Pathologies as a direct consequence of design mistakes: the case study of the “New Fruit and Vegetable Market” in Molfetta (Bari, Italy)

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Pathologies as a direct consequence of design mistakes: the case study of a “Fruit and Vegetable Market” in the southern of Italy

Abstract

This report concerns the study of a new building, designed for being an indoor fruit and vegetable market in Molfetta (South of Italy), which after its completion has been used for only few weeks, because temperature, humidity and indoor air quality were not appropriate for the conservation of the goods and for the healty of the people working there, due to evident errors, attributable to design choices related to the used materials and to the construction typology, completely inadequate if compared to the climatic context in which the building is located.

In particular, has been detected that the building acts with a behaviour typically defined as "greenhouse effect", which determines high values of temperature and humidity content, in absence of a correct longitudinal and transverse ventilation. The research was aimed to study all the failures and pathologies and to identify design solutions to improve the performance of the thermo-hygrometric and internal ventilation of the building, and in general the conditions of the microclimate, in order to ensure a condition of comfort to the users and to ensure, at the same time, a suitable air quality for the preservation of fruit and vegetables. It is targeted to a solution that, using techniques of passive cooling, is able to control and exploit the geometric, locational and technological characteristics of the building, ensuring the maximization of air efficiency and thermal exchanges between the building and the outside. Through a bioclimatic approach, have been proposed solutions able to low the inside temperature in the central gallery of the market in the summer period and an adequate exchange of air: the interaction of the existing building with the external environment has been exploited to produce the necessary internal cooling, thanks to a model that works with "stack effect", by combining solar chimneys and properly designed earth-air heat exchangers in the ground.

Keywords: greenhouse effect, **thermal discomfort**, **ventilated geothermal cooling**, **heat exchangers**, **solar chimneys**

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1. Design criteria and construction characteristics of the building

This study is concerned on a building used as a covered fruit and vegetable market, located in the industrial area of the city of Molfetta. The building case study highlighted a number of issues related to the microclimate that has been established within the covered space; the adopted design choices, in relation to the used materials and to the constructive typology, revealed immediately an inadequate behaviour compared to the climatic context in which the market is placed. The building is rectangular in size 150.00 x 35.00 m and so with a total area of5,000 square meters (see Fig.1). The interior layout of the space is built around a large central gallery with the function of exposure and handling of the fruit and vegetable products (see Picture 1); however, a total of 30 boxes are located on the sides of it, with an area of 992.15 square meters, used as retail with above offices placed in two rectangular blocks with flat roof (see Picture 2). The internal height is variable for the effect of the arched shape that characterizes the cover, ranging from a minimum of 8.55 m to a maximum of 10.85 m, in correspondence of the central zone of the gallery

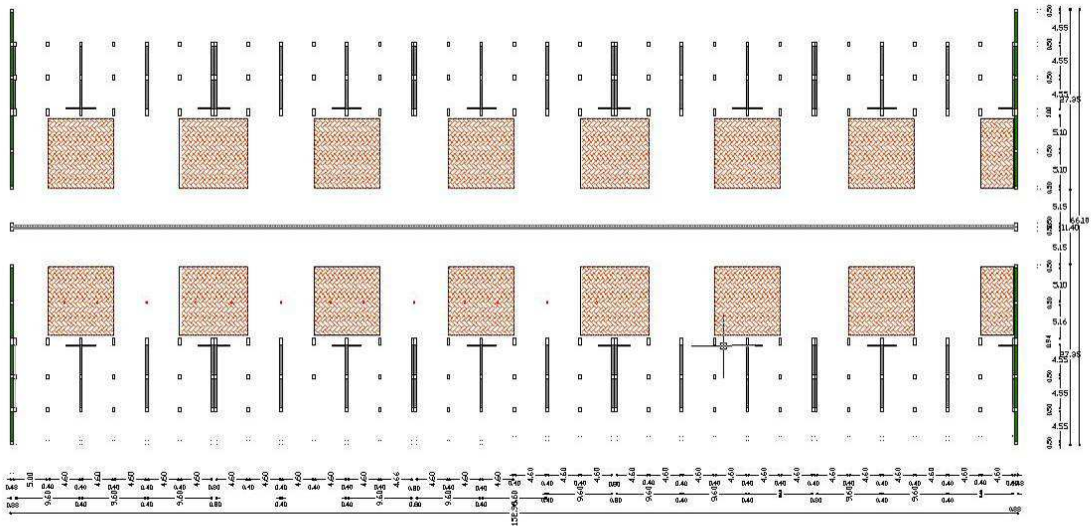


Figure 1: Ground floor plan

Picture 1: Central gallery overlooking the West (left) and East (right)

The building envelope, whose walls are infill cassette with two layers made of blocks near-vibrated concrete, face view and polished, "bull" type, with a thickness of 19.5 cm and 9 cm layer of still air (with a transmittance U equal to 0.908 W/m^{2}K), is not isolated and is open along the perimeter. In fact, in the side elevations of the building (those exposed to the North and South, see Fig.2) are the openings of the box (two for each box, closed with metal shutters) and, at the top, are arranged fenestrated openings and no windows openings, which also contribute to establishing a continuity with the external environment. Moreover, in correspondence of the main elevations (shorter ones, exposed to West and East, see Fig.3), are present the openings used for the maneuvers of loading and unloading of goods, placed in constant connection with the outside. Even in the coupling of the cover with the vertical closures of side elevations, there are spaces directly communicating with the outside.

Picture 2: Box at the sides of the tunnel (left) e inside the box (on the right)

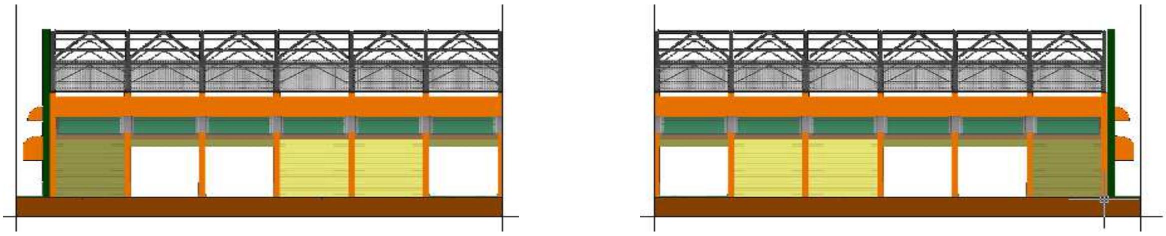


Figure 2: South side elevation

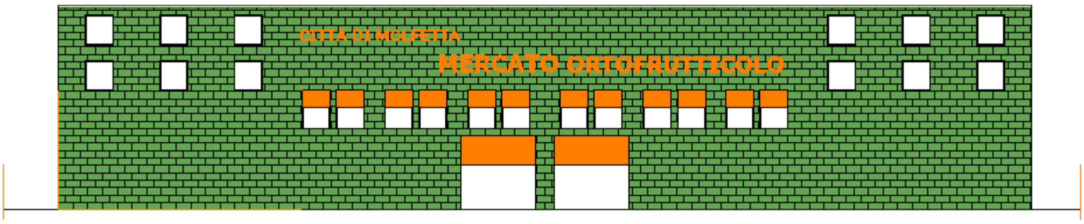


Figure 3: East side elevation

The building has been realized in mixed concrete-steel: the structural part in elevation and the structures of the box were made of reinforced concrete type Rck 300, while the cover has been realized with steel trusses, of arched shape, with a span of approximately 37.60 m. The distance between the upper and lower rafters of composite trusses varies from a minimum of 1.50 m to a maximum of 2.30 m, and are positioned at a variable pitch; at the bottom, the crosspieces are placed at a pitch of 1 m, and act as supports for the cover package made of alveolar polycarbonate, 10.00 mm tick (see Picture 3). The beams, connected to each other through special bolting, are: - type HEB 260, for the upper and lower rafters; - type HEB 140 for the beams of vertical connection; - L-type 80 for connecting beams between the upper rafters; - of HEA 140 for the crossbeams on which the cover rests. The sealing layer is made of polycarbonate multiwall sheets of thickness 10/10.

2. Problems encountered

The building has highlighted a number of problems related to the microclimate that has been established within the covered space. In practice, the building envelope as it was designed, immediately showed inadequacy of design choices, especially in relation to the choice of the used materials, and compared to the climatic context in which it is inserted. In fact, inside the building there is a behavior which is typically defined as "*greenhouse effect*", mainly caused by the type of material used for the cover. Concurrently, however, other causes involved generate overheating within the covered market and which will be represented below.

Picture 3: Coverage of the fruit and vegetable market

The causes that contribute to the thermal discomfort in the fruit and vegetable market, in addition to coverage type, as mentioned above, are: - heat determined by the overheating of the closing blinds made of galvanized steel; - the lack of isolation of the cover of the box office, on which was placed only a bituminous waterproofing layer; - the presence of impermeable surfaces completely asphalted (black) in outer space that surrounds the covered market; - the lack of vegetation to mitigate the effects of the hot weather outside; - the lack of proper ventilation. A series of measurements have been carried out using specific thermo-hygrometric analysis of instrumental type, performed with the microclimatic station BABUC-A and the microclimatic control unit HSA DGT TECORA, positioned in correspondence of the central zone of the gallery at an height from the ground equal to 1.1 m, precisely adapted to detect the microclimate conditions inside the market. These measurements returned values of operating temperature between 34.53 ° C and 37.44 ° C with a relative humidity between 59.9% and 68.4%, and with an air velocity which has always been found to be lower than 0.6 m/s. These values are not consistent with those required by current legislation on temperature-humidity and air quality characteristics that should be secured in a working environment (in fact, with these values the heat exchange by convection is drastically reduced, the sweat fails to evaporate, and then fails to subtract heat to the body, remaining on the skin and increasing the sense of discomfort of workers). Instead, the average radiant temperature, indicative of the average temperature of the surfaces of the gallery, and therefore of the radiative exchange of the human body, was between 42.14 °C and 49.59 °C.

The tens of tons of fruit and vegetables that are daily exposed in the gallery increase their respiration processes, because of the microclimate registered in the air exposure, and accelerate biochemical reactions, leading to the production of additional heat, reducing the amount of oxygen and increasing the production of CO_2, ethylene and other substances. As a result, oxygen-poor air, stale and often smelly, partly because of rotting waste products, negatively affects a thermal environment already compromised. The interior microclimate that has been created, rather than slow down, accelerates the maturation and degradation of fruits and vegetables, resulting in serious damage to the economic activities of the traders. The measurements have therefore shown that the structure does not adequately protect the inside from the outside weather conditions, typical of peripheral urban areas at latitudes of the country characterized by hot humid summers with high radiation, and temperate winters with wet winds predominantly from the North-West.

The cover slabs of polycarbonate, preventing the re-radiation of heat of the internal surfaces at low temperatures, in the summer determines a greenhouse effect inside the tunnel worsens the microclimatic parameters and contributes in a decisive manner to cause the high values of average radiant temperature registered.

3. Retrofit project proposals

The thermo-hygrometric analysis showed that the building is not functional as a working environment, not providing comfort conditions and respect for the welfare of temperature and humidity conditions for workers and users; and even less to its destination use of fruit and vegetable market (bad maintenance of products and economic losses for market vendors).

The climatic analysis of a site is a priority in the design, because the climatic characteristics of a site affect the designer in the choice of materials and building typology and orientation features, in defining the building envelope technology and installation of engineering solutions. As a support of the climatic analysis the UNI 10349 has been used: it provides the climate conventional data necessary for the design and verification of both the buildings casings, and both of installations for heating and cooling. This legislation, in addition to providing daily and monthly average climate data needed for the calculation of the energy requirements and the humidity checks of buildings, presents the project data concerning the verification of exceeding the maximum or minimum values of specific parameters, and the dimensioning, in terms of thermal power, of the heating and cooling systems.

The main parameters determined in the climate analysis for the site concerned by the intervention under study are: - temperature values daily, monthly, yearly (minimum, average and maximum); - direction and force of the prevailing winds in summer and winter; - values of the solar irradiance, monthly and daily; - air humidity (minimum, maximum, average); - period of shade; - sun exposure. Considering the hot and humid climate of the city of Molfetta, as resulted from the construction of the Olgyay and Givoni diagrams, it is necessary to operate the monitoring of temperatures (air, mean radiant and operative), ventilation and relative humidity, in order to restore the conditions for thermal comfort inside the confined environment of the fruit and vegetable market. Some of the building retrofit project interventions were thus envisaged, aimed at resolving the problems encountered, choosing, in accordance with the dictates of bioclimatic architecture, passive cooling techniques (together, geothermal and ventilated).

3.1 Ventilated geothermal cooling

In systems of ventilated geothermal cooling, the transfer of heat between the inside and the ground takes place by means of the air that circulates in pipes in contact with the depth soil and so that it cools before entering inside. The air is circulated through buried pipelines, via a fan (hybrid systems) or passive systems operating at Bernoulli-Venturi effect (downwind extractors) and stack effect (high windows, ridge openings).

It was chosen to use a system of ventilated geothermal cooling, with air circulation mode "open cycle": the system enters outdoor air in the building, after it has been cooled through the passage in the ground; thus the function of cooling is combined with that of ventilation (heat exchangers). The fresh air fed from the bottom in the confined environment, heats up, moves upward as a result of the aerostatic thrust and is extracted through appropriate openings in cover (system operating at "chimney effect").

3.1.1 Heat exchangers

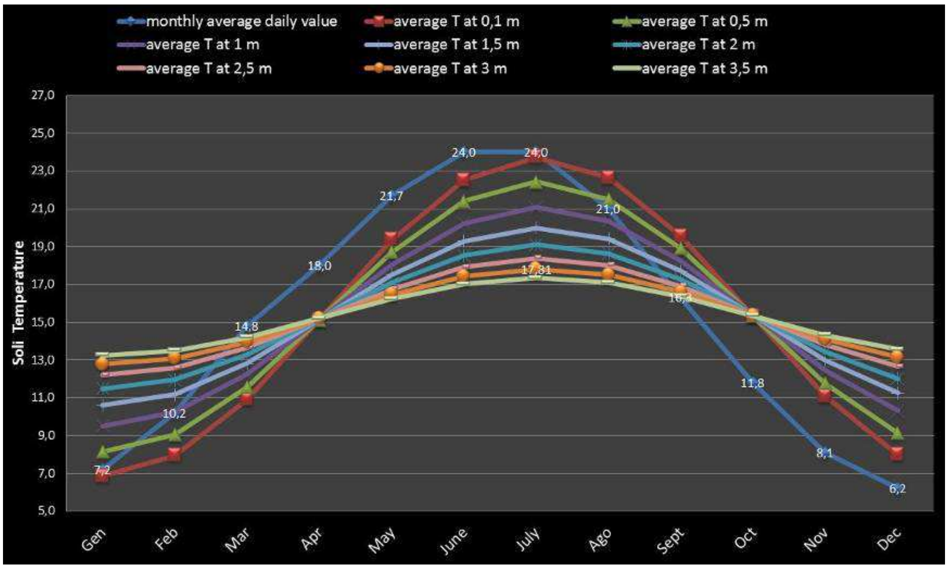
Horizontal heat exchangers "ground-air" were used. The crucial parameter for the assessment of the potential of cooling of the air that passes through the soil, is the temperature of the soil at various depths. In theory, this value can be measured, but in reality, only few weather stations perform measurements of the surface temperature of the soil, while soil temperatures at various depths are even less monitored.

An alternative to the direct measurement of the values of the soil temperature at the different heights is given by some algorithms that have been developed. For homogeneous soils (Santamouris & Asimakopoulos, 1996), with constant thermal diffusivity, the temperature of the soil at any depth “z” and at every hour is:

$$T(z,t) = T_m - A_s EXP\left[-z \left(\frac{\pi}{365\alpha} \right)^{\frac{1}{2}} \right] * \cos\left[\left(\frac{2\pi}{365} \right) \left(t - t_0 - \frac{z}{2} \left(\frac{365}{\pi\alpha} \right)^{\frac{1}{2}} \right) \right]$$

Where: T_m = average annual ground surface temperature (°C); A_s = Amplitude of the variation of the surface temperature (°C); z = depth in the soil (m); α = thermal diffusivity of the soil (m^2h^{-1}); t = elapsed time from the beginning of the year; t_0 = a constant period (number of hours, from the beginning of the year, with average surface temperature lower). This equation shows that the temperature of the ground at a certain depth depends only on the surface temperature and the thermal characteristics of the soil. The ground surface is subject to sinusoidal variations in temperature that are dampened with depth. The effect of the thermal inertia of the soil is such that there is the convergence of the soil temperature at values practically constant when the depth increases.

The values of the relative temperature of the soil at the study site, for depth varying from 0.1 m to 3.0 m, obtained using the above algorithm and starting from the temperature during the season and, of course, on the characteristics of the soil, show that the highest average soil temperature is reported in August (25.63 °C to 0,1 m or 20.25 °C at 0.5 m, 18.37 °C to 1.0 m; 17.82 °C to 2.0 m; 17.79 °C to 3.0 m), even if the values of the average outer temperatures that are higher in July (24.6 °C versus 24.4 °C). This difference of values may be simply explained by the tendency of soil to accumulate heat, thanks to its large thermal inertia, due to its semi-infinite extension, for which the adaptation to external conditions always records a delay by determining a time difference between the two reference values. The following graph (see Picture 3) is representative of the trend of soil temperature at different depths throughout the year.

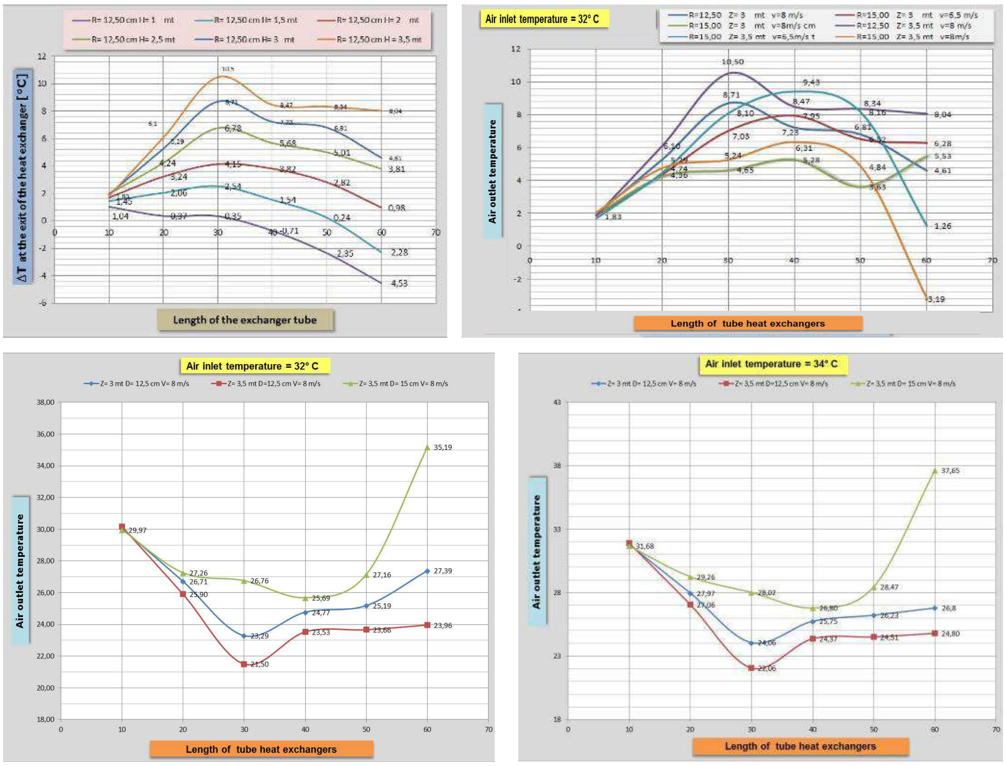


Picture 3: Soil temperature trend throughout the year at different depths (Molfetta)

Interestingly, the trend of temperature variation has a deeply felt values at soil depths close to the ground surface; the curves are gradually flattening as depth descend, until assuming constant values during the year in correspondence with a depth value equal to 3 m.

For the definition of the behavior of the heat exchangers and for the determination of their efficiency, simplified parametric models have been used that relate the geometrical parameters of the tube (length and radius) with the burial depth of the pipe and the air speed inside the heat exchanger. To calculate the overall efficiency of the heat exchanger, a dimensionless coefficient is also defines which compares the difference of the air temperatures at the exit of the tube and that of the undisturbed ground, with the difference of the air temperatures at the inlet of the tube and that of the undisturbed ground. The pipe sizing of heat exchangers air-ground was made by applying an iterative method aimed at finding the best features that will return the maximum efficiency in terms of lowering the temperature at the exit of the duct. Operationally, a tube with a radius of 12.50 cm was chosen, evaluating the function at the burial depth of 1.50 m, 2.00 m, 2.50 m, 3.00 m 3.50 m, for a heat exchanger of variable length in the range between 10 and 60 m. The values were calculated with reference to the warmer period of the year, thus considering the most severe operating conditions, and by setting an air velocity inside the pipe equal to 8 m/s. It is useful to specify that the choice of the air speed of 8 m/s has been conditioned by the availability of experimental coefficients (a_0, a_1, a_2) assigned in correspondence of the flow rate, the minimum value of which table is set equal to 0.393 m^3/s. However, considering that the air is impractical at a such speed within the market, it will be necessary to provide in correspondence of the output section, a widening of the same by using a tube of variable cross-section, such that a value of the output speed is guaranteed equal to 1 m/s, speed that is considered pleasant to high temperatures.

In the graphs below (see Picture 4), the results of calculations are summarized, relating to the determination of the length of the pipe exchanger, depending on the different installation depth, the speed of the airflow, as well as the tube diameter exchanger. As can be seen from reading the graphs, the study has shown that the depth of burial that yields the best results is equal to 3.50 m. With the reduction of the depth there is a proportional reduction in the efficiency of the heat exchangers which, if placed at a depth of 1.50 m or 1.00 m, in correspondence of greater lengths, even produce a temperature increase in the output of the exchanger: this confirms the strong influence of the external temperature at a depth of soil near the surface.



Picture 4: Variations of temperature and absolute temperatures at the exit of the heat exchangers

Subsequently, the behavior of a heat exchanger with a radius of 15 cm was evaluated, without changing other boundary conditions, considered as optimal (depth = 3 m, length = 30 m, V_{air} = 6-8 m/s). The result of the simulation confirmed the greater effectiveness of the heat exchanger of R = 12.50 cm, since the increase of the tube section has returned an air temperature at the exit of the heat exchanger, higher than in the lower section of pipe.

The choice of the geometry of the heat exchangers was made primarily on the basis of the values of the output air temperature as calculated; for comparable values of this parameter, the length of the exchanger has been chosen able to favor a planimetric arrangement such that the normal handling maneuvering of vehicles loading and unloading not to compromise and, in addition, the shadows of the wind to avoid. Along the south elevation, a non-rectilinear path has been necessary to follow in order to reach the desired length and an adequate "buffer zone" ensure in proximity of foundations, necessary for the excavation operations and piping installation. In order to obtain a uniform distribution of the heat exchangers inside the market, suitable to guarantee a fair benefit to the different utilities, two exchangers every three box have been chosen to position. Therefore, a total of n. 44 heat exchangers will be put to work, each capable of providing an air flow equal to 0.393 m^3/s. Therefore, in one hour, air is fed into the market equal to 0.393x44x3600 = 62,251 m^3/h. The material chosen for the exchangers is aluminum which gives a good response in terms of transmittance.

3.1.2 Solar chimneys

The ventilated cooling is guaranteed from the extraction of the heated air through the "solar chimney", often also called "thermal chimney", which is a constructional element of a building structure used to induce natural ventilation inside buildings, through the convection; and this, to keep the internal temperature close to the optimum level of comfort. Numerous studies have focused on the various models of solar chimneys, which have been studied and analyzed in order to identify the most suitable solutions for different needs. The solar chimneys can be classified as follows: according to their location in relation to the building, solar chimneys close to the walls and solar chimneys positioned in the top of the construction (see LI A., et al, 2004); in accordance with their arrangement, vertical solar chimneys and solar chimneys positioned with different tilt angles; depending on the material used, cylindrical solar chimneys and cylindrical solar chimneys transparent coating (see JYOTIRMAY M., SANJAY M., 2006-1). Referring to these and other studies - on the angle of inclination to be assigned to a tilted solar chimney, in order to maximize the summer performance (see JYOTIRMAY M., SANJAY M., 2006-2) and the width of the cavity of solar chimneys to induce a natural ventilation (see GUOGHI G., 2006) - it was possible to choose the type of solar chimney in terms of positioning, tilt, geometry and materials of use, taking into account the constraints dictated by the geometrical shape and structure of the existing fruit and vegetable market.

The solar chimneys will be located at the existing coverage. The data shown in the graphs relating to the experiments described above were used for their sizing. In particular, considering the values of the air flow as a function of the ratio B/H and the length of the solar chimney, it is deduced that the higher efficiency is obtained for low ratios of B/H and for high values of the length L of the solar chimney . In particular, the optimal curve is obtained in correspondence with the value B / H = 0.1; then, starting from this value and by selecting a length of the solar chimney equal to L = 3.5 m, an air flow of 2, 5 Kg/s is guaranteed, and therefore of 9,000 Kg/h. By opting for a B = 0.35 m, a value of H = 3.50 m is the result, able to ensure the chosen ratio of 0.1. Moreover, having noted the advantage of appropriately tilt the solar chimney in order to maximize the heat captured as a result of solar radiation, the solar chimney tilt of 50° with respect to the vertical has been considered, corresponding to the more efficient inclination when referred to the latitude of 41°12' on the site of the fruit and vegetable market. The disposition in coverage of solar chimneys will occur in such a way as to ensure no overlap of their projections of shadows which would lead to a decrease of efficiency of the individual elements. Having defined an input area at the base of the chimney equal to 0.35 x 4.0 m^2 and following the report (A_{ru}/A_{re} = 0.6 to 1) which binds the entry area of the air flow with the exit area, an output area equal to 0.28 x 4 m2 has been defined and a distance of the top of the opening from the top of the chimney of 0.35 cm was calculated, according to the relationship S_c-S_a = 0,1H. The structure of the solar chimney will be quadrangular and made of aluminum profiles, in order to impart a poor overload to the existing coverage. The facade exposed to the sun will be constituted by a laminated safety glass with each thickness of 4mm, and the remaining walls are suitably insulated with EPS of 7.5 cm and a layer of aluminum 10/10 mm, suitably black colored, to attract more sunlight; the outer coating is made of corrugated sheets standard.

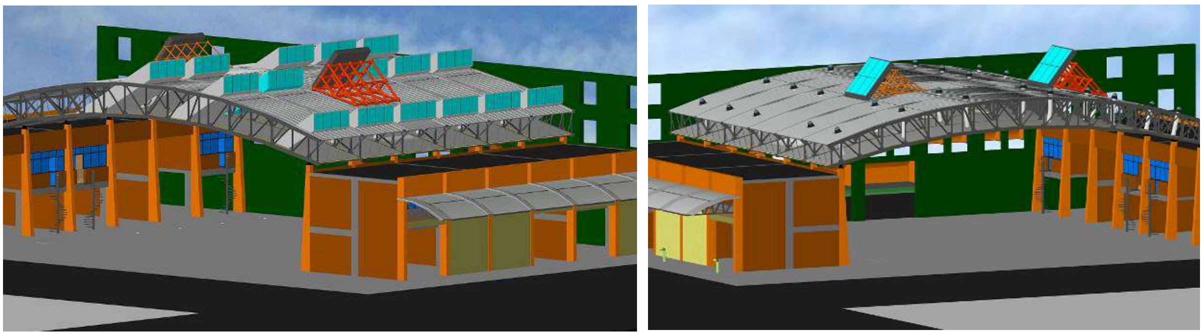
To define the number of solar chimneys to be installed to allow an exchange of air sufficient to ensure the comfort conditions inside the confined environment the chimney must be sized to allow the expulsion of about 52,000 m^3 of air, having estimated 52,014 m^3 of the air volume enclosed by the covered market envelope, and wishing to ensure n=1 air changes per hour as required by reference legislation for the workplace. Because every single solar chimney, as mentioned earlier, is able to expel an air flow of 2.5 Kg/s, it follows that the volume of air extracted in one hour will be equal to 9,000 kg/h; and because 1 m^3 of air is equal to 1.293 Kg, then we will have approximately 6,960 m^3/h. N.12 solar chimneys have to be installed to ensure that a total air volume of 83,520 m^3 is expelled, also because a double-layered glass type "Optiwhite" of Pilkington from 4 + 4 mm, with a transmission equal to 0, 83 and a U = 4.7 W/m2 ° K, has been employed for safety reasons (see Picture 5).

Picture 5: Exchangers-solar chimneys overall operating scheme

3.1 Other interventions in coverage

Other interventions concern the modification of the roof covering package, with the preparation of a second sealing layer on the roof and the shield of polycarbonate sheets: design choice obliged to remove the predominant cause of overheating inside the covered market. First, a static verification of the actual state of the building coverage was necessary to assess the ability to support different loads, and possibly additional, by the truss structure. The analysis of the loads imposed on the knots was priority; then, the stresses imposed on them were calculated with the use of SAP2000, through the modeling of the structure in knots and connecting rods. The verification phase of the tensile and compressive member resistances was then performed according to the UNI 10011. The alveolar polycarbonate has been set in correspondence with the lower currents of trusses and higher currents have been exploited as a base for supporting a second roof covering, consisting of material obviously different from that already present, of metallic type in pre-painted aluminum (thickness 0.7 mm) with draining joints. The requirements requested were, on the one hand, the ability to reflect solar radiation and, on the other, a lower weight, for not excessively overloading the existing structure. In order to reduce the absorption of heat by the polycarbonate, it has been furthermore provided the laying of insulating panels type URSA DF 40. They are made of water-repellent glass wool felt treated with special thermosetting resins. The glass wool consists of long, thin, elastic glass fiber, devoid of material not fibrate and of high mechanical resistance. These properties are obtained thanks to the use of a vitrifiable mixture, consisting of selected and assayed (of inorganic nature) components and to a complex system of fusion and production of fibers. In addition, an insulator reflector in rolls, such as "Over-Foil 2L-2", will be prepared on the layer of glass wool. It has the peculiarity of having the aluminum faces covered with a thin polyethylene film; this film protects the aluminum from oxidation in any extreme situation, also in contact with the fresh concrete and rainwater. Under the aluminum layer there is a double bubble of inert air between the layers of polyethylene, coated on both faces. The composition of this multi-layer insulator gives excellent thermal insulation value and ensures the conditions of comfort, thanks to the reflective surfaces that cancel the effect of direct radiation.

Furthermore, two different solutions have been proposed to allow natural illumination of the buildings within the limits of the law (windowed area greater than 1/8 of the area of the floor; average daylight factor $\geq 2\%$), whereas the technical difficulty determined from having to interact with a truss roof structure: the creation of vertical shed oriented to the north, the construction of tubular skylights on the roof. The shed, oriented to the north, receive direct sunlight only for a few hours in the middle of summer, in the afternoon (from 4 pm onwards). The influence of solar irradiance and the resulting glare and heat, is minimal. This again means that, during the daytime working hours, the penetration of natural light takes place exclusively by diffusion, that creates additional advantages from the point of view of lighting (since shadows are avoided courses) and from that of a higher vertical luminance. The 81 shed (inclined at 45 ° respect to the vertical so as to improve the internal distribution of light, each with 5.61 m2 of windowed area) guarantee an $A_{f\ tot}$. = 453.6 m^2 and the compliance with the law (see Picture 8a). The tubular skylights in the roof (consisting of a sensor device with optical RIR, reflected interactive refraction; consisting of a tubular duct super reflective and of a diffuser) are n.120 from φ 650 arranged in 6 rows by n.20. They ensure that the illuminated area is between 1% and 2% of the FLDM, and combine the advantage of transporting natural light within each individual spaces (see Picture 8b).



Picture 8: Overall view with chimneys and shed (right) and chimneys and solarspot (left)

4. Conclusion

The building under study proved to be particularly interesting for the evaluation of pathological phenomena as temperature and humidity discomfort, due to a behavior which is typically defined as "greenhouse effect": the microclimate of the confined environment is characterized by high values of temperature and humidity levels, moreover in the absence of a correct longitudinal and transverse ventilation, condition much more burdensome when the use of the building is considered.

Starting from the study of anomalies and pathologies induced, design solutions for technological, functional and energy retrofits were sought, in order to improve the conditions of the microclimate that ensures an environment of comfort to the users and to ensure at the same time air quality, appropriate to the preservation of fruit and vegetables. The study addressed, applied to an industrial building, has been a valuable and interesting opportunity to approach the theme of bioclimatic, as delicate as relevant. In fact, preferring a bioclimatic approach that would allow to overcome the usual use of air conditioning systems (low efficiency and high cost of management) and that resorted to passive cooling techniques, intervention solutions have been proposed able to ensure on the one hand the reduction the temperature inside the central gallery of the market in the summer period and the other an adequate air exchange. The interaction of the existing building with the external environment has been exploited to produce the necessary cooling inside the market, and a working model for "chimney effect" has been proposed, created by combining solar chimneys and ground-to-air heat exchangers, appropriately designed. In the design phase, it is of fundamental importance the careful and thorough evaluation of techniques and energy resources which have to be used in an appropriate manner with respect to the function to be performed by the building. The use and exploitation of the potential of the natural environment can return good results, even for the existing buildings, in terms of intervention effectiveness and energy saving, with the dual benefit of environmental protection and economic savings from natural air conditioning of closed spaces.

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