Thermo-hygrometric and physical-mechanical pathologies of the steel flat roofs: the case of a large industrial plant in Tito (Potenza, Italy).

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Thermo-hygrometric and physical-mechanical pathologies of the steel flat roofs - Abstract

The flat roofs made with steel corrugated sheets on steel structure, with isolation from the above and bituminous waterproofing, arranged according to the construction method called *“warm roof”*, and self-protected by thin embossed sheet of aluminium embedded over the bituminous sheath, are one of the most common construction types, the subject of theorizing in popular manuals, aimed at defining the *"compliant solutions"* and the *"rules of the art"*.

In the proposed case of study, a cover of this type, made on a plant of 7,500 sq. m, which are held in machining of high precision electronic components, in a few years has been the subject of twice total renovations, both consisted of adding one additional layer of waterproofing bituminous self-protected sheet, to end the drip of water inside, which continued to be present in winter, despite the work already done and redone.

And there was going to run the third work of the same type, until the writer has identified the cause of the dripping water in absence of a continuous vapour barrier below the insulation. A work of complete restructuring of the construction’s cover has been then proposed and implemented, without modifying the existing roof, and allowing that the industrial production would remain in operation without any interruption: the waterproofing has been used as vapour barrier of new layers of insulation; higher slopes have been made, very useful for large spans of the deformable cover; a new waterproofing and new insulation layer have been put in place as an "inverted roof", protected from the weather and the sun and drained, for cope with the tropical downpours which have now become common even in the city of Potenza. Interventions on the existing skylights, and a floor that provides ventilation, give the coverage characteristics of a "passive house" and his cheap annual expense, and ensure the durability of waterproofing.

Keywords: steel flat roof, vapour barrier, pathologies, thermal upgrade

1. State of the roof building in 2005

The plant of the WABCO WESTINGHOUSE Segnalamento Ferroviario, then ANSALDO Segnalamento Ferroviario, now Ansaldo STS S.p.A. of Tito (Potenza, Italy, 650 m o.s.l.), has

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been built in 1985-86, for the machining of high precision electronic components for automatic control of railway traffic, and ever growing precision required in productive process determined progressive climate control of the spaces, mostly open spaces. It has a surface of 7.500 square meters (approx. 72,00 x 107,00 m) (Fig. 1), and it was built with an anti-seismic steel structure, made of pillars and wind shear trusses, a flat roof deck in zinc coated steel, with typical structural spans of 18,00 x 12,00 m, and gutters on the corners, of 160mm diameter.

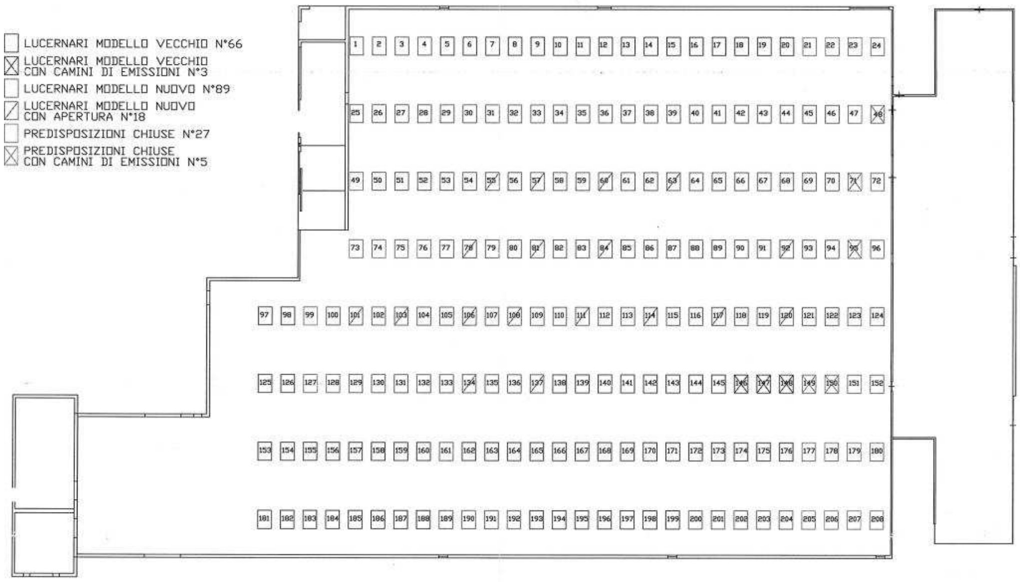


Figure 1: Plan of the coverings of the Ansaldo STS industrial plant in Tito (Potenza, Italy).

The free minimum height under the structure is of 5,50 m; the height of the plain reticular structure which bears the roof is of 1,60 m (Fig. 2 and Picture 1); but the rigidity of the deck is very variable, because in the spans in the middle of the wind shear trusses, typical steel beams, on which are leaned the corrugate sheets, are IPE 220, with span of 6,00 m, very easy to deform. It is their position in height and their inclination, that makes slopes for flowing of the rainwater, with the ratio of 0,5%: in effect there is not a screed for making slopes and for filling the corrugated sheet. The thermic insulation, 3 cm of high density glass fibre wool, with built-in superior bituminous prefabricated membrane, is set directly on the corrugated sheet, and fastened with screws to the metal deck; on this layer has been set waterproofing, originally made by double ply 4+4 mm SBS polymer-modified bituminous prefabricated membranes torch applied, with upper layer with an aluminium facing. N. 208 horizontal skylights, with surface made by hollow polycarbonate and fixed shutters (not very efficient), set in uniform way, ensure lighting.

The flat roof of the building showed, already 4-5 years after the realization, had impermeableness problems, which caused two total renovations, both consisted of adding, every time, almost one additional layer of waterproofing bituminous self-protected sheet, and in some areas, also more than one, to end the drip of water inside, which continued to be present in winter, despite the work already done and redone (see Pictures 2 and 3, which shows two specimens extracted from the waterproofing). And there was going to run the third work of the same type, until the writer has done a complete campaign of investigation on the roof, for understand reasons of the being pathologies.

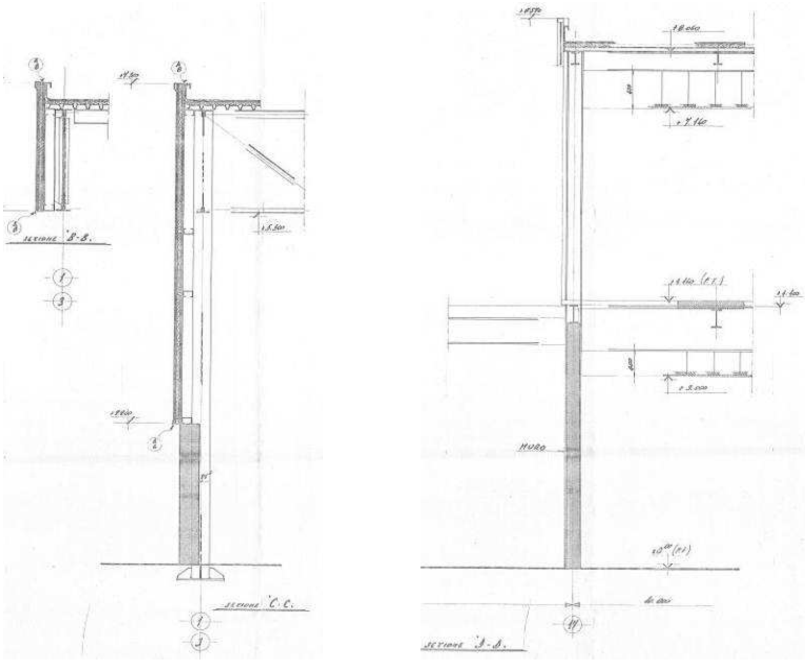
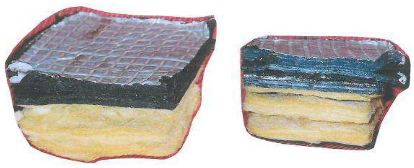


Figure 2: Typical sections of the industrial plant and of the offices

Picture 1: Structure of the roof is characterized by very rigid beams/portal (height 1,60 m on 18,00 m span), alternated with very warpable girder (height 22 cm on 6,00 m span), with the result of fluage and accidental charges cambers different area per area



Pictures 2 and 3: Specimens of the existing watherproofing, exstracted from the flat roof

At the end of 2004-2005 winter, the flat roof of the plant showed extended the dripping water, for this reasons in some areas had been necessary to set, hanging from the ceiling, PVC sheets, for protecting the equipment below. The dripping water appeared not ever in the same points, even if in some places occurred more frequently. Considering the manufacturing type done in the plant, and especially the need of controlled humidity ratio, the occurring of unexpected and sudden dripping water, in random places, leaded to unacceptable risks of damages and malfunctions, with heavy economic consequences, since a signal control cabinet is worth many hundreds thousands euro. On the other hand, already watching from the exterior (see Pictures 4-8), the roof of the plant after a rain was like a quagmire, stained by layers of dust and soil carry by the wind, by the areas in which the clear lack of gradient not allowed to the water of duly flowing, and the upper layer of aluminium embossed facing (third of the layers of this type superposed), showed systematic blistering (Picture n. 9), mark of the presence below of vapour and/or water. Indeed, pressing that blisters, we caused the expulsion of water, if we maked or if there was a crack in the aluminium facing and/or in the prefabricated membrane.

Pictures 4 and 5: After a rainfall, the covering presented itself as one immense quagmire

Pictures 6, 7 and 8: The water was unable to reach downpours, owing to deformation of the covering plane, and to limited slopes

2. First design fault: the lack of a continuous vapour barrier below the insulation

The first cause of dripping water has been identified in the absence of a continuous vapour barrier below the insulation. It must be underlined that normally we think that corrugated steel sheets constitute a vapour barrier, and therefore also on most updated manuals, which are aimed at defining the "*compliant solutions*" and "*the rules of art*" concerning waterproofing, we invent drawings which show "*as model*" steel flat roofs identical to that of this case study; without thinking that, depending on corrugated sheet element selected, every 76 o 100 cm in cross way, and every 330 o 660 cm in longitudinal way, and all facades perimeter long, and all joints with bases of skylights long, the corrugated steel sheets book off, and simply they approach or they overlap to the adjoining sheets , normally (and also in that case) without carry out any vapour sealing, with self-sticking band or liquid sealants, or foams especially formulated for this purpose. In addition, screws for fastening the insulation, anti-wind uplift, make they too thousands of holes in the sheets, and make possible the vapour passing. The result is that vapour coming from internal space reaches the insulation layer, and in it reachs dew point and condenses. This water in liquid state cannot be evacuated towards the exterior trough evaporation (due to the great resistance to vapour diffusion of two prefabricated membranes (later on got four) and their aluminium facings, and due to the total absence of roof vents), after having saturate the insulation, highly decreasing his insulating qualities, dripped in the hollows of the corrugated steel sheets, flowed along them, following their slope, and went out dropping when invented a connection between elements of metal sheets, or a screed hole, or a hook for electric device or false ceiling.

Picture 9: Blistering pathologically large and wide-spread

3. Second design fault: incorrect thermal bridges in correspondence of skylight basements

The basis of the skylights, made in steel galvanized brake formed sheets, completely lacked of insulation (with winter design temperature of -3 °C), and therefore water drippings in their correspondence had to ascribe, at least in part, to the condensations at their perimeter. Due to the presence of n. 208 skylights, every of 1,80 x 2,40 m, distributed in uniform ratio upon all productive plant surface, problem was certainly not secondary.

4. Third design fault: the insufficient slope of the roof

The slope conferred on the roof, with ratio of 0,5%, has proved quite insufficient and, in some area, even absent. The high slenderness of the steel girders of the deck did *fluage* deformations resulted to be equal or more, compared to the slope of the roof (design camber has been the maximum preview by Italian Regulations, 1/200, and then 3 cm on 6,00 m, exactly the same of the slope 0,5% on 6,00m). Therefore, little rise at junctions, caused by crossed orientation of the sheets, has been sufficient to lead to formation of so many little quagmire; while snow load, when present, has buckled deck, obstructing due water drainage, and favoring the inside penetration [CASH 2003, pag.34-35; 39-40].

5. Faults in maintenance intervention done

It was clear that maintenance interventions already done, the first 4 o 5 years after the building, the second in 1997, consisting in torch application of further bituminous prefabricated membranes, with aluminium embossed facing, had not solved problems of the roof, because they:

- had not compensate for the lack of vapour barrier under insulation layer;
- had not solved thermal bridges along the skylight bases;
- had not dehumidified the insulation, ventilating it;
- had not realized slopes, not sufficient or absent.

6. The technological and thermal design for upgrade

Who write then designed and directed the execution in more phases, from October 2005 till September 2009, an intervention of complete restructuring of the roof, which objectives have been:

- to work allowing that industrial production would remain in operation without any interruption, and then without removal of existing waterproofing;
- to use the existing waterproofing as vapour barrier or vapour brake of a new, of necessity thicker insulation, which move dew point above new waterproofing to realize;
- to fulfill the slopes necessary for correct functioning of the roof;
- to remove damp both from the insulation already in situ, both from the new insulation to place for carrying out of slopes;
- to realize an equipment most durable possible, protecting waterproofing from thermal schock and both from the frost, both from solar radiation; and therefore to move from "*warm roof*" typology to that "*inversed ventilated roof*";
- to eliminate thermal bridges and to upgrade in a radical way the energy performances of the roof, both in winter, both in summer, leading that to "*passive house*" performances;
- to operate on skylights too, to set right both to the excessive leakages, both to the dazzling and to the very high and undesired heat gains, due to their horizontal position.

6.1 Digital survey of heights

Firstly, a millimetric survey of heights has been made, with digital diastimeter, which allowed to notice in an objective way the situation of ridges and valleys of the roof, and permitted to operate selectively in each area.

6.2 The removal of the damp from in situ insulation, the recovery of the waterproofing already existing

After a complete roof cleaning, the aluminium facing has been took away with torch, and the at least for sheets of bituminous prefabricated membranes has been punctured with round holes 8 cm diameter, following a mesh of 6,00 x 6,00 m, setting and welding torch roof vents intended to going through all the layers to set subsequently, in such a way to ventilate insulation in situ, drenched in water. In the same time, all waterproofing has been revised, with welding torch, square decimeter per square decimeter, eliminating every existing blister and crack, making water and vapour come out, and drying humidity existing. This way, waterproofing existing turns “*vapour brake*” if cracked, true “*vapour barrier*” if intact, for the further layer of insulation to set out.

In this stage have been carry out also some thin leveling layers of cold ready-made asphalt and/or bituminous mastic, for eliminating greatest spherical deformations of the deck.

6.3 The carrying out of new slopes

Structural design of the building was to reserve 50 Kg/m^2 for ballasting with gravel waterproofing and insulation, but gravel has never been put in place. We preferred to conserve this charge reserve for making use of that for dry setting a ventilated raised floor, to realize a sunscreen. Therefore has been obliged the choice of carry out slopes (of the further ratio of 1,5%) with EPS pre-shaped panels, 1,00 x 2,00 m, and thickness from 2,00 cm minimum to 12,00 cm maximum on the plant roofing, and from 2,00 cm to 24,00 cm on the offices roofing (Fig. 3).

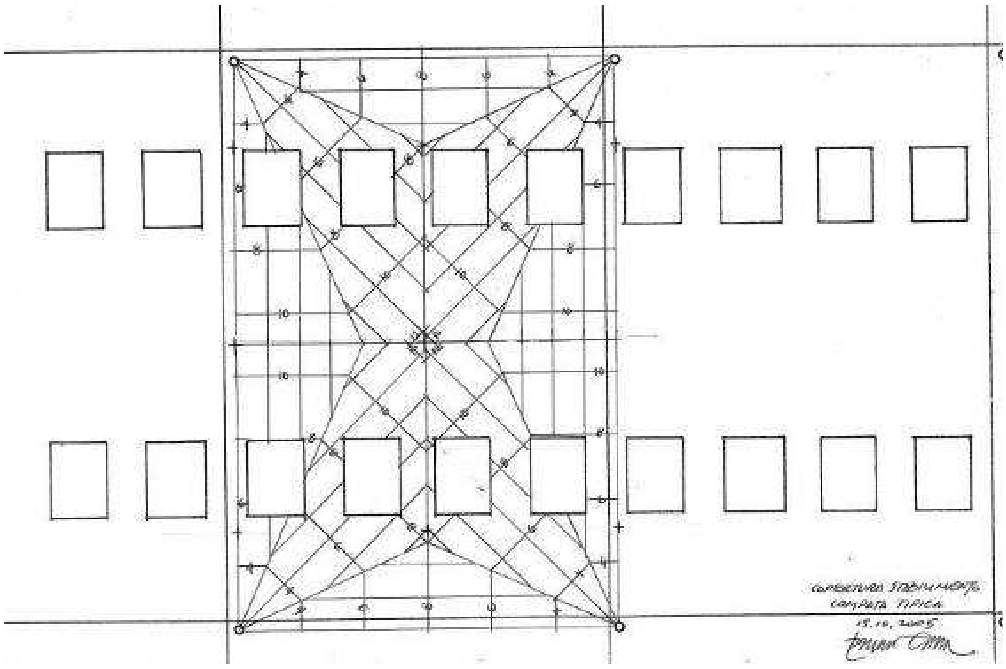


Figure 3: Plan of the typical span of the industrial plant (18,00 x 12,00 m), with EPS panels, used to create slopes. Numbers show panel thickness

These panels, which have on the upper side a smooth built-in membrane bituminous & polymers based, polyester reinforced, with two side flaps projecting (for making possible warm torch welding without fusing the EPS), have been cut on the ground, in the square of the plant, in an area marked out for the purpose (Picture n. 10), numbered and reassembled on the roof, gluing them on more than 40% of surface with bituminous & polymers based mastic, according to a scheme “to star” (Fig. 3), so that to lead really and quickly water of the rain, by most direct way, to the drainpipe. The downpipes already existing, with diameter 160 mm, remain serving existing waterproofing, so that possible leak of new waterproofing is intercepted by that before, which in this way become emergency device, helpful redundancy. In the same downpipes have been leaded new, with diameter 120 mm, into which flows new waterproofing (Picture 11).

Picture 10: The tracing out, cutting, pre-assembling and numbering of the EPS panels with variable thickness for making slopes, has been made at the foot of the building, two spans in the same time, each of 18,00 x 12,00 m

Picture 11: The assembling of new slopes, by means of cold gluing of more than 40% of surface, with bituminous & polymers based mastic . Panels were sealed on the perimeter, to avoid water penetration during work

6.4 New waterproofing and new series of roof vents

At that point has been laid a new waterproofing, made by two layers of distilled bitumen modified with atactic polypropylene (APP), reinforced with non-tissue polyester from continuous spun bound thread, with very high performances (cold flexibility -25°C, very high tensile, elongation and tearing strength), set with the same orientation, half-module staggered, because this sheets, with composite reinforcing layers, have solved problems of older types, which had a higher tensile strength along the length of the sheet, in rapport with the breadth (Figg. 4 and 5).

A new series of roof vents has been set and torch welded, coaxial with these coming from the layer below, and therefore with the same mesh 6,00 x 6,00 m, delegated to evacuate possible condensation forming in this insulating layer, and water of rain that might penetrate during building (Picture 12). The upper layer has been provided with a mineral surfacing, just because was scheduled a works suspension of one year, was necessary to calculate a temporary protection for waterproofing (Picture 13).

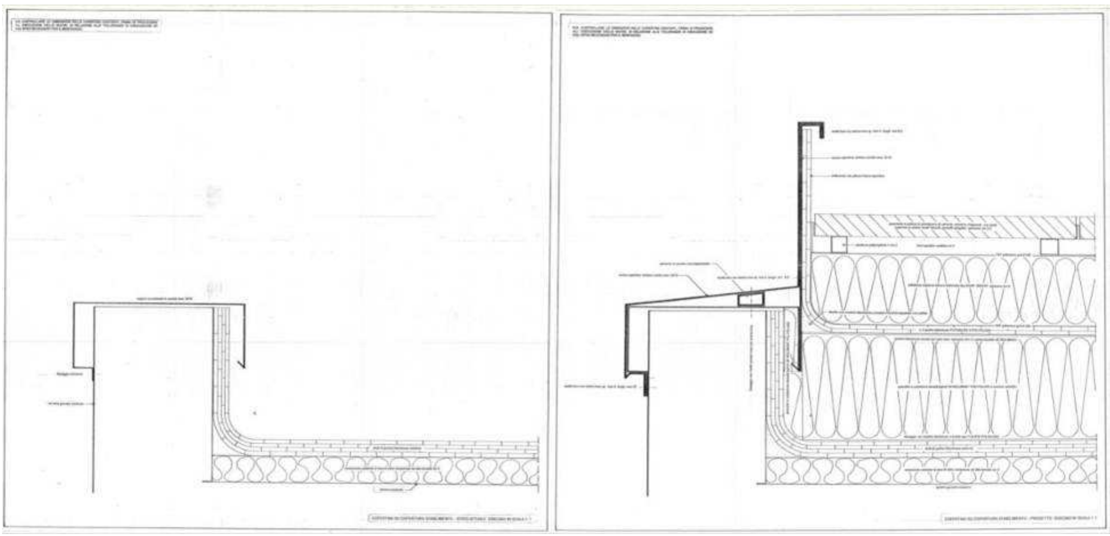


Figure 4: Constructive section of plant covering: on the left, before the retrofit; on the right, after

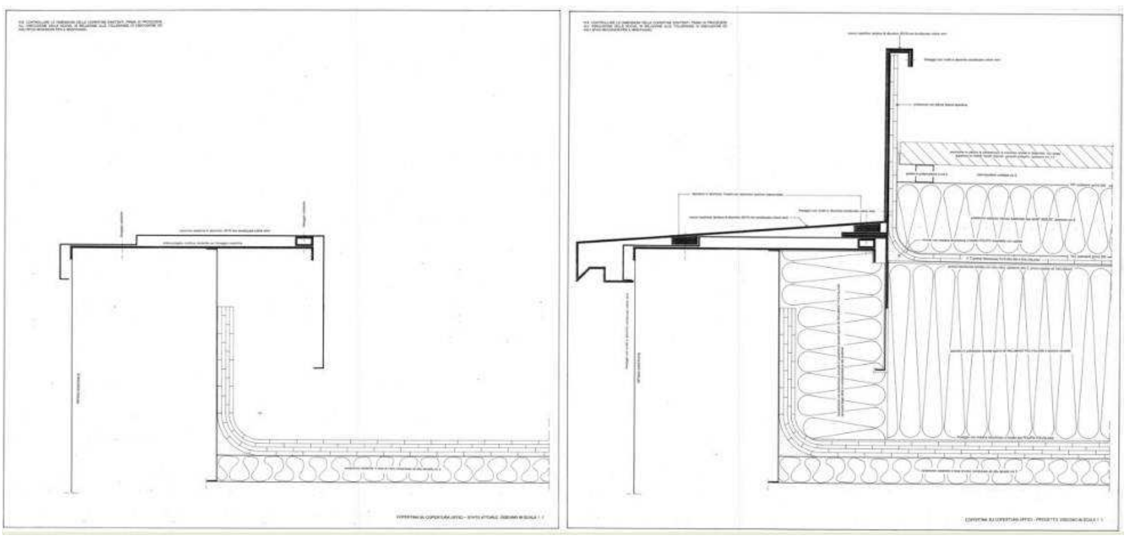


Figure 5: Constructive section of the office covering: to the left, before retrofit; to the right, after

6.5 Permanent protection for waterproofing – thermal upgrading

At that point, for making permanent protection of waterproofing from rays of sunshine and from thermal shocks, it has been made an "*inverse roof*", setting on waterproofing one polyester TNT 200 gr/m^2 sheet, acting as chemical-physical separating layer, and then one layer of XPS with edges "L" shaped, 8 cm thick; then one other sheet of TNT, same of the previous, acting as filter, and then a floor in white concrete stones 30 x 30 cm, reinforced crosswise with zinc plated steel, dry set on circular polypropylene bases, 2 cm high. Summer sun (who in Tito, June 21th, 12,00 am, has a zenithal angle with horizon of 72°) warms stone, who warms the air below, who goes out from 4 mm fissures between stones.

Picture 12: The lying of first layer of bituminous membrane was done partly, little by little was accomplished disposal of EPS panels for making slopes. You can see two coaxial roof vent, the one for venting original insulation, the second for evacuating possible condensations in EPS panels of slopes, and water that might enter during work

Picture 13: The lying of second layer of bituminous membrane, with mineral surfacing, was done as soon as slopes was wholly accomplished

Meanwhile, evaporation of night condensation water keeps cool and to constant temperature both waterproofing, both coverage below (Picture 14). In the phase of setting XPS insulation there had been some "tropical" downpours, who took to open in the panels some drainage grooves, 4 cm deep, 2 cm wide, who constitute preferential ways for evacuating rainwater (Fig. 6). The result, from the point of view of roof transmittance, has been an upgrade of 10 times: from 1,93 W/(m^{2}K) to 0,185 W/(m^{2}K), with an annual saving in primary energy of 262.197 kWh [MARINO, 2009, pagg.188-230, 298-373].

Picture 14: At the end, XPS panels (8 cm thick) of insulation were assembled and reinforced white concrete stones of floor, dry set on circular polypropylene bases, 2 cm high, for protecting and ventilating roof covering

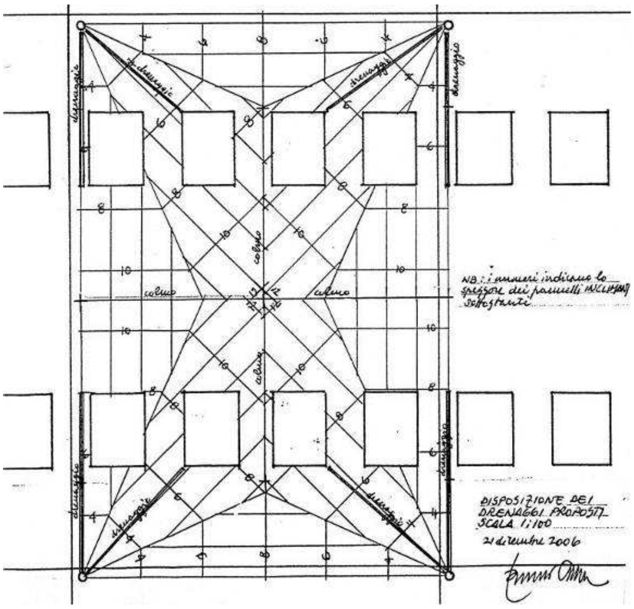


Figure 6: Plan of a typical span of the industrial plant, with drainage grooves added during the work

Picture 15: Then the insulations on the skylight and the flashings for protection and sunshades bases were assembled

6.6 The intervention on skylights

The original skylights were made from hollow polycarbonate, by this time dust stained and opaque, have been replaced with moulded elements in polymetil-metylacril, with air space anti-condensation, transmittance of 2,27 W/(m^2K). Bases are been raised and full insulate from the exterior, removing thermal bridges (Picture 15). They are now provided of a structure that in summer has a tent made by a shading net, that in winter is removable and stackable.

7. Maintenance instructions

At the end of the works, has been released a document containing recommendations for correct maintenance of the roof, and instructions for inspection, to periodically accomplish.

8. Conclusions

The intervention on the large flat roof of the plant Ansaldo STS in Tito (Potenza) teaches that metallic coverings do not constitute vapour barrier, short of a specific design and execution for the purpose. It will be necessary, in the next editions, to modify the pictures of many manuals and "*rules of the art*" containers. It teaches, more, that "*warm roofs*" are very delicate and very exposed to design faults. In particular, they does not exist "*warm roofs*" without vapour barrier and without roof vents [LEMBO, MARINO, 2002, pagg. 84, 189, 218].

It teaches, more, that slopes must be bigger than *fluage* or charge deformation of the structures on which they are built. It is not intelligent to save a little amount of money to build a structure which deforms herself under the weight of a man who do maintenance on the floor, especially when there are great rigid and breakable, as tree-dimensional skylights of 1,80 x 2,40 m.

In the industrial districts, were in the air there are aggressive electrolytes, it is necessary to schedule very frequent inspection, to watch over the behavior of more elementary things: steel screws tropicalized can corrode, till to break, or to decrease their section, and open passage to water, in four years.

Even more, in the next years, the consideration of "global cost" and of sustainability will lead to invest in better materials and in better constructive solutions, who guarantee better durability, even if of higher initial cost.

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