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ICT in BUILDING DESIGN

Project

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SUMMARY

1. SYSTEM OVERVIEW

The aim of this project is to develop a programmable emulation/control system, typically referred to as a Building Management System (BMS). In particular, the modules to be developed are: **Shading Management**, **Lighting Management** and **Air Quality Control System.** A brief description of those systems follows:

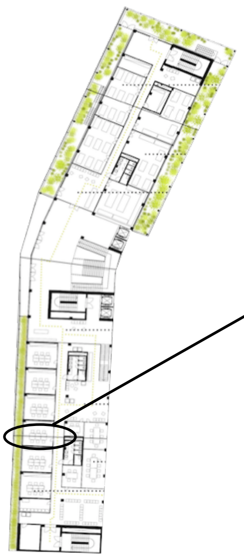
- **Shading Management:** implementation of a controller for an automatic shading device that will change its status in order to satisfy precise shading requirements.
- **Lighting Management:** implementation of a control algorithm for the lighting system, with the goal of maximizing the natural light component and reducing the energy consumption, without compromising the comfort of users. After having verified that the requirement about the daylight factor imposed by Italian regulation is satisfied, the system performs the total flux calculation to eventually activate and properly distribute the artificial lighting.
- **Air Quality Control System:** development of a software module which aims to dynamically adjust the air flow exchange within the room and to satisfy the requirements about Indoor Air Quality (IAQ). An index of IAQ is the amount of Volatile Organic Compounds (VOCs), that has to be kept under a threshold value. Additionally, the minimum air flow rate per person in the room (q_{iaq}) must be guaranteed in any condition.

2. ABSTRACT & SCENARIO

The building considered in this report refers to an hypothetical project located in the“Porta Nuova” area in the city of Turin. This architecture was designed by students Diego De Re, Andrea Liprandi, Ilaria Malano, Mauro Mosca as a project of the course “Final Design Studio 3R: Reduce, Reuse and Recycle in architecture” by Prof. Giordano, Prof. Griffa, Prof Curto in Master Degree Programme in Architecure for Susteinable Design at Politecnico di Torino.

The building is divided into two sections: the “Vertical Farm” (on the west side), and the “Bi-Office Block” (on the east side). In addition to the private offices, the structure also hosts some co-working areas, a restaurant, a bio-market, some relax areas and a spacious event room. The south-oriented offices have a glazed shell that encloses hydroponic cultivations.

The simulation of the control system has been performed on a specific south-oriented office room named “TEAM SPACE - 4° Floor – Room n°3”.



TEAM SPACE – 4°Floor – Room n°3

Here are listed the main specifications about the room selected as case study:

- **Room size:** [height * width * depth = 5m * 5m * 5m]
  (height below countertop = 5m – 0,56 m = 4,44 m)
- **Window size:** [height * width = 4,44m * 5m]
- **# 5 vases for hydroponic cultivation** positioned outside the window
  [distance vase-window = 0,26 m]
  [height * depth = 0,10m * 0,20m, for each]
  [mutual distance between adjacent vases: 0,88 m]
- **Room colours**: white (ceil - wall), light grey (floor), green (wall)
- **# 4 desks** positioned in the center of the room
  [average n. of users = 4]
- Electricity distributed on desks using a column pointing towards the desks

TEAM SPACE – 4°Floor – Room n°3

3. MODUS OPERANDI AND SCALABILITY

The whole system has been conceived to be **modular,** in order to allow an arbitrary selection and combination of the three control systems implemented, and totally **scalable,** to ease the eventual re-use of the modules in other rooms/buildings and the attachment of new components.

The scalability is achieved through the implementation of a configuration file, where all the parameters regarding the room and the requirements to be satisfied are stored. In this analysis, since we focus on a specific room, all the parameters refer to the considered use case. In case the system needs to be replied in a different room, it is sufficient to install a copy of the control system and update the parameters in the configuration file accordingly.

This is a technical choice that takes into account the heterogeneity of the spaces in the building, which may have various features and contrasting needs and requirements to be fulfilled. Of course, upon the control of a single room, as implemented in this example, a multi-layer control system can be implemented, aggregating the rooms by function or by position within the building. Then, a central controller might be used for an overall coordination of the environments.

In order to guarantee a fast observation of the simulation parameters, the sensors will be asked to sample the environmental variables within a shorter period (in the order of seconds) with respect to a realistic scenario (sampling period in the order of some minutes). In addition, in a real case it could be useful for the user's comfort to introduce delays or a double threshold in order to avoid the risk of the continuous change of status of the actuators.

4. SHADING MANAGEMENT

4.1 SHADING REQUIREMENTS

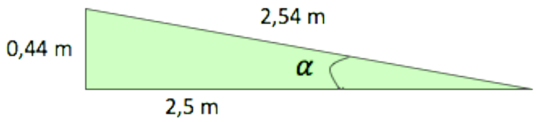
Before proceeding to develop a shading control system, it is necessary to analyze the requirements and evaluate the presence of eventual obstacles or fixed shading devices mitigating the effects of direct solar irradiation.

The Directive 200/91/EC on the Energy Performance of Buildings, specifically related to Piedmont Region, states that during the summer period, taking as reference the 21st of June, at least the 70% of the window surface must be covered by a shadow. Conversely, during winter period, referenced by 21st of December, the shadow must not cover more than the 30% of the window surface.

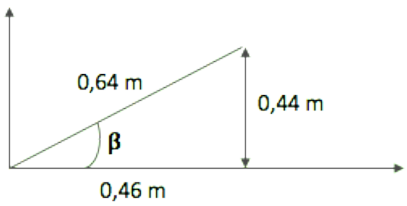
Focusing on our case study, there is no external building or any additional obstruction in the proximity of the structure that can interfere with the solar radiations, while the vases for hydroponic cultivation represent an obstacle and thus can be considered as fixed shading devices.

For the evaluation of the shading requirements during the **SUMMER** period, only the vase at the bottom is taken into account as a shading device, starting from the hypothesis that the other vases (and respectively, the plants) on top of it project an homogeneous shadow that can be considered unique.

Starting from this assumption, we can proceed with the evaluation of the angular elevation and azimuth of the basement, and with the representation over the stereographic diagram together with the sun path diagram to check the requirement constraints.



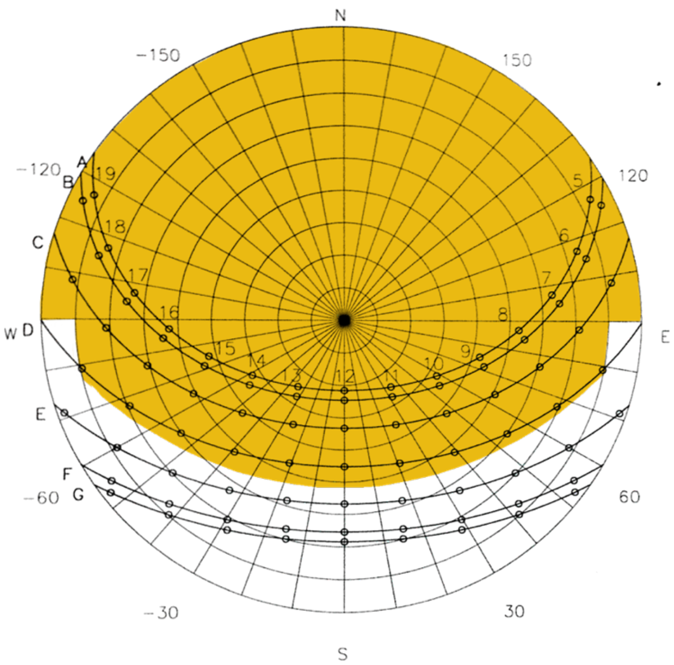
$$\alpha = arcos\left(\frac{2{,}5}{2{,}54}\right) \simeq 10°$$



$$\beta = arcos\left(\frac{0{,}46}{0{,}64}\right) \simeq 45°$$

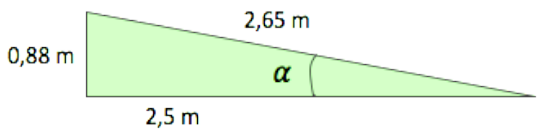
α= angular elevation

β= azimuth

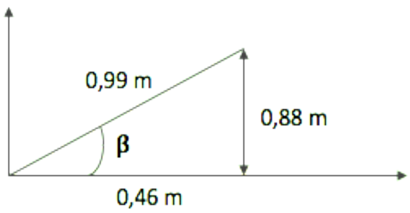


SUMMER SUN PATH

During **WINTER** period, as anticipated, only the 30% of the window surface can be covered by a shadow. So, a point at the 30% of the window height (at 1,33m from the ceiling) is taken, and the angular elevation and azimuth are evaluated with respect to the vase situated immediately above this point.



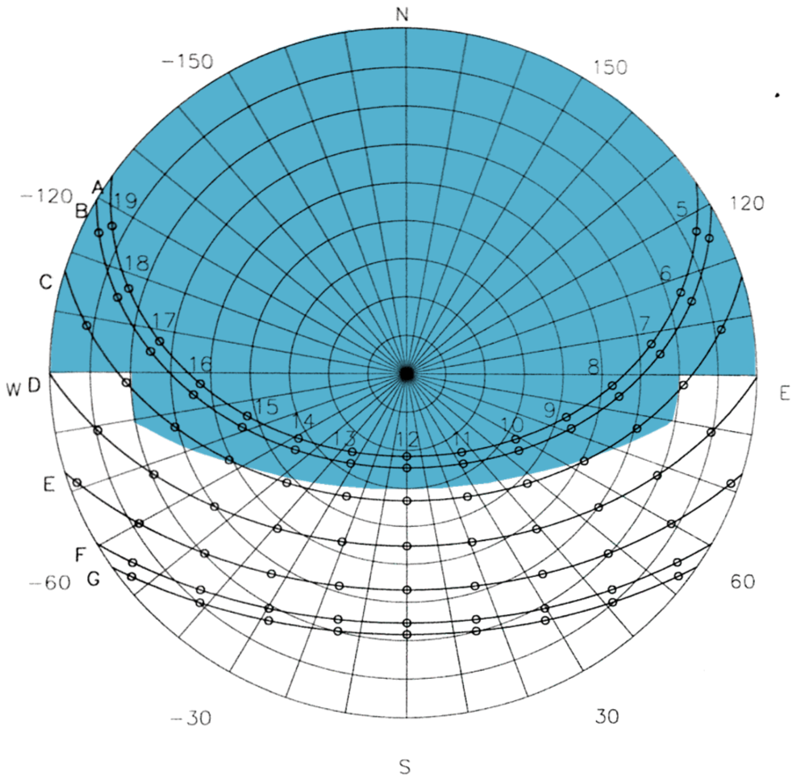
$$\alpha = arcos\left(\frac{2,5}{2,65}\right) = 19,37° \simeq 20°$$



$$\beta = arcos\left(\frac{0,46}{0,99}\right) = 62,31° \simeq 60°$$

α= angular elevation

β= azimuth



WINTER SUN PATH

4.2 PRACTICAL CONSIDERATION

From the evaluation of the shadow goniometers, it can be observed that the requirements related to the Directive on Energy Performance of Buildings are completely fulfilled both during summer and winter periods, without the intervention of any automatic control system.

Although, even if the requirements are satisfied, the heating effect of the solar radiation on the surface of the room can not be neglected. For this reason, an auto-dimming window glass (**SMART GLASS)** has been introduced in the system.

4.3 SMART GLASS

The SMART GLASS solution has many advantages: solar radiation and glare are reduced when the glass is tinted, creating a comfortable indoor climate for occupants, and so letting the building inhabitants enjoy the benefits of the natural sunlight.

The SMART GLASS window consists in a pane of glass with ceramic coating on the inner surface of the outboard glass, which is able to carry an electrical charge. There is also an argon gas layer which improves heating and cooling.

The glass is able to simulate 4 tints, from the less dimmed to the darkest. The tint n. 1 actually introduces no dimming on the glass. This system can be controlled by software: relying on the data acquired from the sensors the control system chooses the most efficient tint to apply to the selected room.

Each tint, in fact, is given a percentage of transmittance of the solar radiation intensity: ($tint_1$ = 58%, $tint_2$ = 40%, $tint_3$ = 10%, tint4 = 1%). *

TINT 1 TINT 2 TINT 3 TINT 4

*this system is inspired from Dynamic Glass developed by View,Inc. Milpitas, CA (U.S.A.) - (http://viewglass.com/product)

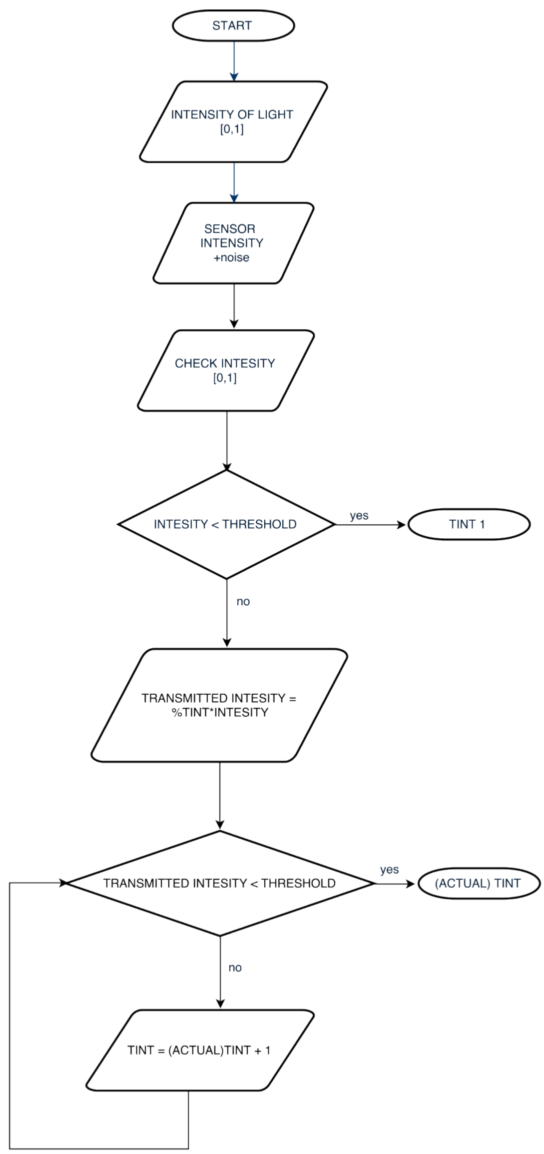
4.4 CONTROL SYSTEM

Therefore, the shading control system will rely on the solar light intensity and on the value transmitted indoor by the current tint in use.

The control is performed comparing the value of transmitted intensity and a threshold. If the solar intensity is above this threshold, the smart glass switches to the lightest tint that keeps the transmitted intensity below the limit value, otherwise, if the transmitted intensity is within the limit, we set as default the lightest tint (tint 1), since shading is not necessary.

To perform this, we consider the outcome of a light intensity sensor located just outside the window and we simulate the “transmittance effect of the tint” by multiplying this value with the percentage of the transmitted light associated to the current tint. This control can be switched OFF when there is nobody in the room in order to reduce power consumption, but by keeping the device active it is possible to guarantee always a comfortable environment in the room.

FLOW CHART related to the shading system control



4.5 SENSORS

As previously explained, the system needs a sensor able to measure the intensity of solar radiation.

Here there is an example of a possible one: http://www.davisnet.com/product/solar-radiation-sensor/

5. LIGHTING MANAGEMENT CONTROL SYSTEM

5.1 REQUIREMENTS: DAYLIGHT FACTOR

Also in the case of the lighting management control system, the first step is to check if the room parameters are such as to satisfy the regulation specifications. A parameter used in this field is the Daylight Factor, a metric used to quantify the amount of diffuse daylight in a room. Each country has its own different regulations for the evaluation of this parameter. In this case study the Italian legislation ("Decreto ministeriale sanità 5/07/1975 Edifici Residenziali") is taken as reference.

The formula that allows to compute this value is the following:

$$DFm_{Italy} = \frac{A_{window} \cdot \varepsilon \cdot \psi \cdot t}{A_{tot}(1 - \rho_m)}$$

- Average Reflection Factor of all the internal surfaces → ρ_m
- Factor to account for external obstructions → ε
- Factor to account for thickness of the window → ψ
- Transmission factor of the glazing → t = 0,58 (according the transmittance of the lightest tint, used to evaluate DFm without taking into account the effects of the control system, that should not be considered for this calculation)

	SURFACE	REFLECTION FACTOR ρ (COLOR)	$\rho \cdot A$
CEIL	$25m^2$	80% (WHITE)	$20\ m^2$
FLOOR	$25m^2$	35% (LIGHT GREY)	$8{,}75\ m^2$
WALL	$\left(\frac{2}{3}\right) 44{,}4m^2$	80% (WHITE)	$35{,}52\ m^2$
WALL	$\left(\frac{1}{3}\right) 22{,}2m^2$	70% (GREEN)	$15{,}54\ m^2$

$A_{tot} = 116{,}6m^2$ $\sum_k \rho_k \cdot A_k = 79{,}81m^2$

$\rho_m = \frac{\sum_k \rho_k \cdot A_k}{A_{tot}}$ $\rho_m = \frac{79{,}81}{116{,}6} = 0{,}684$

$A_{window} = 22{,}2\ m^2 \rightarrow 80\% = 17{,}76\ m^2$ $\psi = 1$

$$\varepsilon = \frac{\sin \alpha_2}{2} = (\alpha_2 = 60°) = \frac{\sqrt{3}}{2} \Big/ 2 = \frac{0{,}866}{2} = 0{,}433$$

$$DFm_{Italy} = \frac{A_{window} \cdot \varepsilon \cdot \psi \cdot t}{A_{tot}(1-\rho_m)} = \frac{17{,}76 \cdot 0{,}433 \cdot 1 \cdot 0{,}58}{138{,}8 \cdot (1-0{,}64)} = 0{,}102 \rightarrow 10{,}2\%$$

“Circolare Ministero Lavori Pubblici No.3151 22/05/1967” states that an office room needs a DFm of at least 1%. As the resulting value is equal to 10.2%, the constraint is fully satisfied.

5.2 REQUIREMENTS: FLUX CALCULATION

Another requirement to be fulfilled is related to the total luminous flux, that is measured in lumen. A simple calculation method is used for this evaluation.

$$\phi_{tot} = \frac{E_m \cdot A}{U \cdot M}$$

Environmental requirements (for an office) → $E_m = 500\ lux$

Utilization factor → U Calculating using space index (K) and related tables

Maintenance factor → M =0,65

A=$25m^2$ $\quad$ $K(space\ index) \rightarrow K = \frac{a \cdot b}{h\prime \cdot (a+b)}$

$h'(h_{room} - h_{desk}) = (4{,}44 - 0{,}8) = 3{,}64 \implies K = \frac{25}{3{,}64 \cdot 10} = 0{,}69$ $\quad$ U→35%=0,35

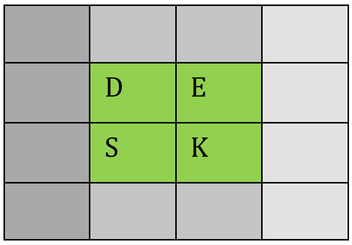
$$\boldsymbol{\phi_{tot} = \frac{E_m \cdot A}{U \cdot M} = \frac{500 \cdot 25}{0{,}35 \cdot 0{,}65} = \frac{12500}{0{,}2275} = 54945 \rightarrow 55000\ lm}$$

5.3 PRACTICAL CONSIDERATION

In order to satisfy the flux evaluated in the previous section, artificial light plant in the room has to be properly dimensioned. A possible approach could consist in devoting 60% of the artificial flux to the working area and the remaining 40% to the other ambients. A model of the artificial light system of the room is shown:

DESKS → 33000 lm (8250 lm x 4)

NO DESKS → 22000 lm (1800 lm x 12)



OFFICE ROOM

For what concerns the lamps surrounding the desks, i.e. the grey ones in the fig., it is possible to identify three *ambients*: the farthest from the window, which is the darkest one, the closest, which is the brightest, and the one standing in the middle. In the control system, this detail is relevant to define a policy for switching ON the lamps.

The chosen lamp for this model is a LED lamp called "Deep Minimal" taken from the IGuzzini catalogue 2013/2014. In order to obtain the required values of flux, this lamp can be installed in groups of 2 or 3.

DESKS → 33000 lm = (3 lamps of 3000lm x square) x 4 squares

NO DESKS → 22000 lm = (1 lamp of 1900lm x square) x 12 squares

sorgente	W	Lm	altezza	ottica	cod.
LED	Dissipazione passiva				
	Completo di alimentatore DALI				
	Neutral white				
	19W	2000	120	46°	MG21
	Warm white				
	19W	1900	120	14°	MG22
	19W	1900	120	30°	MG23
	19W	1900	120	46°	MG24
	Warm white				
	3x35W	3000	195	14°	MG70
	3x35W	3000	195	30°	MG71
	3x35W	3000	195	46°	MG72

TOTAL POWER CONSUMPTION

DESKS → 35W x 3 x 4 = 420W

NO DESKS → 19W x 12 = 228W

TOT = 420W + 228W = 648W

5.4 CONTROL SYSTEM

The lighting controller has to guarantee the minimum luminous flux in the room. The core takes in input the flux sensed by a luminous flux sensor standing over the working desks and it decides whether to activate or deactivate a portion of lamps. In this case the control is performed only if there are people inside the room, otherwise all the lamps are switched off by default.

In case the requirement is not fulfilled, the controller firstly activates the lamps over the desks, and then, if the luminous flux is still below the required one, it activates the lamps over another zone of the room, following this policy:

1) The first zone to be switched on is the farthest from the window, which is supposed to be the darkest zone of the room by construction;
2) The second one is the zone in the middle of the room;
3) The last zone to be activated is the one closest to the window, supposed to be the brightest one.

Everytime a command of “turn ON” is raised, all the lamps belonging to the specified zone are activated.

Conversely, when the total flux in the room is higher than the required value, the algorithm decides to deactivate lamps in reverse order (from the ambient close to the window to the zone over the desk) so as to minimize the exceeding luminous flux and reduce power consumption (“*daylight harvesting*”). The number of zones to be switched off is computed as the *floor* of the ratio between the **exceeding flux** (total flux in the room minus the required one) and the flux contribute of each zone.

5.5 SENSORS

The two kind of sensors used here are:

• LIGHT FLUX SENSOR

An example of a light flux sensor could be found at this link:

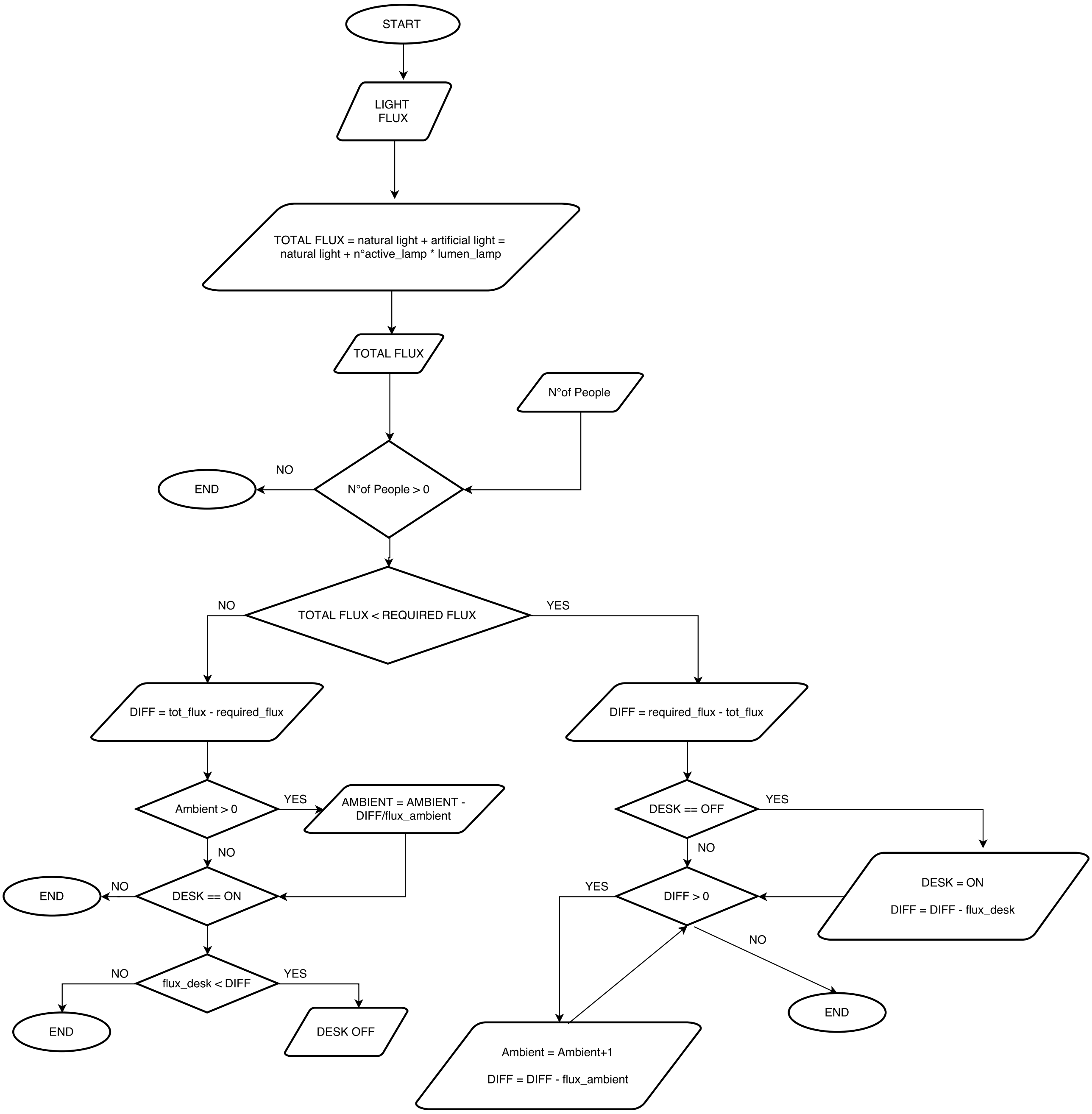
http://www.vishay.com/docs/81521/bpw34.pdf

• PEOPLE COUNTER SENSOR

An example of a possible one to be used could be:
https://www.iee.lu/en/products/building-management-security/people-counter

LIGHT FLUX SENSOR

PEOPLE COUNTER SENSOR



FLOW CHART related to the artificial lighting control system

6. AIR QUALITY CONTROL SYSTEM

6.1 REQUIREMENTS

An air quality control system has been developed in order to dynamically satisfy the requirements for Indoor Air Quality (IAQ) standardized in the UNI 10339 UE regulation.
In particular, the standard rates the level of pollution in a given ambient quantifying the density amount of Volatile Organic Compounds (VOCs) [μg/m^3]. According to the regulation, an ambient of Class A must keep the level of VOCs under 100 μg/m^3.

The formula that allows to compute the total amount of VOCs is the following one:

$$VOCs = \frac{\frac{\sum_{i=0}^{N} femission(i) * Surface(i)}{(Volume * 0.9)}}{ACH}$$

where $f_{emission(i)}$ is the amount of pollution for the i-th material present in the room, and surface(i) is the surface covered by that material.
ACH is the number of required air exchanges per hour, and is computed as follows:

$$ACH = \frac{q_{iaq} * f_{occupation}}{Volume}$$

where q_{iaq} is the minimum required airflow rate per person [m^3/h per person] related to the considered space unit (UNI 10339), and the $f_{occupation}$ is the product of the average number of people in the room times the average occupation hours.
In this sense, the goal of the air quality control system is to ensure at every instant the minimum q_{iaq} that allows to satisfy the VOC requirement for a Class A environment.

Object	Material	$f_{emission}$ tot [mg/m^2*h]	Surface [m^2]	$f_{emission}$* Surface
Walls	Water paint	48	66,6	3196,8
Floor	Gres Porcelained	25	25	625
False ceiling	Drywall	48	25	1200
Desk	Steel + Plywood	110	4	440
Desk panels	Plastic	68	0,9	61,2
Hydroponic Vases	Aluminum	10	5	50
Chairs	Alluminum + Fabric	110	1,7584	193,424

Computing the previous formulas we obtain:
Min. ACH = 0,5772 [1/h]
q_{iaq} = 48.5 [m^3/h per person]

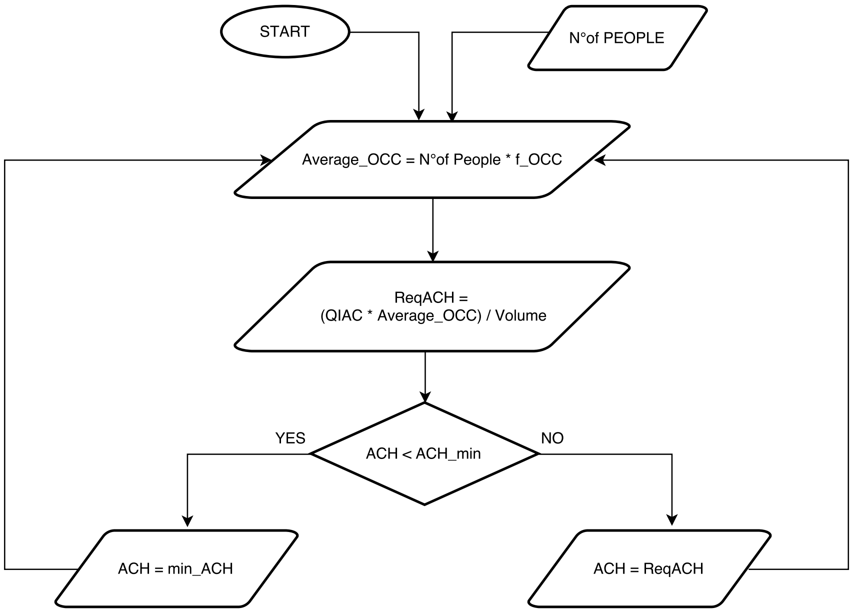
The resulting minimum ACH, that must be always satisfied, ensures the air change ratio required by the Directive 2002/91/EC on the energy performance of buildings.

6.2 CONTROL SYSTEM

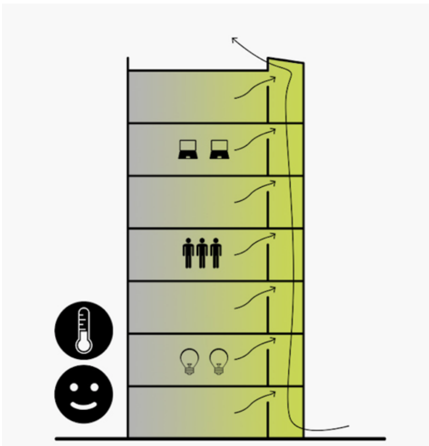
The Air Quality monitoring system must ensure that the amount of Volatile Organic Compounds (VOCs) is kept under a threshold value. Additionally, the minimum air flow rate per person in the room (q_{iaq}) must be guaranteed in any condition.
The q_{iaq} and the minimum ACH value depend on the specifications of the room, and must be evaluated considering the constraint on the VOC value. Then, by

knowing how many people are in the room, the value of ACH is set accordingly. Moreover, if the number of people in the room is below the average, ACH is set at the minimum value that allows to respect the VOC requirement.

FLOW CHART related to the artificial lighting control system



Since the project foresees a system of inlets and vasistas, the actuation of the ventilation within the room can be performed automatically through these openings, that would create a vertical air flow through the interspace dedicated to hydroponic cultivation. This air flow would be naturally forced by the thermal gradient between the exhausted air and the fresh one.



6.3 SENSORS

The only sensor exploited by the air quality control system is a people counter sensor. We can use the one linked before: https://www.iee.lu/en/products/building-management-security/people-counter

7. ENVIRONMENT

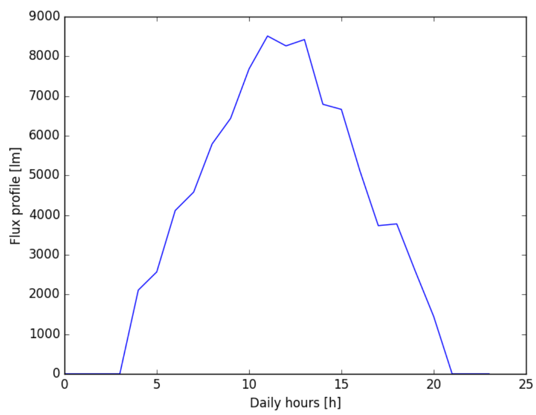
The *Environment()* class is the one in charge of simulating environmental variables which are then detected by sensors. Boundaries values used for the models are taken from the configuration file of the environment.

In particular, this class provides three parameters:

A. Flux

The flux is modeled according to the season of the year. A profile of the solar irradiation for the 24 hours of a day is used as starting point. Then some noise is added, and, in order to bring those values in the flux reference frame, the values are scaled by the daylight factor of the room and the surface of the working area.

This final value refers to the flux due to external sources (the sun, the season, possibly the weather, the actual tint of the shading glass etc.) and has to be added to the flux coming from the sources inside the room, as the artificial light. The following figure represents a possible daily profile of external flux in the summer.



Flux Profile in a summer day

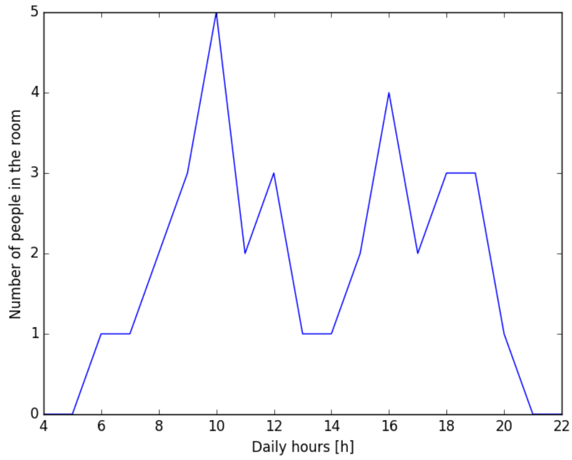
The artificial flux is clearly dependent on the number of active lamps in the room. Of course, in a real scenario, the sensor will measure a value of flux that is the outcome of both the contribution of natural and artificial light. To implement this in simulation, the sensor needs to be *"advised"* about the current flux state of the room. Clearly, in a real situation the sensor will not have any knowledge of the single sources of the total light flux.

B. Intensity

The model for the solar intensity is built upon the same starting model of the flux , i.e. relying on the model of the solar irradiation defined for each season of the year. This time the values are mapped in a different scale, with a different unit of measure [W/m^2].

C. Number of people in the room

In order to model the number of people present in the room, the *Environment()* class takes in input from its own configuration file a plausible trend taking into account the hour and the day of the week. In particular, for each hour, the class generates an integer random value in an interval that is weighted with respect to the actual day of the week. An example of this behavior is shown in the following figure, which refers to the 31st January 2017.



Number of people profile in the room in a typical day

8. COMMUNICATION

The exchange of information between the involved entities is developed using a Mosquitto broker, which exploits the MQTT protocol for the communication. The broker has the role to receive inbound messages coming both from controllers and from sensors (more properly from an eventual Arduino connected to the sensor) and dispatch them so that each component can retrieve the message on the topic to which he subscribed.

Each component initializes a connection to the broker, which can be physically wherever in the world, even on the cloud or locally (as in our case study), and performs the subscribe to the topics from which it aims to receive messages through the *message_callback_add()* method.

In order not to overload controllers of messages with values sampled by sensors, each controller publishes a request message for the value it needs to retrieve on the topic "/Get*Value*", where *value* refers to Intensity, Flux or Npeople.

Each request is a Json message which contains in the payload two keys: the request type and the timestamp.

The methods used to emulate the *sensing* of the sensors are called in the *parse_msg()* function, invocated in the message callback.

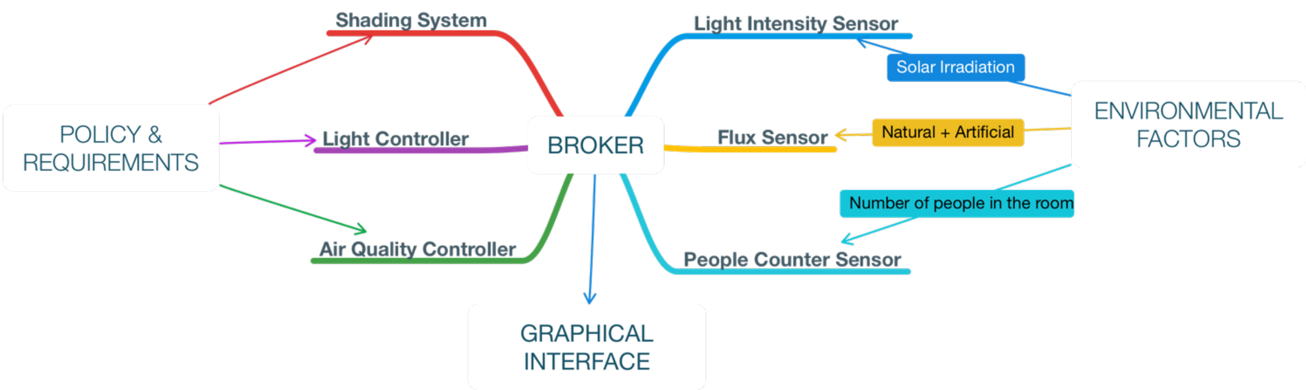
In fact, the sensor which subscribes to the associated *Value* firstly performs the parsing of the message to understand if it is really the addressee of the request. If so, it replies by publishing on the topic *"/Value"* a Json which contains the value sensed (got through the sense_*value()*), the timestamp and the name of the sensor.

All the parameters given in input to the sense_*value* methods are there <u>only for the sake of simulation</u> (apart from the client information which are used to perform the publish). In particular,

- The *sense_intensity()* method takes in input the intensity as generated by the Environment() class;
- The *sense_flux()* method takes in input the transmittance factor of the actual tint in use to scale the contribute of external flux and the internal flux. The sum of the two contributes is the total sensed flux;
- The *sense_person()* method takes as variable the number of people in the room as generated by the Environment() class.

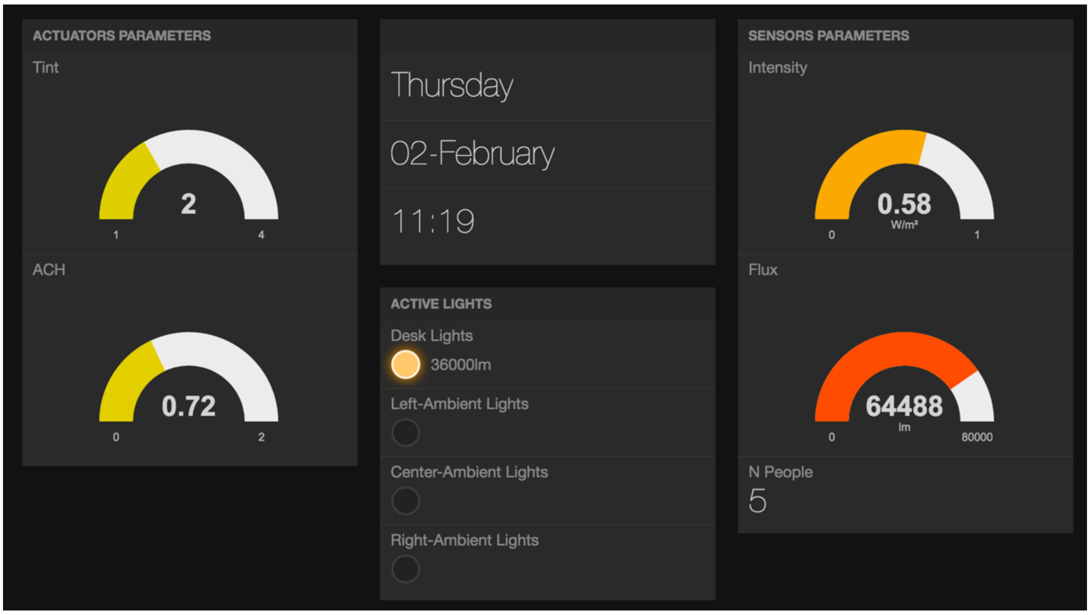
When the controllers receive the reply messages, similarly to what sensors do, they perform parsing of the Json message and operate control coherently to what described in the previous sections.

A global technical overview of the system described so far is shown in the figure:



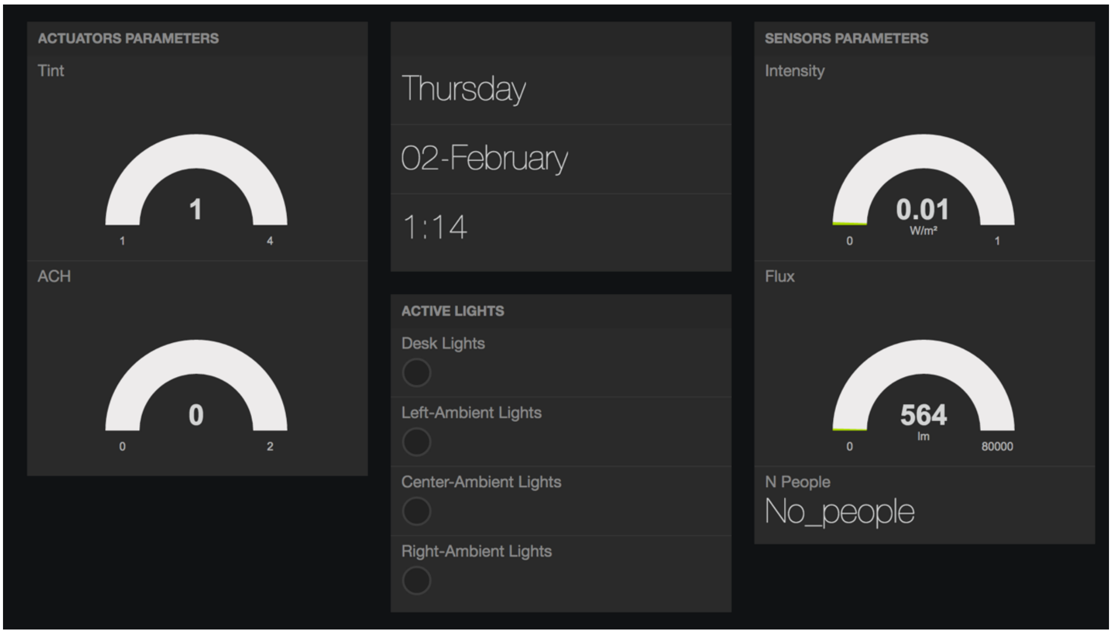
9. GRAPHICAL INTERFACE

In order to have an overall understanding of the system behavior with respect to the environmental parameters, a graphical interface has been developed on top of our control algorithms. The interface is publicly available at this link: https://freeboard.io/board/XY7qMD



MORNING SCENARIO

This module has been implemented using Freeboard, a free online tool thought for IoT applications, that allows to create simple dashboards that dynamically show the evolution of some input parameters. In our case, the input variables of the system have been pushed to the Freeboard dashboard through another supplementary tool, *Dweet.io*, that offers a service for messaging and alerting for Internet of Things.

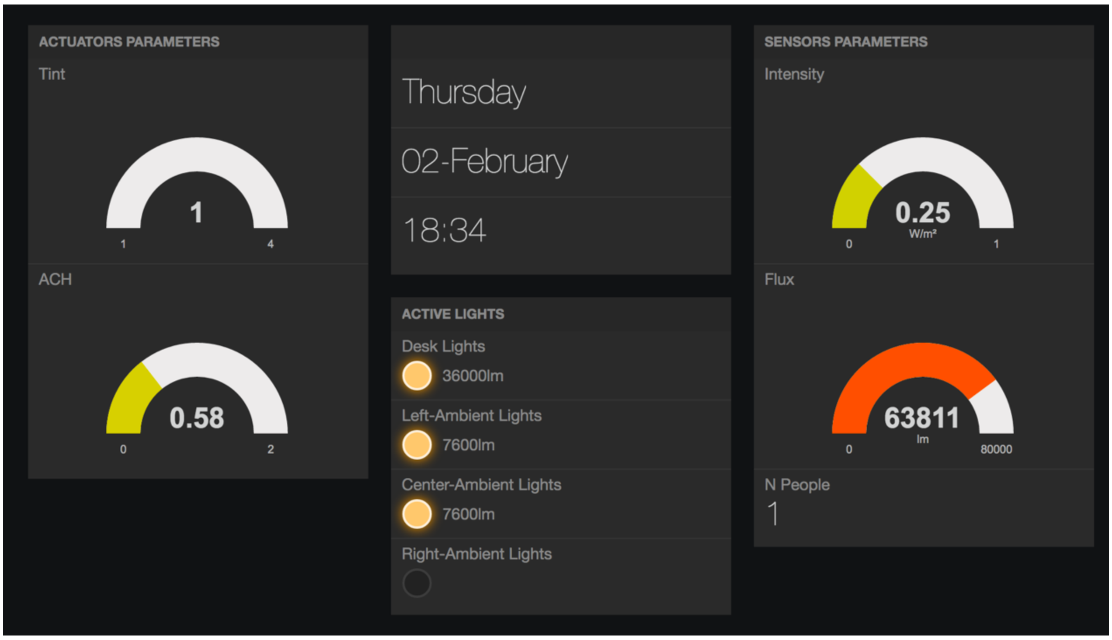


NIGHT SCENARIO

At every cycle of the system simulator, the main parameters coming from the sensors and controllers have been collected in key-value pairs and, then, an http GET method is performed using the following Dweet syntax:
`https://dweet.io/get/stored/dweets/for/`**`mything`**`?param1=`**`value1`**`&param2=`**`value2`**`&param3=`**`value3`**.

"*Mything*" is the specified name for the data source, while *param-* and *value-* represent the key-value pairs of the parameters we want to display.

Once subscribed to the chosen data sources, Freeboard offers a wide set of widgets for showing our data.



EVENING SCENARIO

The interface is intuitive and quite simple, and it is very helpful for having a preliminary test of the algorithm, whereas for having a better understanding about the flow of instructions and on how the system behaves.
It could also be thought as a sketch of the interface intended for the users of the spaces involved by the control system as well as the personnel in charge of monitoring the system.

10. CONCLUSIONS & REFERENCES

The whole code attached to this report has been developed using Python. It is also available at the GitHub link:
https://github.com/flaviasalutari/BuildingManagementSystem

The Python package used for the implementation of the mqtt protocol is the *paho-mqtt* one. Other relevant modules used are: *DateTime* for time references and *sys* for support and stability of the code.

All the technical observations and counts described in this report and the resulting software implementation do not refer to a real existing building, but are only based on a university project. Moreover, this kind of work can be considered as a reference for a real existing building and for an hypothetical implementation of these 3 control systems on it.

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