Preliminary EER analysis for sizing HVAC rooftop units

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***Abstract*—In daily life, a lot of time is spent inside the confined environments, for example: children in school spend between 6 and 8 hours a day, in the work environment 8 hours a day, in restaurants a few hours, and finally the rest of the time is spent at home. The environment, given the hours spent within it, must provide quality and comfort to the occupants. Indoor environmental quality is referred to as "Indoor Environmental Quality (IEQ)" and is defined as the set of environmental conditions within buildings that can affect the well-being, health, and productivity of the people residing in them.**

Keywords—Indoor air quality, IEQ, Rooftop technology, energy saving, HVAC

I. Introduction

Thermo-hygrometric comfort is a fundamental and necessary parameter to ensure: the correct perceived temperature within occupied spaces, the quality of air within the same environment. It is defined as "the mental condition in which a person is satisfied with the climatic conditions around him[1]." It is related to the values of temperature and relative humidity of indoor air because the exchange of heat and water vapor between the human body and the air around it depends on them. Air quality in the confined environment, i.e., Indoor Air Quality (IAQ), depends on the concentration of contaminants in the occupied environment. To ensure IAQ, it is necessary to ensure an adequate number of air changes, defined within the UNI 10339 technical standard depending on the intended use of the indoor environments[2], [3].

VOCs (volatile organic compounds) are chemical compounds, made up of molecules of different natures, but all of them volatile, that is, from the ability to evaporate easily in the air at room temperature. VOCs (volatile organic compounds) are chemical compounds, made up of molecules of different natures, but all of them volatile, that is, from the ability to evaporate easily in the air at room temperature. They may be man-made, or they may be of natural origin. They are present in many common products: building materials, solvents, and alcohol. The harmful effects of these compounds depend on the amount of their concentration in environments and the duration of exposure.

In the indoor environment, occupants' activities, hygienic conditions, furniture, ventilation systems, appliances, and the entire management of the building-plant system contribute to the quality of the environment and the production of VOCs[4].

Nearly all buildings used in the tertiary sector now feature what is known as controlled mechanical ventilation (CMV): a system of fans, ducts and vents that allow outside air to be drawn in and fed into the confined space, following appropriate heat, filtration and humidification treatments.

The air taken from outside, called replacement air, must have flow and thermo-hygrometric characteristics in quantities such as to guarantee IAQ for the occupants.

If the air introduced via the CMV system also has the task of conditioning the confined environment, then the system is called all-primary air. If the air introduced only performs the IAQ resolution function, then these are primary air systems. The air conditioning is carried out by another system which powers emission terminals such as fan coils, radiators, radiant floors, etc.

This article aims to analyse an HVAC system serving a commercial building in southern Italy. An all-air system will be analysed, and a focus will be described on the consumption of the compressors of the refrigeration cycle of latest generation rooftop units.

II. HVAC in Commercial Building

The air conditioning of a commercial building is generally composed as follows:

- Heating with gas boiler, cooling with chiller and air handling unit (AHU).
- Heating and cooling with heat pump and Air Handling Unit (AHU)
- Heating and cooling with rooftop unit (RTU).

The most common HVAC system involves the use of an "Air Handling Unit" (AHU). It is a machine made up of a casing inside which a heat exchange coil and fans are installed. It serves to provide or extract heat from the air to be treated, to introduce it into the environment with appropriate thermo-hygrometric conditions. The heat transfer fluid which has the task of providing or receiving heat to the air to be treated is typically hot or cold water produced by an external generator which can be a boiler or a refrigerator. The air treated by the coils is filtered and sent into the environment thanks to the fans in the delivery section of the unit. Inside the room there will be air vents designed to distribute the necessary flow.

The necessary components of an AHU are:

- Supply and return fans.
- Filters.
- Heat recuperator.
- Recirculation and air mixture sections.
- External fresh air intake.
- Heating and cooling batteries connected with appropriate piping to the heating and cooling generation.

The following figure 1 shows the typical HVAC system to power a commercial building.

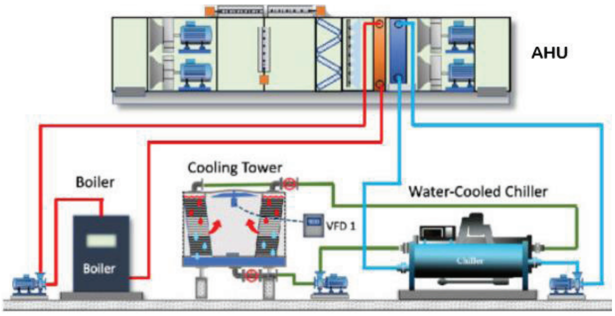

Fig. 1. Typical HVAC power plant

The principal classification related to AHU are related to air flow direction and technical structure. Considering the first classification AHU could be listed:

- Unidirectional AHU: it is used to move the air in one direction and usually consists of a fan, a filter and a heating or cooling coil. The extraction of air from the rooms, if necessary, takes place using an independent extractor.
- Bidirectional AHUs: these are units that contain a part used for treating and introducing air into the environment, and the other used for extracting air from the environments. It follows that these units can have sections used for mixing the extracted air and the air taken from outside, and/or sections used for energy recovery.

Considering the second classification AHU could be listed:

- Compact AHUs: standardized solutions in which almost all ventilation components (filters, fans, recuperators) are installed in one casing. Other components such as heating and/or cooling batteries are instead installed on the distribution ducts.
- Modular AHUs: more customizable solutions based on needs. They are made up of multiple modules, each with a specific function: a module with the supply fan, one with the filters, one with the heat exchange coil and so on.

The following figure 2 shows a bidirectional AHU composed by crossflow heat recuperator, heating coil, cooling coil and humidifier coil, and figure 3 shows the same AHU working principle.

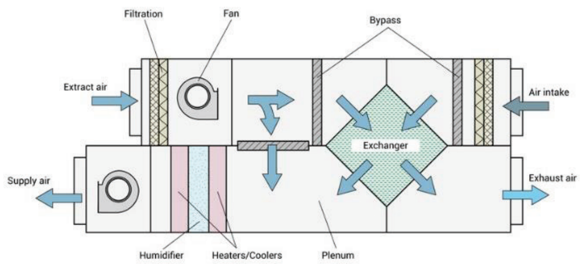

Fig. 2. Modular AHU

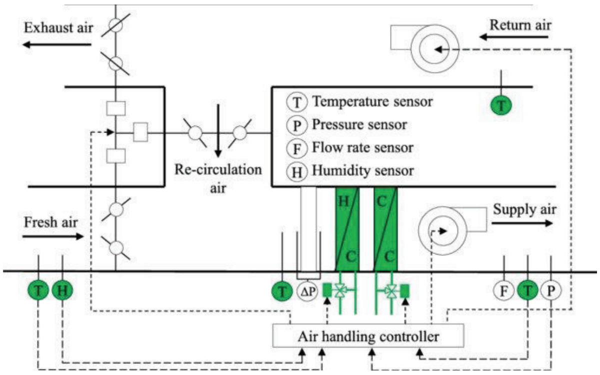

Fig. 3. Modular AHU working principle[5]

Rooftop units (RTU), also called packaged, are self-sufficient units that combine different components necessary for HVAC within a single machine, often positioned on the roof of buildings. They use the technology of traditional refrigeration machines, which exploit the thermodynamic vapor compression refrigeration cycle. The evolving fluid is called refrigerant (currently necessarily with low environmental impact), and is subjected to transformations in order (in the case of an ideal cycle):

- Reversible adiabatic compression (therefore isentropic) inside the compressor, typically volumetric.
- Heat release at constant pressure inside the condenser. It is a heat exchanger in which the refrigerant fluid acts as a heating fluid, transferring heat to the air that touches the coil, and therefore condensing.
- Expansion with final enthalpy equal to initial enthalpy: inside the expansion valve. The refrigerant expands, decreases its pressure and cools.
- Heat absorption at constant pressure inside the evaporator. It is a heat exchanger in which the refrigerant receives heat from the air that touches the battery, evaporating.

The figures 4 and 5 show the vapor compression refrigeration cycle four components, and the p-h diagram.

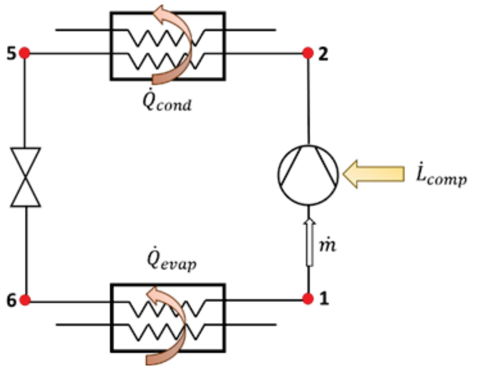

Fig. 4. Vapor compression refrigeration cycle.

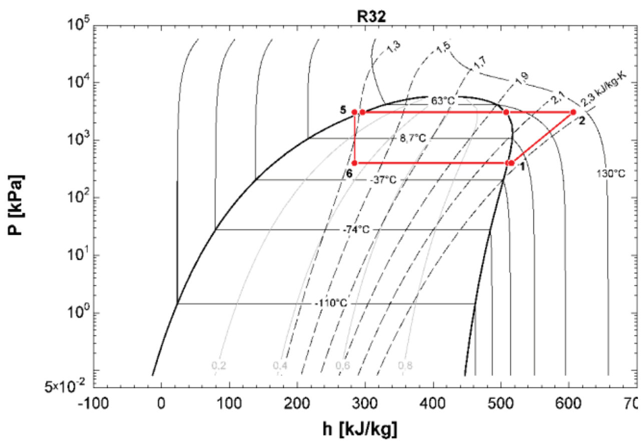

Fig. 5. P-h diagram refrigeration cycle

The Eurovent guidebook shows the most important characteristics related to AHU and RTU. The table 1 lists this comparison[6].

TABLE I. COMPARISON BETWEEN RTU AND AHU

	Rooftop	AHU
Aim	Air conditioning and IAQ	IAQ priority
Design	Compact, composed of thermal generation and air distribution	Compact or modular
External air	External air ratio around 30%	100 % external air
Automation	Always guaranteed	Upon request

The figure 6 shows the RTU configuration and its working principle. In the left section it is equipped by thermal and cooling heat pump vapour compression, and in the right section is equipped by air treatment components composed by filters, fans, air return section and supply air section.

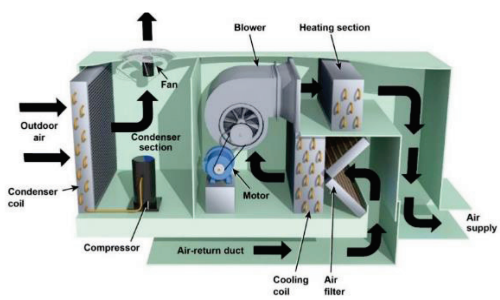

Fig. 6. RTU working principle.

III. CASE STUDY

A. Methodology

The most common commercial RTUs are classified varying the heat recovery section:

- RTU without heat recovery section, following called NHR.
- RTU with crossflow heat recovery section, following called CFHR.
- RTU with enthalpy wheel heat recovery section, following called EWHR.
- RTU equipped with thermodynamic heat recovery section, following called TDHR.

The aim of this research is to compare the energy efficiency ratio (EER) in a commercial building sited in south Italy, considering the energy consumptions in the fourth configurations listed above[7], [8]. Considering the equation 1 to calculate the EER.

$$EER = \frac{\dot{Q}_{evap}}{\dot{L}_{comp}} = \frac{\dot{m} q_{evap}}{\dot{m} l_{comp}} = \frac{q_{evap}}{l_{comp}} \quad (1)$$

Where the heat absorbed by the refrigerant can be calculated using the equation 2. It will be calculated using the product between the enthalpy difference of points 1 and 6 of the graph in figure 5 and the air flow rate to be treated.

$$\dot{Q}_{evap} = \dot{m}(h_1 - h_6) \quad (2)$$

The power supply to compressor similarly will be calculated in equation 3:

$$\dot{W}_{comp} = \dot{m}(h_2 - h_1) \quad (3)$$

The simulations were carried out using these input data:

TABLE II. SIMULATION DATA INPUT

Technical parameters	Values
Crossflow heat recovery efficiency ε_t	0,7
Enthalpy wheel heat recovery efficiency ε_t	0,7
Enthalpy wheel heat recovery humidity efficiency ε_w	0,6
Internal temperature T_i	25 °C
Internal relative humidity HR_{int}	45 %
External temperature T_e	32 °C
Internal thermal load	50 kW
Internal latent load	20 kW
Internal number of occupants	100/300/600
Ventilation flow rate per occupant[2]	39,6 m^3/h per person

The percentage of variation of external air is linked to the sensible load, see equation 4.

$$\dot{Q}_s = \dot{m}_{air} c_{p,air} \Delta T_{imm} \quad (4)$$

As the external temperature increases, there will be an increase in the intake air flow. Instead, as the external temperature decreases, there will be a decrease in the intake air flow rate, which however can never be lower than the ventilation air flow rate requested UNI EN 10339 standard. This parameter is strong connected to the occupants. The following figure 7 shows the relation between the two flow rates and the occupants.

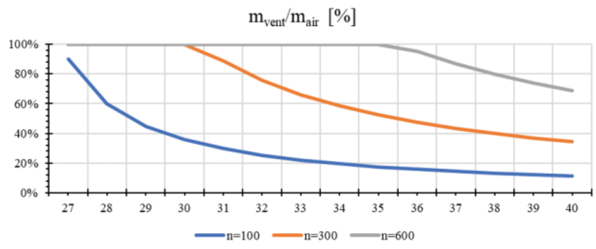

Fig. 7. Relation between flow rates, occupants, and external temperature.

The picture shows that higher the number of people in the room, the all-external air configuration will be necessary. The following section shows the result carried out by the simulations.

B. *Results and discussion*

The simulations were carried out using the equation solver EES software[9]. EER was evaluated varying external temperature and relative internal humidity.

Regardless of the number of people inside the room and the thermo-hygrometric conditions of the external air, there is an advantage in the configuration with thermodynamic recuperator. The results have been depicted in the three following diagrams, where are shown the EER variations. See figure 8, 9, and 10.

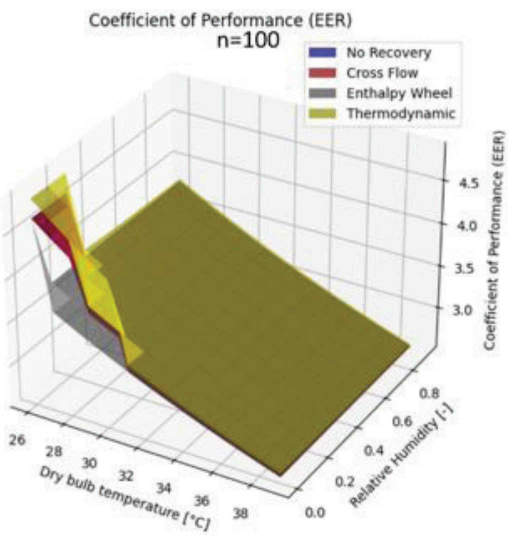

Fig. 8. EER varying internal relative humidity and external temperature considering 100 occupants.

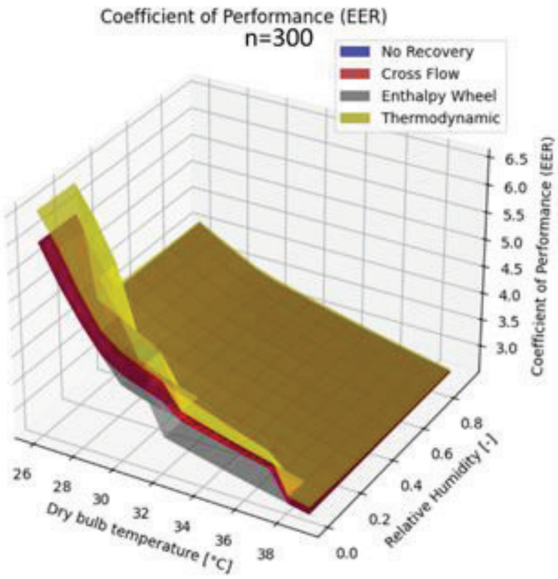

Fig. 9. EER varying internal relative humidity and external temperature considering 300 occupants.

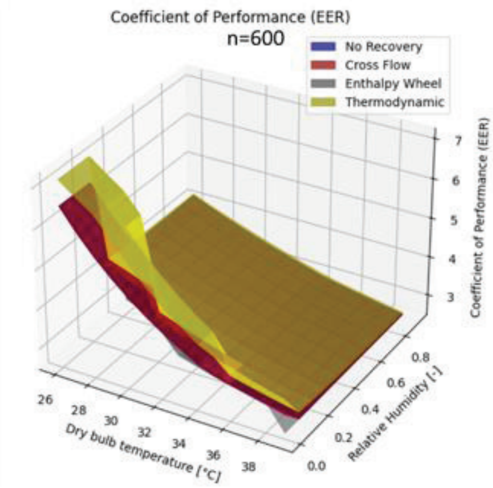

Fig. 10. EER varying internal relative humidity and external temperature considering 600 occupants.

However, it is observed that the trends relating to thermodynamic recovery do not differ significantly from those relating to the other three configurations. This means that active thermodynamic recovery does not guarantee such a high increase in terms of EER. The following tables 3, 4, 5, 6 show all the values carried out from simulations for each kind of RTU configurations with 600 occupants and plotted in the figures 8, 9, 10.

TABLE III. RTU WITHOUT HEAT RECOVERY

NHR						
EER [-]		Relative humidity [%]				
		0,2	0,4	0,6	0,8	1
External temperature °C	27	6,51	4,14	4,14	4,14	4,14
	28	5,98	3,97	3,97	3,97	3,97
	29	5,51	3,80	3,80	3,80	3,80
	30	5,10	3,65	3,65	3,65	3,65
	31	4,73	3,50	3,50	3,50	3,50
	32	4,40	3,36	3,36	3,36	3,36
	33	4,11	3,23	3,23	3,23	3,23
	34	3,85	3,10	3,10	3,10	3,10
	35	3,61	2,98	2,98	2,98	2,98
	36	2,88	2,88	2,88	2,88	2,88
	37	2,80	2,80	2,80	2,80	2,80
	38	2,72	2,72	2,72	2,72	2,72
	39	2,65	2,65	2,65	2,65	2,65
	40	2,57	2,57	2,57	2,57	2,57

TABLE IV. CROSSFLOW RTU

CFHR						
EER [-]		Relative humidity [%]				
		0,2	0,4	0,6	0,8	1
External temperature °C	27	6,51	4,14	4,14	4,14	4,14
	28	5,98	3,97	3,97	3,97	3,97
	29	5,51	3,80	3,80	3,80	3,80
	30	5,10	3,65	3,65	3,65	3,65
	31	4,73	3,50	3,50	3,50	3,50
	32	4,40	3,36	3,36	3,36	3,36
	33	4,11	3,23	3,23	3,23	3,23
	34	3,85	3,10	3,10	3,10	3,10
	35	3,61	2,98	2,98	2,98	2,98
	36	2,88	2,88	2,88	2,88	2,88
	37	2,80	2,80	2,80	2,80	2,80
	38	2,72	2,72	2,72	2,72	2,72
	39	2,65	2,65	2,65	2,65	2,65
	40	2,57	2,57	2,57	2,57	2,57

TABLE V. ENTHALPY WHEEL RTU

EWHR						
EER [-]		Relative humidity [%]				
		0,2	0,4	0,6	0,8	1
External temperature °C	27	6,51	4,14	4,14	4,14	4,14
	28	5,98	3,97	3,97	3,97	3,97
	29	5,51	3,80	3,80	3,80	3,80
	30	5,10	3,65	3,65	3,65	3,65
	31	4,73	3,50	3,50	3,50	3,50
	32	4,40	3,36	3,36	3,36	3,36
	33	3,23	3,23	3,23	3,23	3,23
	34	3,10	3,10	3,10	3,10	3,10
	35	2,98	2,98	2,98	2,98	2,98
	36	2,88	2,88	2,88	2,88	2,88
	37	2,80	2,80	2,80	2,80	2,80
	38	2,72	2,72	2,72	2,72	2,72
	39	2,65	2,65	2,65	2,65	2,65
	40	2,57	2,57	2,57	2,57	2,57

TABLE VI. THERMODYNAMIC RTU

TDHR						
EER [-]		Relative humidity [%]				
		0,2	0,4	0,6	0,8	1
T External temperature °C	27	7,16	4,28	4,22	4,20	4,19
	28	6,84	4,13	4,07	4,04	4,02
	29	6,54	3,98	3,91	3,88	3,86
	30	6,07	3,83	3,76	3,73	3,71
	31	5,57	3,68	3,62	3,58	3,56
	32	5,14	3,53	3,47	3,44	3,42
	33	4,76	3,40	3,34	3,31	3,29
	34	4,42	3,26	3,21	3,18	3,16
	35	4,11	3,13	3,08	3,06	3,04
	36	3,13	3,02	2,98	2,96	2,94
	37	3,03	2,93	2,89	2,87	2,86
	38	2,93	2,85	2,81	2,79	2,78
	39	2,84	2,76	2,73	2,71	2,70
	40	2,75	2,68	2,65	2,63	2,62

IV. CONCLUSION

The proposed article analyzed the current state of HVAC systems. It analyzed AHU and RTU focusing on the second systems. The preliminary study carried out aimed to verify the variation in EER by modifying the number of occupants in the internal commercial environment, the external temperature, and the internal humidity. Simulations run for a 50 kW case study produced some very interesting preliminary results. The thermodynamic recuperator, installed in the new units on the market, appears to be not so advantageous in summer.

Future developments will aim to size all the components of an RTU to verify what the overall behavior is.

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