Long-term monitoring of the performances of an innovative HVAC system for cinemas

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ABSTRACT

In this paper, the results of the elaboration of the experimental data from 1-year long monitoring of the performances of an innovative HVAC system installed in a multi-rooms cinema of the Warner Bros Village near Venice is presented. This system is based on a roof-top expressly designed for cinemas applications.

The behaviour is analysed to verify the machine design choices in terms of reliability, energy efficiency and comfort level achieved. The study confirms the validity of the design which characterizes this HVAC system.

INDEX TERMS

HVAC system; Recovery; Heat pump; Cinemas; Monitoring

INTRODUCTION

The analysis of the building-plant system behaviour over a sufficiently long period of time can be based on dynamic simulations by comprehensive computer programs which are today available also for the professional designer (BLAST, 1993; DOE, 1994; TRNSYS, 1996). These tools are very useful in the initial phase of the design to compare different possible solutions. However, the most reliable verification still consists in testing the actual performances by monitoring over a long period. Besides a detailed monitoring of the real behaviour of the plant, the precise knowledge of the heat, cold and electric needs and of the operating conditions of the installed machines also permit to elaborate simple models to evaluate the advantages with respect to alternative solutions in terms of plant, management and control. The reliability achieved in this way is certainly not inferior to the one offered by computer programs (Schibuola, 1998, 1999a,b). In this case the experimental test has regarded an innovative roof-top equipment especially designed to be used for cinema rooms. In a multi-rooms cinema located in Marcon near Venice, the operating conditions of one of these unitary air conditioners are recorded since the end of September 2001 for 1 year. The room has an internal volume of about 1300 m^3 and a maximum capacity of 152 seats. Its architectural characteristics are typical for this kind of application. The external structures are well insulated and no glazing surfaces are present, the normal access is possible only from adjacent air conditioned rooms. The cinema room is served by a single roof-mounted packaged reversible air conditioner with constant airflow rate. The unit is essentially composed of two parts: the air handling section and the compressor–condenser unit. Two fans are installed in the equipment. The supply air fan ensures a constant airflow rate during the operating hours, measured 6500 $m^3\ h^{-1}$. The exhaust air fan instead is controlled to expel a variable air volume related to the simultaneous outside airflow introduced for the ventilation. In fact, the ventilation airflow rate can be varied from zero to a value equal to the supply airflow rate, by the position of the outdoor air damper. The movement of this damper is controlled by the automatic management system on the basis of the ventilation demand measured by a CO_2

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sensor installed inside the room. In the middle seasons the opportunity offered by free cooling is full utilized. Heat recovery can be carried out from the exhaust air. In fact, before the expulsion, this airflow rate passes through a coil which operates as an evaporator in winter and a condenser in summer. Therefore, the exhaust air is used alternatively as heat source or sink in the heating or cooling operation of the equipment. The three coils presented in the air handling section are direct-expansion coils.

The return and ventilation airflows are mixed in a suitable plenum of the machine and then the mixture is treated through the first coil. In the heating phase this coil provides the heat required to ensure the set point internal temperature fixed, by the supervisory system. In the summer operation the first coil cools and dehumidifies the air to control the internal humidity level. The second coil has a post-heating function. Three independent refrigeration circuits are present in the unit, each of them equipped with one scroll hermetic compressor. The refrigerant is R22. The total nominal capacity is about 50 kW in cooling (referred to indoor temperature 27°C, outdoor 34°C) and 44 kW in heating operation (indoor temperature 20°C, outdoor –5°C). All the refrigeration circuits have one heat-exchange coil included in the first air treatment coil which works as evaporator or condenser. The other evaporator/condenser coil is the reclaim coil for one circuit, while each of the remaining two refrigeration circuits is connected to an air cooled condenser positioned in vertical position, with the pertinent fans to move the outside air located on the top of the unit.

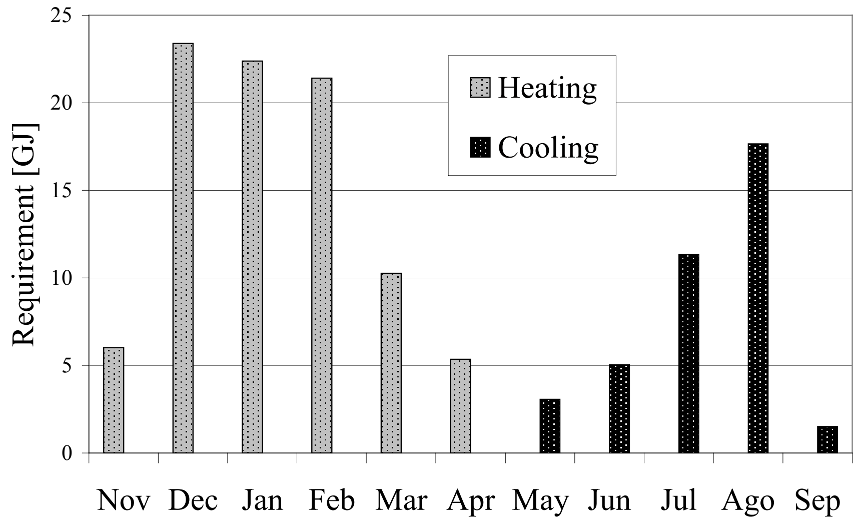

Figure 1 Monthly thermal requirements of the room in the monitoring period.

For this study it was decided to concentrate the long-term monitoring on the data regarding comfort and energy performances of the unit. By continuous measuring of temperature and humidity of the air in different positions inside the machine, the enthalpies of the airflows can be calculated. Flow rate measurements and enthalpy balances provide the energy fluxes exchanged with the coils inside the equipment and therefore the performances of the refrigeration unit and of the recovery system. The electric absorption of the supply and expulsion fans and of the whole unit has been also recorded. In Figure 1, the monthly thermal requirements of the room provided by the machine, in heating and cooling modes are reported. The extreme variability is caused by the frequent operating in free-cooling, especially in the middle seasons which, for example, has permitted to reduce to zero the requirement in October. The scheduled operating hours of the system normally coincide with the use of the cinema every day from 2 p.m. until 1 a.m. (or 2–3 a.m. depending on the attendance of the people and the duration of the films) on all days. Obviously the occupancy is strongly greater over weekend.

HEATING PERFORMANCES

The efficiency of the equipment is evaluated by its coefficient of performance (COP). For the heating mode it is the ratio of the heating capacity supplied to the handled air to the electric consumption of the equipment. In order to generalize the results and to compare this COP with those of other types of heat pumps, the electric consumption of exhaust and supply air fans has been subtracted from the total electric absorption considered in the previous ratio. Figure 2 shows the monthly mean coefficients of performance and the seasonal one. Very high values for the COP can be observed, especially in November. In fact, during this month the heating load is low and only the refrigeration circuit using heat recovery from exhaust air as heat source is active. The heat pump operating mode is then particularly favoured by the high temperature at the evaporator. Besides also the temperature level of the three condenser coils forming the first air handling coil is low and this contributes to increase the COPs.

To compare the heat pump performance with the efficiency of traditional boilers or gas fired roof-top unitary packages, the mean primary energy ratios (PER) are also reported in Figure 2. The PER is the ratio of the obtained heat power to the primary energy necessary to produce the electric energy absorbed. For this calculation a transformation ratio from fuel energy to electric energy equal to 0.36 has been assumed (typical value for Italy). This PER can be directly compared with the efficiency of a boiler. The remarkable performances of the system considered here are immediately clear.

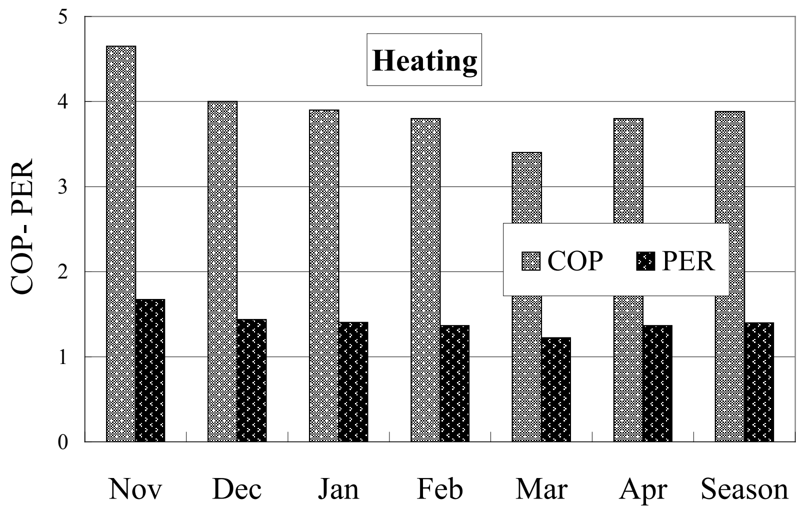

Figure 2 Monthly and seasonal coefficients of performances (COP) and primary energy ratios (PER) during the heating period.

Because of its importance, a further analysis of the heat recovery is shown in Figure 3. First of all, Figure 3 shows the monthly and total contribution, in per cent, of the heat quota provided by the heat pump circuit which uses heat recovery as source. As this circuit has the operating priority, this contribution is quite high in the mild period when the heating requirement is lower. In November, the intervention of the heat recovery circuit is sufficient to satisfy the demand and the contribution reaches 100%. The total contribution is greater than 40% and it demonstrates the fundamental influence of the heat recovery on the global performances of the equipment. In addition, the mean monthly and total thermal efficiencies, in per cent, of the recovery are reported in Figure 3. As for traditional recuperators, this efficiency is the ratio of the real recovery heat flux to the maximum theoretic one attained when the exhaust air is carried to the same enthalpy as the outside air. In Figure 3, this mean efficiency is always greater than 0.72. In November, only the refrigeration circuit (active as heat pump) based on the heat recovery as cold source, was working and the exhaust air is here always reduced to an enthalpy level lower than the outside one. With respect to the outside air, therefore, it is possible to recover all the available energy and the recovery efficiency can become equal to 100% as in November. The global efficiency of the recovery is greater than 0.86.

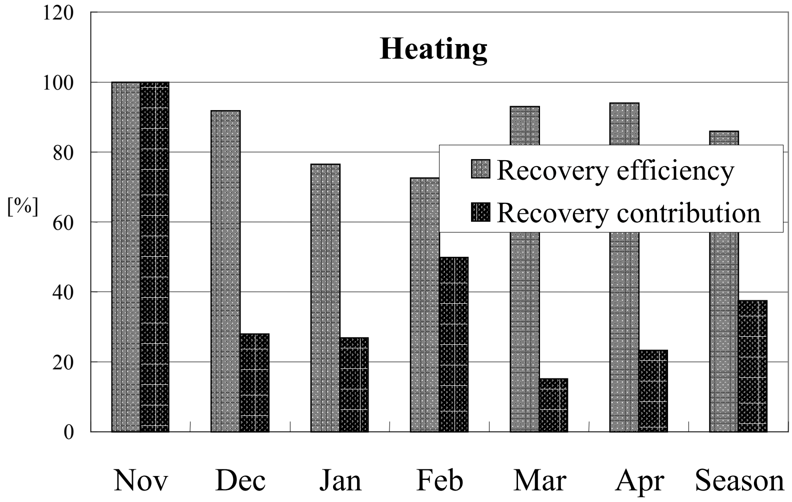

Figure 3 Percentage recovery efficiencies and contributions, referred to the total heat requirements of the heat pump circuit using heat recovery as cold source. The values reported are the monthly means and the total ones over the heating season.

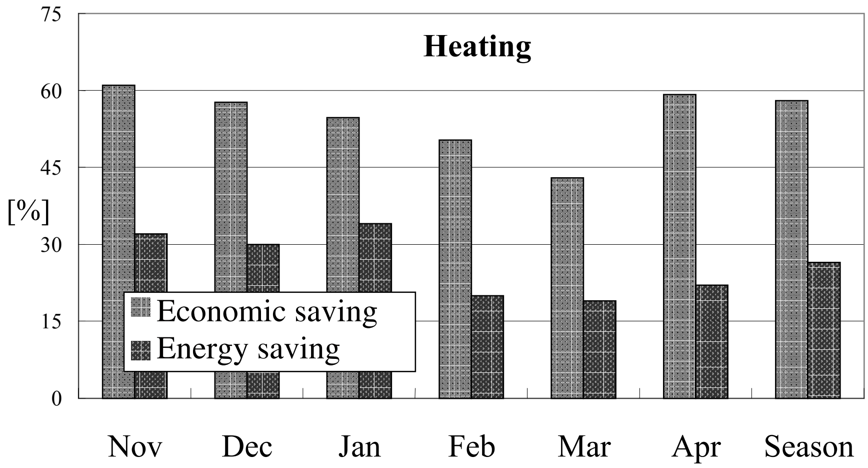

Figure 4 Monthly and seasonal percentage primary energy and economic savings obtained by the installed equipment in the test period. These savings refer to the consumption of the alternative gas-fired heating system.

In order to evaluate the real advantages with respect to other possible solutions, we have simulated the behaviour of a more traditional air handling system with reference to the same room loads and operating conditions. The heat was assumed to be supplied by hot water from a boiler or by a gas-fired roof-top with a mean seasonal efficiency equal to 0.85. Figure 4 shows the percentage saving in terms of primary energy attainable with the machine for each month and global in the test period. These savings refer to the primary energy consumption with the alternative traditional solution. But the best result is the economic saving also reported in Figure 4. In fact, the most part of the cinema demand falls in the off-peak hours (night and week-end) when the electric charge is particularly low. As a consequence the economic saving, thanks to the use of the electric equipment, is over 50% in the whole test period, if referred to the management cost of the gas-fired alternative solution.

COOLING PERFORMANCES

As shown by Figure 2, during air conditioning the machine has operated in free-cooling mode for long periods also because the evening and night working. Referring to the total working hours of the machine the percentage hours of the operation of all the three refrigeration circuits present in the apparatus are reported in Figure 5.

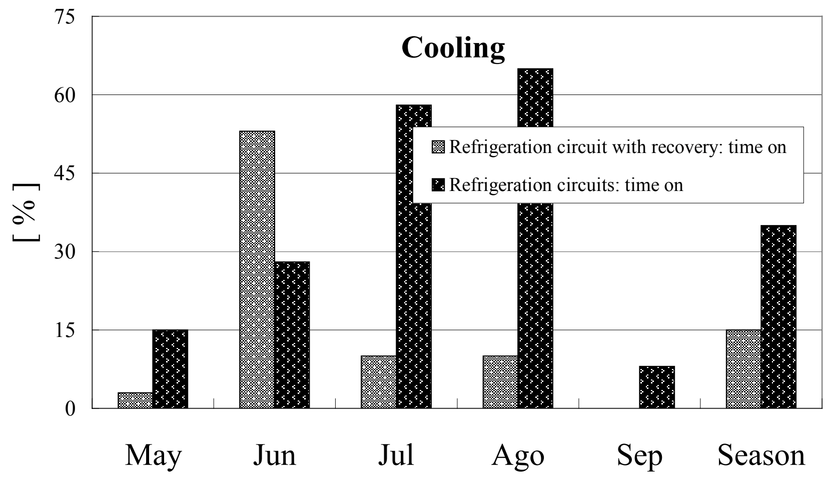

Figure 5 Percentage time on of the refrigeration circuits referred to the total time on of the machine and of the only refrigeration circuit based on the recovery referred to the total one of the refrigeration circuits. Monthly and seasonal values are reported.

In the same figure the percentage time on, but only for the recovery based refrigeration circuit, is also shown. In this case it refers to the total time on of the refrigeration circuits. Owing to the reduced occupancy of the room in the air conditioning period monitored, the ventilation requirement was modest and consequently also the use of this refrigeration circuit, the most efficient one, which though operates only in the presence of expulsion air connected with the ventilation flow rate. In order to test the real possibilities of the machine in full load conditions, in the last days of June, the ventilation flow rate was forced to its maximum value. In this period, on some days characterized by low cooling load, only the refrigeration circuit based on recovery was active. The corresponding daily mean values of the operating conditions are shown in Figure 6. The possibility to cool the condenser by air temperature deep lower than the outside one permits mean COP between 5 and 7 in this particular period. Owing to the reduced ventilation rates during the other periods, the actual monitoring of the whole summer has provided instead a seasonal COP equal to 3.8 with mean monthly values between 3 and 4. Anyway the monitoring of an air cooled chiller, installed near Marcon, have given in the same period a seasonal COP equal to 2.7. The comparison, even if only approximate, shows a better behaviour of this unit with respect to a chiller which could supply a traditional air handling unit.

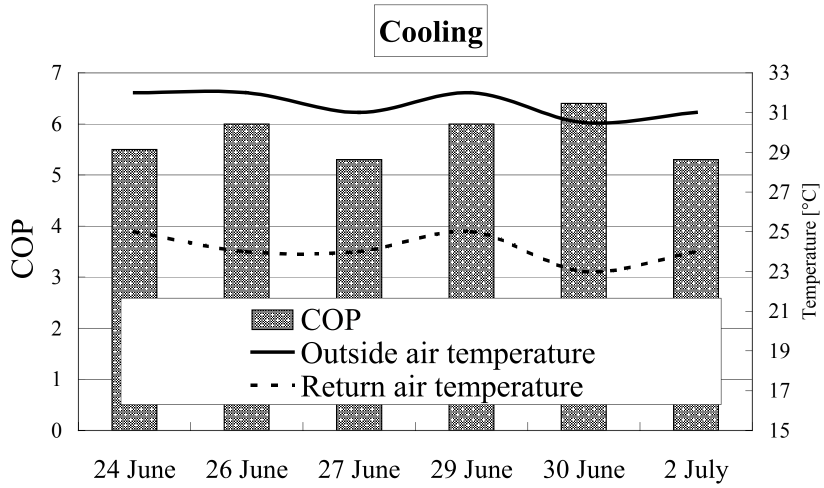

Figure 6 Mean values of COP, outside and return air temperatures in some days when only the refrigeration circuit using recovery is operating.

CONCLUSIONS

The monitoring has permitted to verify the excellent behaviour of the considered air conditioning system. During the heating period the advantage is evident especially in economic terms in comparison with gas-fired heating systems. In fact, the use of an electric motor-driven heat pump permits to take full advantage from the time of day electric rate. For this reason the choice of the electric heat pump is absolute profitable for this kind of buildings. In the air conditioning period the modest use of the room could not permit to take full advantage from the opportunities of the machine. The tests during June have anyway shown a relevant increase of the performances in the presence of high ventilation rates. The experimental study has therefore confirmed that the installation of this kind of machines is indicated for the climatization of room characterized by high crowding.

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