (RTD);
  - Integrator (microprocessor);
  - Interface to transmit the calculated value to the BMS.

  The RTDs are of the PT500 type or equivalent;

  - Multimeters for measuring electrical quantities such as:
    - Phase current;
    - Phase voltage;
    - Frequency;
    - Power factor;
    - Real power;
    - Reactive power.

Actuators: the actuators for the louvers and the control valves are of electromechanical type with modulating, floating, or on/off control depending on the application.

Network: LAN/WAN Ethernet network to ensure data transfer between system controllers.

Load control: the BMS has to allow setting a limit on the number of on/off cycles of a certain equipment within an hour. It has to be possible to insert delays between one command and the next during the start-up phase to avoid the start-up of more than one heavy equipment within a short time period. The software controls, with a predefined frequency, the electrical energy consumed. If a set limit tends to be exceeded, the software has to exclude end users (tenants or possibly equipment) automatically according to an established priority list. After the critical time period, the excluded end users have to be reinserted according to the same priority list.

Energy saving measures: every central unit has to be able to perform the following basic energy saving actions:

- Daily scheduling;

- Scheduling according to calendar and holidays;
- Temporary manual programming;
- Optimal start-up/shutdown;
- Nightly setback;
- Peak load limiting.

3.2.2 HVAC

The automatic regulation of the HVAC equipment is composed of programmable units that operate autonomously.

Regulation of the warm water temperature: the temperature control is realized via three-way valves with temperature sensors located downstream of the pumps.

Regulation of the warm and chilled water secondary circuits' flow rate: the secondary circuits for the tenants have variable flow rate and are controlled by a differential pressure sensor positioned at 2/3 of the most distant circuit. According to the differential pressure sensor, the rotational velocity of the functioning pumps is adjusted by acting on the respective inverters. If the flow rate is less than 50% of the nominal flow rate of the electric pump and a further increase of the pressure difference occurs, the system doesn't modify the number of revolutions anymore, but opens the two-way bypass valve. The last terminal in each floor is equipped with a three-way valve instead of a two-way valve to maintain a constant water circulation.

AHUs regulation: the AHU starts only after checking the following signals (non-exhaustive list):

- "local"/"remote" switch of blower and exhaust fan in position "remote";
- Concordant with timer switch;
- No frost alarm signalled by thermostat;
- No overheat alarm signalled by fans;
- No inverter damage signal;
- Normal start of the blower fan and successively exhaust fan;
- In case of an abnormal state, the fans shut down and the external air intake and exhaust louvers close.

In winter, if the temperature is below 2°C, the respective heating valve opens even if the AHU is off.

Table 14 shows the handling of alarm signals.

Table 14: AHU alarm signal handling

Signal	Actions undertaken
Anti-freeze	Fans are shut down; External air louvers close; Heating valve opens;

	Restart has to be performed manually.
No fan status approx. 30 seconds after start-up command	Alarm signal issued
Humidification system damage	Only signalling
Inverter damage	AHU shutdown
Clogged filters	Only signalling
Smoke detector alarm	Signal to fire alarm system

The louvers for external air intake, circulation, and exhaust air extraction are actuated via servo motors.

AHU start-up phase: only air circulation for an adjustable time period (via time delay switch).

Regulation of heating/cooling: via two-way valves in sequence according to sensor installed in the return air duct.

Filter state: signalled via differential pressure sensor.

Anti-freeze protection: via thermostat with manual reset, shutting off the fans and sending an alarm signal.

Inverter regulation: the inverters function according to timer switch or on demand. The flow rates are controlled via pressure sensor in the duct or by manually issuing commands.

Radiant ceiling panels regulation: CPU-controlled; the CPU communicates via bus with the BEMS. The CPU sequentially controls the two-way valves for warm/chilled water supply according to the ambient temperature. The ambient temperature setpoint can be set at the local control panel (one for each zone), and by the BEMS. Every zone with radiant ceiling panels is equipped with humidity sensors that act on the chilled water supply temperature if compatible with the ambient temperature sensor. Otherwise, the chilled water supply valves of the respective zone are closed.

Energy optimization:

- Heat recovery of the air extracted by the AHUs for free pre-heating of the external air in winter;
- All-air free-cooling if external air enthalpy allows it;
- Adoption of VAV systems for external air;
- Adoption of variable water flow rate systems.

3.3 Kind of Areas & Uses

The following table lists the different zones of the Black Monolith together with their use.

Table 15: Black Monolith zone names and types

Zone name	Zone type	Floor
U1Atrium	Atrium	Basement
U1ConfHall1	Conference hall	Basement
U1ConfHall2	Conference hall	Basement
U1ConfHall3	Conference hall	Basement
U1Server	Server room	Basement
0Atrium	Atrium	Ground floor
0Expo	Expo	Ground floor
0EastOffices	Offices	Ground floor
1Atrium	Atrium	First floor
1CentralOffices	Offices	First floor
1EastOffices	Offices	First floor
1SouthOffices	Offices	First floor
2Atrium	Atrium	Second floor
2CentralOffices	Offices	Second floor
2EastOffices	Offices	Second floor
2NorthOffices	Offices	Second floor
2SouthOffices	Offices	Second floor
3Atrium	Atrium	Third floor
3CentralOffices	Offices	Third floor
3EastOffices	Offices	Third floor
3NorthOffices	Offices	Third floor
3SouthOffices	Offices	Third floor
4Atrium	Atrium	Fourth floor
4CentralOffices	Offices	Fourth floor
4EastOffices	Offices	Fourth floor
4NorthOffices	Offices	Fourth floor
4SouthOffices	Offices	Fourth floor
Patio	Patio	Second to fourth floor

3.4 Control Strategies

3.4.1 Modes of operation wanted

3.4.1.1 HVAC

Natural ventilation: a direct natural ventilation during the day without an air velocity control is unwanted because it could disturb the work in the offices. The winds in Bolzano are weak. Therefore it was decided to base the natural ventilation strategy only on the driving force caused by the temperature difference between outdoors and indoors and not on wind pressure on the façade. Operation mode in summer: nightly natural ventilation to dissipate heat accumulated by the thermal mass during the day, exploiting the lower external air temperature. This way, the cooling load for the next day is reduced. The nightly natural ventilation is more efficient if the thermal mass of the building is higher. As the internal partition walls are lightweight to permit a flexible partitioning of the internal spaces, ceiling and floor structures have to be exposed as much as possible to ensure thermal exchange with the internal spaces and an exploitation of their thermal capacity.

3.4.1.2 Illumination

To reduce the electricity consumption due to artificial lighting, an illumination level of 500 lux will only be provided at the desks. For the surrounding areas, 300 lux will be provided according to EN 12464-1.

Offices: a study on the occupancy of the EURAC main building offices showed that about 33% of the workplaces are constantly vacant because of business trips, meetings, and sickness absence. Keeping that in mind, it was decided to illuminate the entire offices area using fluorescent technology and to provide an illumination level of 500 lux only at the desk by using LEDs. The lighting system is DALI (Digital Addressable Lighting Interface)-compatible. The technology allows, in addition to dimming, a modification of the connections between control panel/switches and lamps without intervening on the cabling.

User acceptance studies carried out internally by EURAC have shown that presence sensors in the offices are not very well accepted by most people. People feel controlled or are annoyed by the light going on and off in adjacent offices. Rather than installing dimmers and occupancy sensors in each lamp, although principally possible in a second step, an active participation of the users in the proper use of the lighting systems will be strived for. To achieve that, an initial training will be delivered to the tenants, followed by monitoring, periodic controls, and reports on the effects of actual user behaviour.

Foreseen on/off typologies:

- Common spaces, staircases: automatically controlled from centralized lighting system;
- Offices, conference halls, expo area: manual control via centralized lighting system;

- Sanitary rooms: presence sensors.
- Outdoor illumination: automatically controlled from centralized lighting system with twilight switch and timer.

All gas-discharge lamp power circuits feature switches with three positions “manual – 0 – auto”. For these circuits it is always possible to manually control the lights from the control cabinet, turning the switches to the “manual” position to switch lights on, to the “0” position to switch lights off, and to the “auto” position for automatic centralized control.

3.4.2 Variables to be controlled

3.4.2.1 HVAC

Natural ventilation, together with forced ventilation, will guarantee indoor air quality. Variables to be controlled are thus indoor air temperature, humidity, pollutants concentration, and air change rate amount and frequency. Energy demand is being controlled indirectly through control strategy selection and optimization. Extensive monitoring of external conditions and electricity, gas, and heat consumption permits to carry out the optimization.

3.4.2.2 Illumination

Factors to be controlled are the daylight factor, the illuminance (lux) and luminance (cd/m^2) distribution in the indoor spaces, glare (detected by luminance measurements or subjectively by tenants), electricity consumption, and excessive gains. Additional factors may include information on light quality such as the colour rendering index.

3.4.3 Possible strategies

3.4.3.1 HVAC

Natural ventilation: the building has been divided into three zones depending on the fire compartments as shown in Figure 21. There are no direct flow paths from one fire compartment to another to avoid exceeding costs. Safety reasons make a use of natural ventilation for the underground floor and for the expo areas at the ground floor prohibitive. A small offices zone in the center of the building is ventilated from one side and connected with the patio.

A stack effect-driven cross ventilation has been chosen as the most effective configuration that balances performance needs with constraints given by fire compartments, acoustic comfort, and privacy requirements in the offices during the working hours.

To increase the height difference between inlet and outlet air openings, connecting floor grilles are used. This solution minimizes the impact on the architectural concept of the building seen as an unchanging monolithic block by reducing the amount of movable parts integrated in the façade. In addition, the internal spaces are kept free.

The floor grilles will be closed automatically during the working hours to avoid acoustic discomfort and maintain privacy between adjacent offices.

The foyer is directly connected to a light well and ventilated through a stack effect-driven cross ventilation, thus avoiding overheating.

Only the basement and expo areas are mechanically ventilated to cool down during the night.

Optimized start-up and shutdown of HVAC equipment: based on indoor air temperature, humidity, and air quality, the equipment start-up/shutdown has to be offset with respect to occupancy such that the comfort during occupancy is guaranteed and the overall energy consumption is minimized.

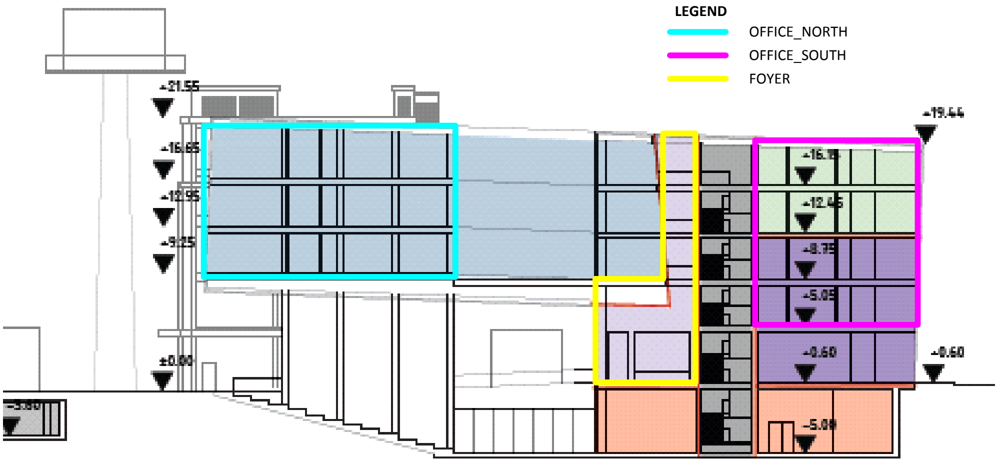


Figure 21: Cross section of the building with fire compartments (coloured patches) and building zones for the natural ventilation analysis (outlined in colour)

The zone OFFICE_SOUTH was divided into two parts to respect the fire compartments. The strategy foresees openings for fresh air in the lower part of the façade on the first floor and openings for the warmed up air in the superior part of the façade on the second floor. The air flows from the first to the second floor through vents in the floor. The same strategy is used to ventilate the third and fourth floor.

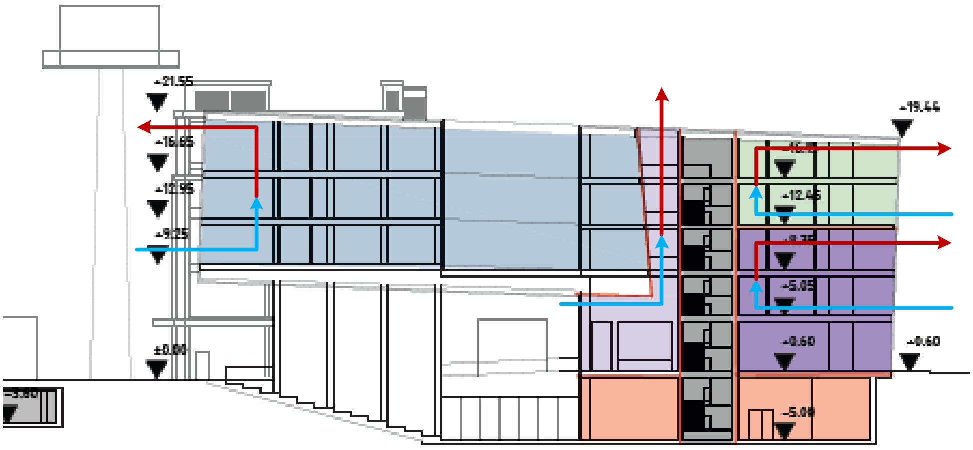


Figure 22: Proposed natural ventilation strategy

The zone OFFICE_NORTH is ventilated by letting fresh air enter at the second floor. The warmed up air exists the fourth floor.

The FOYER zone has a roof opening to exploit the stack effect due to the vertical cut.

The natural ventilation is activated, that is, the vents are opened, whenever the following conditions are fulfilled:

- Time interval: 6 pm – 8 am;
- External temperature: > 14°C;
- Internal temperature: > 24°C;
- Internal temperature higher than external temperature;
- External dew point ≤ 17°C.

The air humidity control was introduced to avoid latent load to enter the building, an effect which would occur for an external dew point lower than 17°C (corresponding to an air temperature of 26°C with a relative humidity of 50%).

During working hours, the comfort conditions are guaranteed by the HVAC system.

The windows automation system will allow a controlled opening/closing of the windows and grilles according to indoor temperature, outdoor temperature, and humidity as explained above.

Other strategies could involve frontal ventilation strategies instead of the proposed horizontal grilles integrated in the floors:

- With a single opening;
- With two openings at different heights.

The flow rates were calculated according to the formulas in the British standard BS 5925:1991, see also Figure 22.

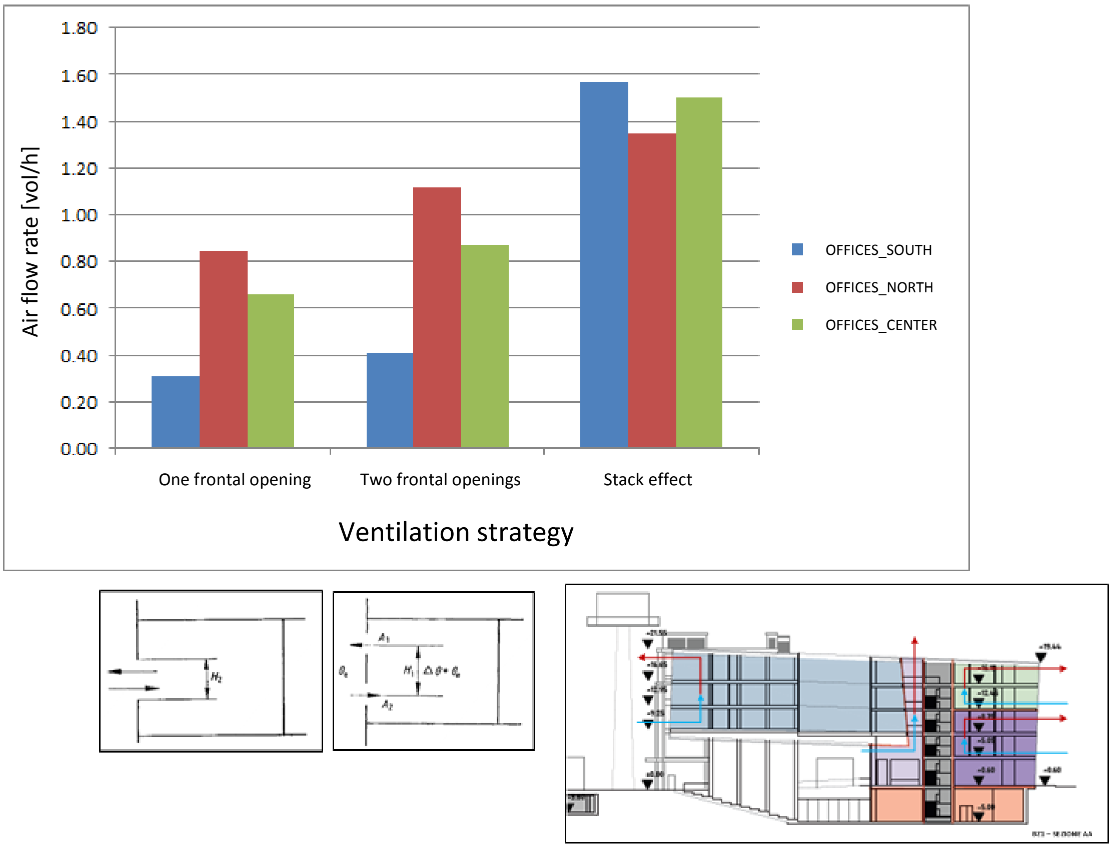


Figure 23: Comparison of estimated ventilation air flow rates for three ventilation strategies and three office zones on a typical floor.

In case of frontal ventilation strategies, the area of the openings necessary to obtain the same air change rates would be much higher than for stack effect driven ventilation.

Mechanical ventilation control strategies:

- Automatic
  - Summer mode: set point 26°C and 50% RH, setback 32°C and 100% RH
  - Winter mode: set point 21°C and 50% RH, setback 16°C and 100% RH
  - On/off daily and weekly schedule
  - On/off special schedule for holidays
  - Indoor air quality control (like maximum CO_2 concentration)
- Manual (indoor air quality requirements might override manual settings)
  - Temperature set point/setback adjustments
  - Expert settings: change of PID (proportional-integral-derivative) controller parameters.

For louvers regulation to control external air intake, circulation, and exhaust air extraction, the following three actuation modes can be selected:

1. Control of external air flow rate according to room occupancy via air quality sensor;

2. Optimization of external air flow rate for energy saving purposes via comparison of enthalpy; in any case, air quality (that is, actuation mode one) has priority;
3. Forced positioning via manual control or computer.

3.4.3.2 Illumination

Based on the illumination control system and the requested modes of operation of the Black Monolith indoor spaces, the following strategies are proposed:

- Offices
  - Manual
    - On/off of background lighting (fluorescent lamps)
    - On/off of desk lights (LED technology) when workplace is occupied
  - Automatic
    - Daily and weekly schedule for background lighting
    - Special schedule for holidays
- Conference halls:
  - Manual
    - Audience: On/off (fluorescent lamps)
    - Podium: On/off (LED technology)
- Atriums, corridors, facilities:
  - Manual (on/off)
  - Automatic
    - Daily and weekly schedule for background lighting
    - Special schedule for holidays
    - Dimming and/or presence sensors

The automatic settings can be overridden by manual actions (working outside normal working hours, maintenance, etc.).