The refurbishment of the air conditioning of a commercial building – a case history

FILIPPO BUSATO[1] – RENATO LAZZARIN[1]

1 – University of Padova – Department of Management and Engineering

SUMMARY

The present paper illustrates the analysis of the HVAC plant and the energy audit of an existing office and commercial building; the analysis highlights strong inefficiencies in the plant, partly due to errors occurred in the design phase, that reflect into high energy consumption. Once the proper calculations and verifications are done, a redevelopment of the HVAC plant is considered, suggesting several actions to be taken – if possible – on the pumping-piping system, the ventilation system, the heating and cooling generation system and the control strategy, in order to reduce the energy needs keeping the same comfort level. Energy analysis and economic evaluation of the solutions are finally presented.

1. INTRODUCTION

Considering both environmental and economical issues, buildings and their HVAC are required to be more energy efficient, while facing an ever-increasing demand for better indoor comfort. Italian buildings present the lowest specific energy consumption, that is per square meter, among the developed countries, except for Japan; but they score the greatest consumption per square meter and degree-day (FINCO-ENEA, 2004 and Busato F. et al., 2008). Of course, the low consumptions per square meter are due to the mild weather (the average degree-days is lower than 2,000), but the high consumptions per square meter and degree-day are due to bad insulated buildings or inefficient HVAC system. This clearly indicates that the HVAC system of a building has a potential for energy saving (Canbay et al., 2004).

The aim of this work it to reduce energy consumption of a commercial building, through the refurbishment of the air conditioning, taking action on the heating and cooling production, distribution, recovery and its control strategies. An energy audit carried out on a building allows to determine the global demand of thermal and electric energy, identifying the energy request of each sector of general service, i.e the HVAC system, the EMF (*Electro Motive Force*), the illuminating system. Then a detailed analysis should be performed of the HVAC system, identifying the energy needs of the different devices and components of the plant: pumps, fans, heating and cooling production.

After that the eventual system inefficiencies have to be identified. These can be due either to a bad design or to a bad plant management or to both. So the design of the system, regarding pipes, pumps, fans sizing, should be verified. Then solutions to reduce the energy consumption should be found – if possible – acting on the refurbishment of the HVAC system and its components, introducing state-of-art energy recovery solutions, evaluating new control strategies. A final energy and economic analysis drives the feasibility of the intervention.

2. THE CASE STUDY

The case study of this work is about the building that hosts from the beginning of the 90's the headquarter of BMW Italia SpA, located in San Donato Milanese, in the north of the Milan province (IT) (Tezze, M., 2007). The building is a 8 floor: the underground floor is a parking; the groundfloor hosts the showroom, some offices and the jobshop; floors from 1 to 7 host the administration section, where 200 people work. The plans drawings were omitted for sake of brevity.

The areas served from the HVAC system are the office building area of about 4200 m^2 (floors 1 to 7) and a showroom area of about 1000 m^2 on the groundfloor. The building's main sizes are listed in Table I.

Table I - Building's main sizes

Parcel area	m^2	10,854
Area served from the HVAC system	m^2	5,200
Basement area (not served from the HVAC system)	m^2	9,085
Outdoor driveways and parkways	m^2	5,103
Indoor driveways and parkways	m^2	7,735
Green area	m^2	1,998
Gross volume	m^3	45,000

The building general services include illuminating system, EMF distribution and HVAC. A 15 kV electric cabin to connect to the building to the mid-voltage electric grid is located the building inside, as well as a 1,200 kW District Heating (DH) substation. The CHP based district heating system distributes water at a temperature of 125 °C; during winter the DH supplements the heating system by means of two plates heat exchangers of 600 kW each, while during summertime it drives the two LiBr absorption chiller of rated cooling capacity 400 kW and 600 kW.

The HVAC system is based on two technologies: the showroom and offices at the groundfloor are served by a V.A.V. all-air system, while the 7 floors of the administration section are served by a mixed water-air system: 4 pipes fancoil and ventilation.

In 2006 the energy requirements were monitored, per each sector of general service. The gross energy consumption is illustrated on Table II. Figure 1 splits the measured electric consumption per each general service of the building.

Table II - Energy consumption 2006.

Energy consumption	kWh	€
Thermal energy	2,732,900	126,854
Electricity	2,138,606	270,827
Thermal energy summertime	1,577,200	45,052
Thermal energy wintertime	1,155,700	84,802

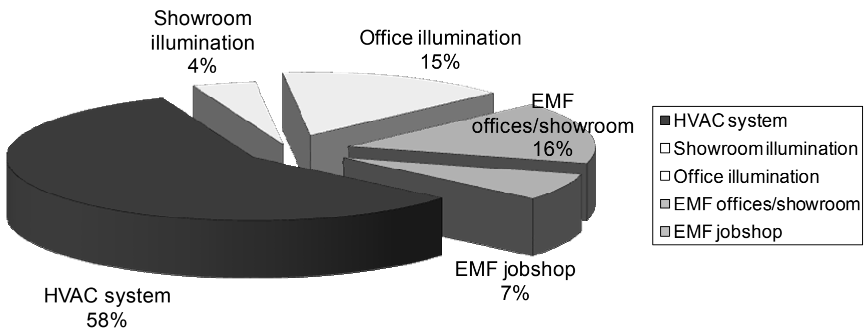

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Figure 1.Electricity consumption per sector.

As it is shown in Table II thermal energy consumption in summer is higher than in winter, due to the use of absorption cooling. Regarding electricity consumption, the rather high recorded figure might be ascribed to the illuminating system. Instead a more careful analysis obtained by monitoring the plant reveals that about 58% must be ascribed to the HVAC plant even if it is thermally driven.

Figure 2 shows the detailed shares of electricity consumption. The 58% of electricity used for HVAC is divided into: office fancoil 5%, the datacenter HPAC 9%, fans of the showroom all air air-conditioning system 9%, jobshop split system unit 1% and the HVAC main plant (installed on the roof) 34%.

The monitored electricity consumption indicates a huge consumption in the HVAC main plant, that therefore deserves a careful analysis. There it could be the most favorable potential for saving energy.

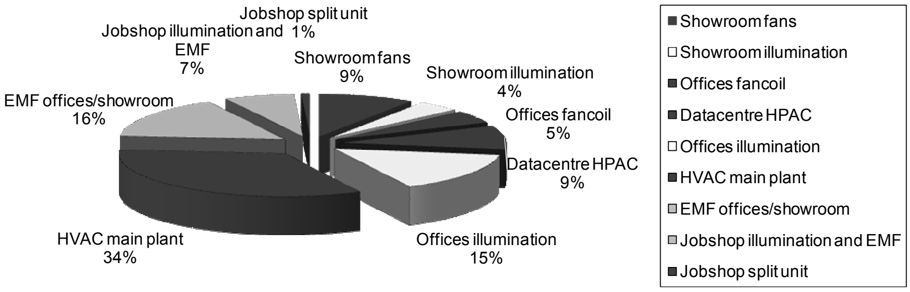

Figure 2. Electricity consumption in detail.

3. SURVEY OF ELETRIC AND THERMAL ENERGY USE

The survey of the elements of the HVAC plant took into account the showroom main AHU's fans (all-air HVAC system), the hydronic system water pumps, the cooling tower lift pumps, the cooling tower fans and the office forced ventilation fans, i.e. basically the distribution system and the cooling towers.

The actions to reduce energy consumption of those devices are presented in this paragraph, and will be discussed in the next paragraph 4.The heating and cooling production will be analyzed in paragraph 5.

The results of the survey are reported by Table III, as well as the hint for the reduction of consumption that was investigated. As it can be seen, no solution could be found in order to reduce the lift pump consumption nor that of cooling tower fans.

Table III - Rated electric power of the main plant elements.

Element	**Rated power (kW)**	**Analysis conducted**
Showroom main AHU's fans	57 = 40 (supply) + 17 (return)	Possibility for inverter installation
Hydronic system water pumps	5.5 (heating) + 11 (cooling)	Verification of the pipe sizing
Lift pumps for cooling towers	46 = 23+23	-
Cooling tower fans	15	-
Office forced ventilation fans	-	Possibility for heat recovery on ventilation

3.1 The hydraulic system
An analysis was carried out on the pipe sizing, starting from the as-built drawings of the piping system and the fan-coil technical data available. The calculation of the pressure drop revealed an average pressure drop of 250 Pa/m (at 50 °C), which is quite far from the value of 100 Pa/m, usually considered as a target for the design phase. Furthermore, from the original plots of the plant test report it was found that both pumps work at an efficiency that is far from the maximum, between 70% and 80%.

3.2 The showroom V.A.V. system
A second analysis considered the showroom all-air HVAC system, equipped with fan assisted boxes; Figure 3 shows the main AHU while Figure 4 shows the local box.

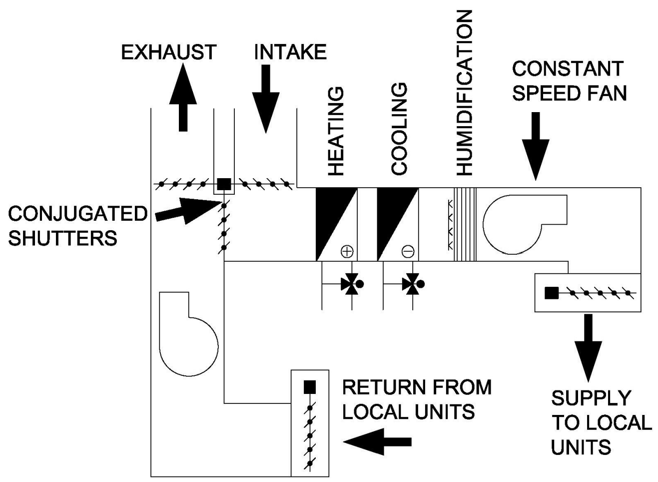

Figure 3. Example of fan assisted box V.A.V. – Main AHU.

As it can be seen from the drawing, the system is properly a 4 pipes “fan assisted box V.A.V.”, that means that the outdoor airflow is controlled at the main ventilating unit. The main fan supplies outdoor air to the boxes, and inside the boxes the mixing of outdoor and re-circulated air takes place. The volume flow of outdoor air (from the main fan) is controlled by choking the conjugated shutters (rolling-gate). So it is a system that works at variable flow with respect to the main distribution and at constant flow with respect to local boxes. The control in this kind of V.A.V. works accordingly to the scheme of Figure 5: at low outdoor temperature the outdoor air flow is kept at its minimum (choking), 40% of nominal flow, and the three-way mixing valve of post-heating coil is fully open; while temperature increases the valve closes and the outdoor flow is constantly kept at minimum. In the cooling mode – for outdoor temperature > 15 °C – the post-heating valve is completely closed and the volume flow of outdoor air increases. The advantages of this kind of system are ascribed during winter to the reduction of ventilation load due to the fact that the outdoor air flow is kept low, and during summer to the fact that the post-heating coils are kept off.

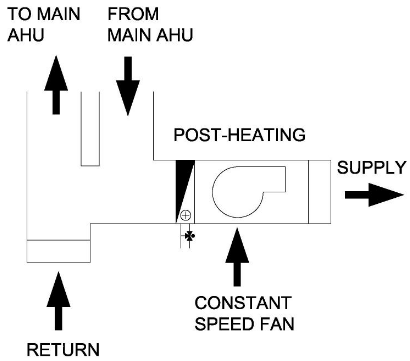

Figure 4. Example of fan assisted box V.A.V. – Local box.

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More than being too expensive, it is impossible to install inverters on the boxes' fans, because this would jeopardize the local control of the units (post-heating); in wintertime – for example – the local unit should control both the flow and the post-heating coil valve. It is not possible to control two independent parameters with the only feedback of indoor ambient temperature. Otherwise it is possible to control the volume flow of outdoor air by speed variation of the main fans, thus coping with the shutters, while they close or open. The installation of inverter on the main fan engines has been evaluated, and the results will be shown later.

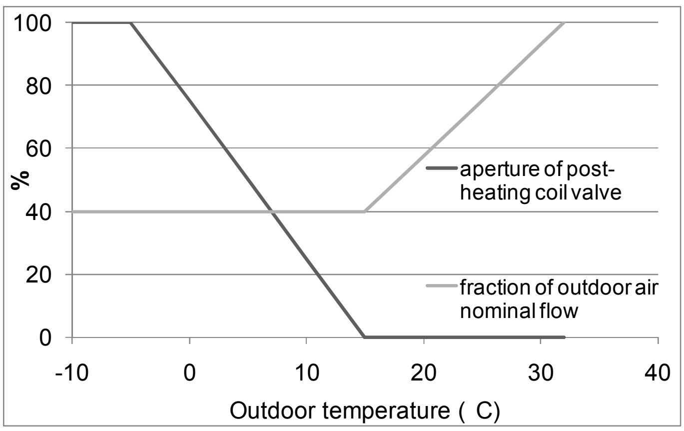

Figure 5. The control strategy of V.A.V. fan assisted box.

3.3 The offices' ventilation system

A further analysis was performed on the offices ventilation system; the system works at a fixed volume flow of 20,000 m³/h, which appears to be highly oversized if it is considered that it is sized to serve 200 people only. The space heating and cooling loads are satisfied by means of the fan-coils, this system only provides ventilation. The ventilation rate has been designed according to the volume of each office, so it is not possible to reduce the ventilation flow. On the other hand, the possibility for heat recovery on ventilation was considered, indeed taking advantage from the intake and exhaust relative proximity, both on the roof of the building.

4. ACTIONS TO REDUCE THE ENERGY CONSUMPTION

The performed analysis lay on the following assumptions:

- The heating system is active 7 months a year (1 October – 30 April);
- The cooling system is active 7 months a year (15 April – 15 October);
- The weather condition are those reported in TRY (Commission of the European Communities, 1985) for the city of Milan.

There is a simplified approach, since there is partly an overlapping in the working period of heating and cooling systems; since both are driven from the same DH supply of 1200 kW rated capacity, it is clear – even considering the seasons in which the overlapping happens – that the two systems work at part load.
The analyzed solution for the reduction in energy consumption will now be presented following the same order as in paragraph 3.

4.1 The hydraulic system

The average pressure drop has been calculated considering to replace each branch of piping with that of one step larger in diameter (i.e 1" replaces ¾", 2" replaces 1½" and so on). This would result in an average pressure drop equal to 99 Pa/m, so hitting the correct target for the design phase (100 Pa/m). The pumps could then be downsized from 11 kW to 3.8 kW for the cooling circuit, and from 5.5 kW to 1.9 kW the heating circuit. Considering that both the pumps operate 7 months a year, 24 days a month, 16 hours a day, so 2,688 hours a year, the replacement of pipes and the downsizing of the pumps would theoretically generate 37,374 kWh/year of savings in electricity. Considering the electricity price of 14 €cent/kWh (the price BMW Italia S.p.A. pays for the electricity), the saving equals 4,252 €/year. At any rate, either from the energetic or from the economical point of view, the savings would never payback the replacement of the whole piping across a 5,200 m² building.

4.2 The showroom V.A.V. system

Considering the assumption and the rated power of the fans, the consumption of the showroom main fans was calculated as high as 285,000 kWh/year. As it was previously said, the supply fan speed will be controlled to keep constant the pressure in the duct, at the same level corresponding to the fully open shutters in the boxes, and the maximum flow required. The same control strategy applies to the main return fan.
Over the year the fan will be controlled as follows; during winter the volume flow will be kept at its minimum, i.e. 40% of the nominal flow. This allows the fan assisted boxes to work properly, and the control of the indoor temperature will act on the three-way mixing valve of the post-heating coil. During summer the volume flow will increase as

the load increases; the nominal flow of the fan corresponds to an outdoor temperature equal or greater than 32 °C.
The calculations performed over the year, according to climatic data of TRY (Commission of the European Community, 1985) show that the installation of inverter on the main fans leads to a consumption of 171,000 kWh. The electricity saving on the ventilation is then equal to 114,000 kWh/year, thus the economic saving will be 15,960 €/year.

4.3 The heat recovery on ventilation

Considering that a cross flow heat exchanger is not easy to be installed in an existing plant, since it would need to replace part of the ducts and move at least one the fans, the installation of two run around coils was considered. The two coils are interconnected by a hydraulic circuit, so the recovery can be simply activated by a pump. For an office building the recovery should be activated when outdoor temperature is either < 15 °C or > 26 °C, since when outdoor temperature is between 15 and 26 °C it is possible to take advantage of the free cooling effect. Actually the cooling system is on for outdoor temperatures > 15 °C (roughly from beginning/mid of April), since the office buildings presents remarkable heat gains. The efficiency of the heat recovery system was assumed equal to 50%.
The calculations reports an energy saving that is:

- 156,000 kWh/year in winter;
- 3,000 kWh/year in summer (no latent recovery).

Taking into account the price of DH thermal energy, which is 0.074 €/kWh during winter and 0.026 during summer (for corporate or marketing reasons of the DH company), the economic savings are equal to:

- 11,544 €/year in winter;
- 94 €/year in summer.

5. ECONOMIC EVALUATION OF HEATING AND COOLING PRODUCTION

During wintertime the DH exchangers produce thermal energy at a maximum temperature of 65 °C, and the request is 1,155.7 MWh. If the present system is replaced with a condensing boiler, with a yearly efficiency of 0.95 (0,95 underestimates the average efficiency, but it's a safety coefficient, since the boiler cannot work in condensing mode all the time), a consumption of about 127,000 Sm³ of natural gas can be predicted. Considering an average price of 0.4 €/Sm³ available for mid consumers, this makes an expense of 50,800 €/year, quite less than the expense the company pays now for the DH in winter, that is 84,802 €/year. The saving would be of about 34,000 €.
In summer district heat drives the LiBr absorption chillers, that have a rated efficiency of 0.83. Summer cooling demand can be evaluated dividing the thermal supply of 1,577.2 MWh by 0.83: this gives 1,309 MWh of cooling energy. If the absorption chillers are replaced with vapour compression chillers, having an average EER equal to 3.5 (this overstimates the average efficiency that could be 3.2, but it's a safety coefficient), the additional electric consumption would be 374 MWh/year, so 52,360 €/year. This figure

exceeds of 10,308 €/year the amount that the company pays for DH energy in summertime.
Whereas the use of DH for winter heating is not an advisable option with respect to condensing boilers, cooling through DH driving absorption chillers is a good option. The main reason is the low cost of district heat in summer. It is doubtful that the DH company accepts to supply only heat in summer.

CONCLUSIONS

The conclusions of this work are represented by means of the following synoptic Table IV.

Table IV - Synoptic table of the results of the analysis.

Action	**Cost of the action (€)**	**Yearly energy saving (kWh)**	**Yearly economic savings (€)**
1. Variable speed fans	20,000	114,000 - electric	15,960
2. Heat recovery on ventilation	6,000	159,000 - thermal	11,638
3. boilers for winter heating	65,000	-	34,002
TOTAL	91,000	-	61,600

The considered costs include the cost of the equipment and the installation. First of all, all of these savings are greater than those eventually coming from the piping replacement. As it can be seen the best results in terms of payback are achieved by the heat recovery on ventilation, which allows to repay the investment in about 6 months. On the other hand good results on the long term are achieved from the installation of boilers for winter heating, responsible of more than 50% of the savings.
It can be argued that the DH company would turn down for serving the building only in summertime; however, reminding that is a CHP based DH company they could be more eager to keep customers for summer heat than for winter.

SYMBOLS AND UNITS

DH District Heating
EMF Electro Motive Force
HPAC High Precision Air Conditioning (for Datacentre)
AHU Air Handling Unit
V.A.V. Variable Air Volume

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