INNOVATIVE HVAC SOLUTIONS FOR AN AUTOMOTIVE PLANT IN SOUTHERN ITALY

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Abstract An automotive part manufacturing plant in Southern Italy, which has just recently been modernized and extended, offers an interesting panorama of innovative cost-effective solutions for ventilating, air-conditioning and process cooling. Some of them are:

- Indirect evaporative cooling with demineralised water and heat recovery for outside air treatment
- Variable geometry and displacement diffusers for production area ventilation
- VAV systems for office areas
- Large capacity DX systems for cooling retrofit
- High precision HVAC control for metrology rooms
- Variable flow chilled water plants with hydraulic decoupling and heat recovery for reheat and sanitary hot water production
- Variable-flow cooling tower systems for air-conditioning and process needs

All systems are controlled by a BMS system with user-friendly interface, which monitor the technical gas storage stations as well.

This paper offers an insight of the design decisions taken and of the difficulties met in the design, construction and commissioning of a large modern production facility in the sometimes harsh ambient conditions of a coastal environment, and shares the experience gained by design engineers and operating personnel.

Keywords: Air conditioning, Industrial applications, Evaporative cooling

1. INTRODUCTION

The present paper illustrates a few unusual and uncommon solutions adopted for the air-conditioning, ventilation and process cooling in a manufacturing plant in Southern Italy. After a brief outline of the geographical and climatic conditions of the site, ad a description of the manufacturing plant, the main highlights of the systems will be illustrated, together with the rationale for their adoption. Commissioning and operation experiences will also be briefly mentioned.
2. GEOGRAPHICAL AND CLIMATIC CONDITIONS

The plant is located in an industrial zone on the outskirts of the city of Bari, the regional capital of Puglia. As well as being a traditional producer of wine and olive oil, the region is reputed to be the most developed and industrially advanced in the Italian South. The city is a thriving port, as well as a renowned cultural and tourist centre. The climate is typically Mediterranean, with very hot summers and mild winters. Although Summer design conditions, according to Italian standards, are 33°C with 50% relative humidity, temperatures in excess of 40°C are not uncommon. In winter on the other hand the temperature does not usually drop below freezing. Strong winds from the sea are frequent is Summer.

3. THE PLANT BUILDINGS

The manufacturing plant produces components for the automotive industry.

Production is carried out in two main buildings: one, denominated Building 1, has a total area of 25 500 m², and was built over ten years ago. Originally heated with low-cost air heaters, it has been gradually revamped and upgraded recently; however, it will not be considered in this paper except in passing.

The second building, denominated 2, (Fig. 1) has a production and assembly area of about 10 000 m², and two office areas of 600 and 250 m². It was built ex novo in 1998 and subsequently upgraded with several interventions on both the building and the systems. The present paper will refer mainly to this building.

From the architectural point of view, its plan is almost square. The production area is single-floor, while the office and locker room areas are on two floors. A salient feature is the technical space, denominated Penthouse, which runs at high level across the whole building, and houses the cooling and the water treatment plant, as well as all the air-handling units for the production and office areas. The building has a load-bearing structure featuring steel trusses and “cassette” type panel cladding for the perimetral walls. The thickness of the glass wool panel is 12 cm, yielding a k factor of about 0.32 W/ m² K, well in excess of the minimum required by Italian energy-saving regulations.

Fig. 1 Building 2 with the office block in the foreground
The building is completely sprinklered; the system is wet-pipe type for the production and the office area, and dry type for the outdoor unloading and loading canopies.

The roof features a series of skylights, which are also used for natural ventilation. They are opened and closed by pistons actuated with compressed air from the plant. The opening can be manual or automatic via the building management system. Rain sensors close the skylights automatically if the weather conditions warrant it. Furthermore, they can be opened manually in case of fire with nitrogen stored in cylinders located in the building Sprinkler alarm valve station, which override the compressed air system.

The outside windows on all sides except North are protected against solar radiation, very strong at Bari latitude, with motorized external lamellar blinds. They are lowered automatically by the BMS system whenever direct solar radiation is detected, and raised when direct sunlight has gone (Fig. 2). Manual override by users is always possible if desired.

Fig. 2 Office block with outside solar protection

4. BUILDING 2 – HVAC SYSTEM FOR PRODUCTION AND ASSEMBLY

The production area in Building 2 can be divided into two main zones:

- The production proper and the packaging, having a floor area of about 7500 m², where originally only heating and ventilation was required. A minimum temperature of 18°C is required in winter, while no summer air-conditioning cooling was originally specified.
- The assembly, with a floor area of about 2000 m². Here summer conditions of 25°C with a relative humidity not exceeding 55% are required for process reasons.

In addition, a metrology room, with a dedicated air-handling units, is included in the production area. It is served by dedicated air-handling units, which will be described in another paragraph.

The production area is treated with seven air-handling units, denominated AHU 1 thru 5 and 8 thru 9, each having a flow rate of 11 111 l/s (40 000 m³/h), while the assembly area is served by two units denominated AHU 11-12, having each a flow rate of 11 700 l/s (42 000 m³/h). Their assembly is identical, except that units AHU 11 and 12 were provided with a chilled water cooling coil right from the start, while the others were only provided with a space for the future installation of a cooling coil. As will be seen later, this proved an excellent idea.
The units are designed to operate with 50% recirculation in winter, and with 100% outdoor air in summer. Outdoor air is taken in from the longitudinal wall of the Penthouse, which is completely grilled; however, the grille area not actually used by the units is blanked off with sheet steel cover plates. Exhaust air is discharged through the clerestories on the roof.

![Fig. 3 Scheme of Production Area AHU](image)

The most salient feature of these units, which sets them apart from current industrial ventilation practice, is the adoption of indirect evaporative cooling associated with heat recovery. As the unit schematic shows (Fig. 3), return air is humidified adiabatically to saturation, and is passed through the sensible-only heat recovery wheel before being exhausted to outdoors. The wheel is then used to cool incoming outdoor air.

The benefit of this solution is particularly evident when the outdoor air is relatively hot and dry. For example, with an outdoor air condition of 30°C with 37% relative humidity, which is fairly frequent in Southern Italy in summer, and assuming a heat recovery efficiency of 80%, the exhaust air is adiabatically cooled by 8 K, and the incoming outdoor air, assuming a heat recovery efficiency of 80% (which is achievable with a rotary type heat wheel), is cooled from 30 to 23.5 °C. This result allows us to keep the production area cooler than outdoors, without mechanical refrigeration.

It is interesting to note that demineralised water is used for adiabatic humidification. In fact, using ordinary industrial water, which is very hard in the Bari area, would soon lead to clogging of the spray nozzles and fouling of the heat wheel. Even using softened water would not help, because water softening only replaces calcium with sodium ions, but does not remove the dissolved solids. The result would be the same. Admittedly, demineralised water is expensive, but since a reverse osmosis plant was required anyway for the production process, it was felt that the cost increase deriving from the higher plant capacity would be more than offset by the reduced maintenance needed by the nozzles and heat recovery devices. As required with demineralised water, all piping is either high-density PE or stainless steel, and the spray pumps have stainless steel impeller and casing.

In summer the Assembly area units operate with 100% outdoor air in indirect humidification cycle for cooling as far as possible, then they switch to 50% return operation as chilled water coil operation is called for. As hot water from the main heating plant is unavailable in summer, the reheat coil for humidity control are supplied with 45° low-temperature hot water produced with heat-recovery chillers as described later.
The supply and return ductwork is arranged so that all the seven air-handling units serving the Production area discharge downward into a common duct linking all of them and running under the ceiling. Motorized dampers on the fan discharge allow any unit which must be shut off for maintenance to be serviced without disrupting air distribution to all zones of the area, which are thus always supplied with air, even if at a reduced rate. The same common duct arrangement is used for return. The two units serving the Assembly area are also linked by common supply and return header ducts, which run parallel to the two already described.

The air is supplied to both areas by means of motorized variable-geometry diffusers (Fig. 5), located along the perimetral walls and the columns at a height of about 3.5 m. Each diffuser is equipped with a modulating operator which moves an incorporated sliding valve so that the direction of throw can be progressively varied from vertical in winter to horizontal in summer, according to the difference in temperature between the room and the supply air detected by the Building Management System. Return air is drawn at high level through duct-mounted grilles at high level.

Part of the air supplied to the Production area is directly drawn from the machinery, and exhausted to outdoors via longitudinally-welded circular sheet steel ducts running at high level. The air collected from these ducts, which is laden with lubricating oil droplets from the machines, is passed through oil filters with specially designed baffles, where the air is forced to change direction many times at high speed so that the droplets are separated, collected and subsequently discharged via a special drain. The oil filters, produced by a specialized German firm, have a very high pressure loss (about 850-1000 Pa), which required the provision of high-pressure centrifugal fans, equipped with variable speed drive and suitable
controls so that the exhaust flow rate could be adjusted depending on the number of machines working, and also kept constant as the oil filter loads. A common duct header is foreseen in this case too, and the fans run in sequence; the first one modulated from minimum to maximum speed, and then, as the second one is started, they share the load by operating in parallel.

The system was commissioned in the year 2000. After one year of operation, the following conclusions were drawn:

- The air distribution system performed very well in winter, with hardly any stratification or draughts. The terminal velocities measured at person level were consistently lower than 0.15 m/s in winter and 0.2 m/s in summer, and indoor winter temperatures were kept at 21-22°C practically with the sole contribution of the internal loads and the heat recovery wheels. Only in some extreme days was it necessary for the heating coils to operate.
- The oil-laden air exhaust system operated satisfactorily after calibration of the flow rate and the static pressure controls.
- Indirect evaporative cooling worked very well; almost complete saturation of the exhaust air was achieved, and the cooling of the outdoor air was in line with the design assumptions. However, in later years (2003 in particular) it was found that the evaporative cooling was insufficient to guarantee a comfortable working environment in the Production area, where no mechanical cooling had been foreseen. It was then decided to retrofit the air-handling units with cooling coils. The solution adopted will be described in a later chapter.

It is interesting to note, in passing, that a different solution for air diffusion was adopted in the first stage of revamping of the existing Building 1 (other stages are currently in progress). Because of the large pillar spacing, 16 x 20 m, a mixed solution was adopted, incorporating both special industrial displacement diffusers installed near the columns (Fig. 6), and motorized diffusers of the type described above. While the latter did not give any
problem, the displacement diffusers were a source of complaint from personnel which was located too near to them. A set of measurements was made, and it was found, however, that at a distance of 0.5 m from the diffuser, the residual air velocity was $\leq 0.1$ m/s.

5. BUILDING 2 – OFFICES AND LOCKERS

The office area (about 600 m$^2$) is equipped with a single-duct VAV air-handling system featuring ceiling-mounted swirl diffusers, which is a rather uncommon solution for Italy. The air-handling unit is also located in the Penthouse, and has the same assembly as the units previously described, except that indirect humidification is not foreseen. On the other hand, all-outdoor air operation in free-cooling cycle is foreseen whenever the outside air conditions warrant it.

Separate terminal boxes serve the rooms and open spaces making up the office. The boxes serving outside spaces are provided with hot water coils, while those serving the internal offices towards the plant, where no winter heating is normally required, are equipped with electric coils. Each set-point can be adjusted separately from a PC unit connected with the BMS system, upon request from the individual tenants. It was specifically requested that no uncontrolled tenant adjustment be possible.

It should be noted that the average installed cooling capacity in the office area, despite the heavy summer outdoor conditions in Bari, is of 80 W/m$^2$ only. This is mainly due to the high efficiency of the outdoor blinds in cutting out solar radiation.

The system is well liked by the personnel because of its quiet operation and lack of maintenance in the occupied space.

The lockers are served with 100% outdoor air and have no summer cooling, but just winter heating with no humidification. Heat recovery is provided as well with a rotary type sensible-only device.

6. BUILDING 2 – METROLOGY ROOM

This area requires maintaining a temperature of 20°C all year round with a tolerance of $\pm 0.4$ K. Humidity conditions are less stringent; all that is required is that it be maintained between 30 and 55%. For this purpose a horizontal type air handling unit was adopted, featuring a chilled-water cooling coil, an electric reheat coil and a high-efficiency bag filter. The air is supplied to the room via swirl diffusers incorporating an H-11 high-efficiency filter, as often used in hospital application. Although a cleanliness class was not explicitly specified, it was expected to achieve Class 100 000 conditions. The unit is designed for 90% recirculation, with 10% pre-treated air drawn from the main ventilation system of the Production area.

The chilled water coil is equipped with in-line circulating pumps, so that the water flow to the coil is constant and modulation is achieved by varying the chilled water temperature with the two-way control valve indicated in the AHU schematic (Fig. 7). Because very little latent load was expected, a leaving coil condition of 12°C with 90% r.h. was specified.

This decision was proved wrong in the first summer of operation. While the temperature was easily kept within the specified tolerances, the relative humidity was very often too high, reaching 60-65%, and the coil produced a large amount of condensation. The reason was probably due to the insufficient vapour tightness of the room walls, one of which faced outdoors, and the others towards the production area where there was no humidity control.
The remedy was drastic: the chilled water coil was replaced. By almost doubling the coil capacity, with an apparatus dew point of 8.8°C, (not easy to achieve with 6°C chilled water), the room relative humidity could be kept within the specified tolerance.

7. BUILDING 2 – COOLING RETROFIT FOR THE PRODUCTION AREA

As previously seen, no mechanical cooling was originally foreseen in the Production Area, in accordance with the Owner’s standards; however, complaints from both the working personnel and the Quality Control Department led to the decision of installing cooling coils in the air-handling units 1 thru 5, 8 and 9, previously described. The capacity calculated for each coil was determined at 240 kW, for a total of 1680 kW. The cooling plant installed in the Penthouse included three water-cooled chillers of 450 kW each, which were already used almost to the limit for HVAC of the other zones and process cooling. Since there was no room for plant extension, and insufficient tower cooling water available, the alternative appeared to be the installation of air-cooled chillers either on the building roof or outdoor. The former was rejected because of structural problems, and the latter was deemed undesirable for its visual impact and potential noise problems.

The rather drastic solution adopted was then to install an R-407c direct-expansion system (Fig. 8 and 9), featuring, for each unit:

- One DX coil, divided into two circuits with thermostatic expansion valves, mounted inside the existing units. Hot gas-bypass is provided for control at low loads. Due to the added air-side pressure loss, the fan motors had to be replaced with larger ones
- Two reciprocating compressors for each unit, contained in a soundproof casing and installed on the top of the air-handling units
- Two condensing coils (one for each circuit), hung from the Penthouse roof structure
- Two axial exhaust fans equipped with variable-speed motors for condensing pressure controls, also hung from the roof structure, discharging air to outdoors via the clerestory skylights
- A three-way control valve on the humidification water supply, so as to control the leaving exhaust air relative humidity.
The control logic (Fig. 10) was modified as follows:

- When is needed, the unit initially operates as before with 100% outdoor air, the heat recovery wheel operates and the compressors are off.
if cooling is insufficient and the room air temperature tends to rise, the unit dampers are positioned so that operation takes place with 1/3 outdoor air and 2/3 recirculation air; the compressors are started and their capacity controlled by the supply and return duct-mounted temperature sensors. The three-way valve on the humidification water supply controls the leaving air relative humidity at 70%. The condenser fans are controlled to maintain the specified condensing temperature. The psychrometric chart plotting of the cooling process is shown in Fig. 11.

Fig. 11 The cooling process plotted on the psychrometric chart

This “Maxi-split system is certainly unusual both because of its size and because it was field-assembled using techniques normally applied in industrial refrigeration. It was sized so as to maintain a temperature no higher than 28°C with 35°C outdoor air temperature. Commissioning was carried out without major problems, and the system ensures comfortable working conditions even in the hotter summer days. The noise level inside the plant was not measured; however, it is bearable, even though the axial exhaust fans have a sound power level of over 100 dB. This is chiefly due to the variable speed control. No problems to noise or vibration propagation to the production room or to adjacent buildings was reported.

8. BUILDING 2 – UTILITIES

The following utilities are used for HVAC and process:

- Chilled water
- Demineralized water
- Hot water for heating
- Cooling tower water
As already said, chilled water is produced within the Penthouse via three water-cooled chillers, each having a capacity of 450 kW. A primary-secondary scheme has been foreseen, one pump being provided for each chiller, plus one stand-by, and secondary pumps with variable-speed drive drawing from a decoupling header. Because of the extension of the system, no inertial storage tank was provided; on the other hand, a 5000 l storage and decoupling tank was adopted in Building 1, which also had the added task of covering short-duration peaks. Since distribution to coils and process users is variable-flow, all motorized shut-off and control valves are two-way type.

Demineralized water is used for winter humidification and process, and is produced in a reverse-osmosis plant located in the Penthouse of building 2, using industrial water which is softened prior to entering the demineraliser.

Three stainless steel tanks, each having a capacity of 5 m³, store the water leaving the treatment. Conductivity, which must be ≤ 20 μS, is constantly monitored.

All the other utilities, with the exception of technical gases, are produced in a separate building denominated 6, and delivered via a pipe rack (Fig. 12), sized to allow for future doubling of the plant.

Hot water for heating is produced with two boilers of 2 MW capacity each, space having been provided for the future addition of a third one. A primary-secondary scheme is also used in this case; the operating supply/return temperatures are 90/45°C, so the ΔT is 45 K, much higher than normal practice.
Potable water is drawn from the city mains, while neighbouring wells supply industrial water which is very hard and requires softening and filtration before use for closed circuit and cooling water make-up.

The concept of the cooling tower plant is rather interesting (Fig. 13). It was designed on two levels, the lower one housing two above ground storage tanks in painted steel and the upper one where two cooling tower of 1 MW each (with space for two more) are installed. Again, a primary-secondary system is provided, in the sense that the cooling water production is decoupled from its use; it is interesting to remark, though, that both systems are open type.

The water returning from the user circuit is supplied to a return tank, from where the pumps serving the towers draw. The cooled water is then collected in a supply tank, from where the secondary pumps, equipped with variable speed drive, feed the users in building 2. The number and the speed of the operating pumps is controlled by the minimum pressure to be guaranteed at the furthest point of the system. From the hydraulic point of view it is worth noting that, since the water chillers in building 2 are higher than the return tank, a vacuum breaker is provided at the highest point in the system and a back-pressure valve is installed just before the inlet into the return tank, so that no danger of system emptying or potentially disastrous sub-atmospheric conditions can arise.
The building is completely sprinklered, with an electric, a Diesel and a fire pump located in a room in Building 106. Industrial water is used for fire purposes, and the system is designed according to Italian UNI 9490 and 10779 standards.

The following technical gases:

- Pure methane
- Nitrogen
- Oxygen
- CO2
- Ammonia
- Helium

are stored in a special area called 16 in specially constructed bunkers and supplied to building 2 with copper or steel piping running on a pipe tray on the rack.

9. CONCLUSIONS

It is quite normal that some problems are encountered during commissioning of HVAC systems. Therefore the designer should keep an open mind, and include in his design provisions for remedial measures if something does not go according to plan. Also, he must not be afraid of adopting new or unfamiliar solutions whenever needed to tackle unforeseen problems. A striking example of this is the integration of evaporative with mechanical cooling in the production area of Building 2.