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Energy Savings through Variable Speed Compressor Heat Pump Systems

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Abstract

In the present study, four different kind of HVAC systems based on heat pump technology at three site locations (Milan, Rome and Palermo) were implemented and simulated. The simulated HVAC systems consisting of: ground source borehole (W-W (bh)); ground water wells (W-W(well)); air to water (A-W); air to air (A-A) heat pump systems applied for heating and cooling applications in a low energy residential building. In particular, the study is focused on comparative performance of single speed and variable speed compressor equipments based on heat pump technology. In this respect, the chosen site locations characterize the typical climatic zones of Italy (Milan-Continental, Rome-Intermediate and Palermo-Mediterranean). The results demonstrated that variable speed equipments can achieve considerable energy savings especially in the air source heat pump system applications. The estimation pointed out that variable speed heat pump equipment can enhance energy savings in comparison to constant single speed equipments especially at Palermo and Rome, in particular during heating season where most of the time, the equipments operate at lower part load ratios (PLR).

Keywords: Energy savings; heat pumps; variable speed equipments; low energy residential building

1. Introduction

During the last decade, the rapid growth of energy consumption and CO_2 emissions in the built environment has made energy efficiency and savings strategies a priority objective for energy policies in most countries developing new building regulations and certification schemes targeting to minimum

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performance requirements. In Europe, a clear example is the European Energy Performance of Buildings Directive (EPBD) [1,2]. In this context, the intensification of energy consumption in HVAC systems has been especially important, which has now become almost essential in parallel to the spread in the demand for thermal comfort. This is the largest energy end use both in the residential and non-residential sector, comprising heating, ventilation and air conditioning.

The application of heat pump systems, especially Ground source heat pump (GSHP) recently have gained popularity and seem to be a competitive solution compared with traditional heating and cooling systems. The GSHP systems are the fastest growing application of renewable energy in the world [3].

Air source heat pumps have Coefficient of Performance (COP) in the range of 2 to 4 and a corresponding Seasonal Energy Efficiency Ratio (SEER) of 9 to 13 [4]. Between 1991 and 2001, the variable speed units based on variable speed capacity-controlled compressors became standard in air-to-air heat pumps. The use of capacity controlled compressors provides opportunities for increasing the efficiency of heat pumps, mainly due to heat exchanger unloading, increased compressor efficiency and reduced need for defrosting [5]. Energy savings in the range of 10-25%, compared to fixed speed On/Off controlled heat pumps [6]. An experimental study [7] has been carried out to accurately determine the energy efficiency, COP of air cooled chillers under part load conditions.

Laboratory tests [8] have been conducted to investigate the energy-saving potential of using variable-speed capacity control instead of the conventional intermittent operation mode for domestic ground source heat pumps. The analysis shows that, to take full advantage of the capacity control, care should be taken to achieve the correct relationship between refrigerant flow and heat transfer media flows.

In the present study, four different kind of HVAC systems based on heat pump technology at three site locations (Milan, Rome and Palermo) were implemented and simulated. The chosen site locations characterize the typical climatic zones of Italy (Milan-Continental, Rome-Intermediate and Palermo-Mediterranean). In particular, the study is focused on comparative performance of fixed single speed and variable speed compressor heat pumps in a low energy residential building.

2. Methodology

2.1. Building description

The HVAC systems are implemented in a residential complex building which consist of a three-story block subdivided into 15 apartments with total net floor area of 1050 m². The building was designed according to the advanced rules of sustainable architecture for each site locations and satisfies all the requirements of the Italian National Standards implemented under Energy Performance Building Directive (EPBD) [9]. A 3-D view of the building is shown in Fig.1.

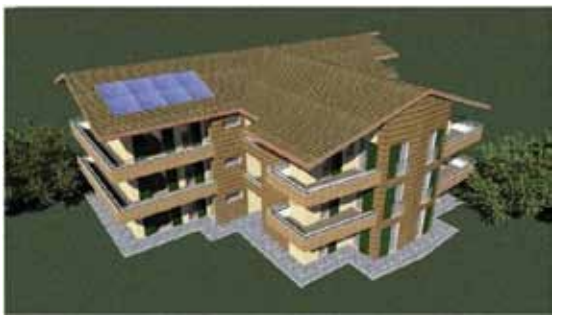

Fig.1. 3-D view of the case study building

As in this case study the simulations has been carried out corresponding to three different locations, also the building envelope has been designed according to local building energy standards [9] for each site location. Table 1 presents the envelope materials and thermal characteristics of building implemented at each site location Milan, Rome and Palermo.

Table 1: Envelope materials and thermal characteristics

Construction	U-value (W/m² K)		
	Milan	Rome	Palermo
External wall	0.32	0.35	0.43
Roof (flat or sloped)	0.28	0.28	0.36
Windows (glass-frame mean value)	1.41	1.7	2.1
Ground floor	0.32	0.35	0.47

2.2. Energy simulation

The energy simulation of the building has been carried out by using the software *EnergyPlus* [10], which runs dynamic analysis on hourly or smaller time steps basis The climatic hourly data used for simulation is corresponding to a typical meteorological year (TMY). The analysis assumes common Italian standard parameters adopted according to the functional destination of the building and are reported in Table 2.

Table 2: Description of simulation parameters

Parameters	Units	Site location					
		Milan		Rome		Palermo	
		Heating	Cooling	Heating	Cooling	Heating	Cooling
Internal gains (people, lights, equipments)	W/m²	5	5	5	5	5	5
Ventilation/Infiltration	V/h	0.3	0.3	0.3	0.3	0.3	0.3
Solar control	Yes/No	No	Yes	No	Yes	No	Yes
Heating set point	°C	20	20	20	20	20	20
Cooling set point	°C	26	26	26	26	26	26
Application period	date	15/10-15/4	16/4-14/10	1/11-15/4	16/4–31/10	1/12-15/3	16/3-30/11

The internal gains from people, lights and equipments can be input as individual parameters or as compressive total value in simulation file. In this case compressive value has been adopted for calculation simplifications. In same way ventilation and infiltration are two parameters which can be defined separately as simulation parameters. Infiltration parameter has been adopted for loads calculation to ensure minimum outdoor fresh air for building zones. Building solar control is done by movable and adjustable shading devices on windows in order to control the excessive heat due to the solar radiation during the summer and allow useful solar gains in winter. The solar control has been adopted only for cooling season for all of three simulation cases. The heating and cooling set point temperatures and

boundary for heating and cooling season are set according common Italian standard parameters. To simulate the solar control, it has been assumed that if the total solar radiation (direct plus diffuse) incident on the windows exceeds 150W/m² the shading device is active.

2.3. HVAC system simulation

Four different kind of HVAC systems based on heat pump technology at three site locations (Milan, Rome and Palermo) were implemented and simulated using *EnergyPlus* simulation program. The simulated heat pump based HVAC systems applied for heating and cooling applications are:

- Ground source borehole (W-W (bh))
- Ground water wells (W-W (wells))
- Air to water (A-W)
- Air to air (A-A)

The technical data corresponding to different kind of heat pump technology are shown in Table 3, the data is based on the actual products available in the market.

The single speed plant equipments normally when operate at part load conditions have lower performance. The performance of plant equipments operating at part load conditions can be improved if instead of single speed equipments variable speed equipments are applied at HVAC systems. In effort to understand performance improvement and potential energy savings by variable speed equipment in comparison to single speed equipments, an estimation was carried out. For this purpose, typical performance curves were used for two variable speed heat pump units (air to air & air to water) operating at four stages of part load ratios: 100%, 75%, 50% and 25%. An approximation and interpolation method was applied on these curves to evaluate the performance of water source heat pump units operating at part load ratio conditions. The evaluation of variable speed plant equipments performance and potential energy savings was done by using the recovered performance curves of variable speed heat pump units and time step output data of simulated results from *EnergyPlus* simulation program for single speed heat pump units. The time step output data furnish power input and thermal output of single speed heat pump units operating at each part load ratio during each time step.

Table 3: Heat pump performance data

Item	Unit	Performance data					
		Air to Air		Air to Water		Water to Water	
Operation method	-	Heating	Cooling	Heating	Cooling	Heating	Cooling
Capacity	kW	27.4	26.5	27.5	24	24.9	26.9
Compressor power input	kW	7.4	7.8	6.4	7.3	4.4	4.8
Total power input	kW	9.5	8.9	6.7	7.6	4.4	4.8
COP / EER	W/W	2.9	3.0	4.1	3.2	5.3	5.1

3. Results and Discussion

The energy simulations are carried out using *EnergyPlus* simulation program which is built on an integrated simulation engine, where by integrated means that building, plant and system simulations are

solved simultaneously at each time step by a successive substitution scheme. Fig. 2 shows the annual heating and cooling energy demand of the building for the site locations of Milan, Rome and Palermo.

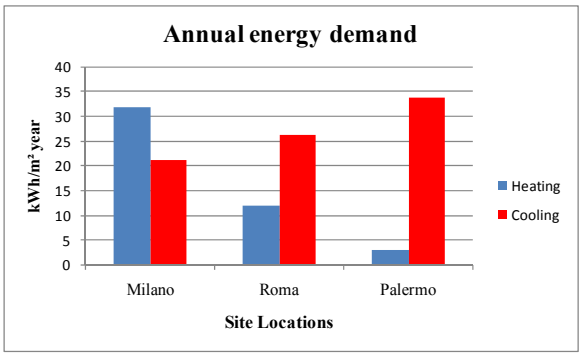

Fig.2. Annual heating and cooling energy demand for site locations of Milan, Rome and Palermo

The single speed plant equipments normally when operate at part load conditions have lower performance. The performance of plant equipments operating at part load conditions can be improved, if instead of single speed equipments, variable speed equipments are applied at HVAC systems. Fig. 3 shows the variation of part load ratio (PLR) and COP with evaporator inlet air temperature for air to air variable speed and single speed heat pump units operating during heating for Palermo. It can be observed that variable speed heat pump unit has better performance than single speed unit. At this specific case heat pump units operate at low PLR especially because heat pump unit has been selected according cooling design loads which dominate over heating peak loads. The single speed heat pump has seasonal COP of about 2.95 while variable speed heat pump unit has about 3.7. For this case the variable speed heat pump unit can save about 18% primary energy compared to single speed heat pump unit.

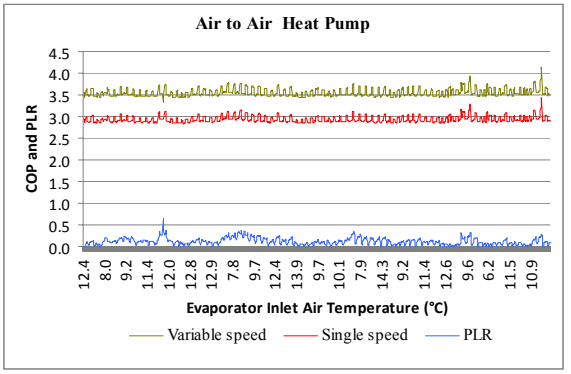

Fig. 3. Performance of variable speed and single speed air to air heat pump units operating in heating mode at site location Palermo

Fig. 4(a) shows the primary energy consumption by HVAC system based on variable speed heat pump equipments. Fig.4(b) demonstrates the potential energy savings of variable speed equipments at each site location operating during the year. It can be observed from the figure that air to air heat pump unit has higher savings than other equipments and the highest saving occur at site location Palermo where unit operate at lower part load ratio especially during heating season. As can be noted from the figure, the air

to water variable speed heat pump unit has also considerable savings in comparison to single speed units and the trend of saving increase from site location Milan to Palermo which means that during heating season the savings are higher than cooling season. The water source heat pump units also have considerable saving.

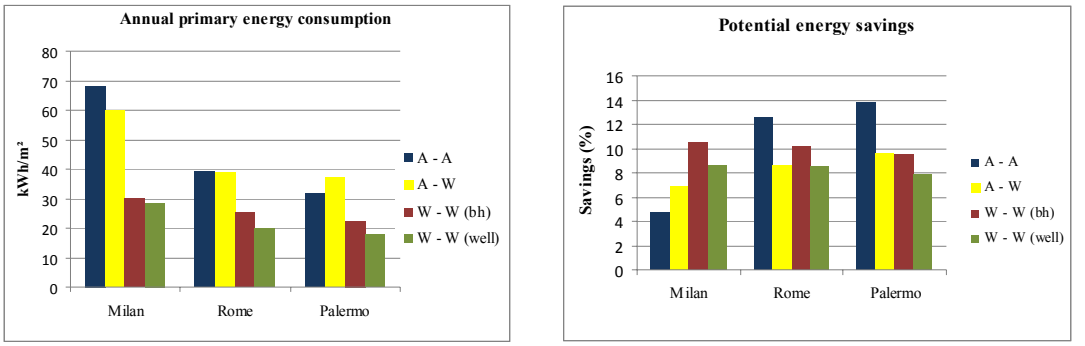

Fig.4. Primary energy consumption (a) and potential energy savings (b) with variable speed heat pump units

4. Conclusions

It has been shown that variable speed equipments can achieve considerable energy savings in comparison to single speed, especially in the air source heat pump systems. The estimation pointed out that variable speed heat pump systems can enhance energy savings, especially in hot climates (Palermo and Rome), in particular during heating season when equipments operate at lower part load ratios (PLR). The implemented methodology in the present research is based on sophisticated analysis for carrying out simulations leading to more reliable and accurate results. However, a detailed economical analysis should be required for assess the techno-economic feasibility of these system.

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