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Production of water from the air: the environmental sustainability of air-conditioning systems through a more intelligent use of resources. The advantages of an integrated system

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Abstract

The possibility of extracting water from air is an activity that has been studied recently, especially with the purpose of producing it for emergencies or exceptional events, when drinking water is not temporarily available. Several mobile/transportable equipment have been designed in order to producing water from the air: they can be placed, if necessary, in appropriate locations where water is needed. Water extraction can be done with different technologies, one of which is represented by cooling water below the dew point, to cause condensation of the vapour content of the air. The system efficiency, normally calculated in standard conditions, should be tested in the climatic conditions in which it will be used, because water production varies significantly with temperature and air water vapour content. An interesting solution may be an equipment for water extraction that contemporarily uses the cooled air for refrigeration, which consists in a combined HVAC system for the dual purpose of water production and air-conditioning. A case study represented by this kind of HVAC system, for a hotel in a sub-tropical arid climate, is proposed in this paper, to demonstrate the advantages of this solution. To this aim, the comparison is made between a typical HVAC system and an integrated air conditioning system, optimized for water production from air, in order to highlight advantages and capabilities of the second one.

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Keywords: water from air; HVAC system; drinking water production; moist air condensation

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1. Introduction

The possibility of extracting water from air is an interesting process that has been studied for many years, mostly referring to desalination of seawater. In this field, several researches were developed on reverse osmosis, membrane distillation, water desalination, also by means of solar technologies.

In addition, the opportunity of water recovery from atmospheric air has been studied deeply. In arid climates, hydrated salts supported on carrier beds allow for extracting water from cool night air and employ solar energy for recovering the moisture for use it as drinking water [1].

In recent times, other technologies were proposed, to use systems especially for emergencies or exceptional events in which drinking water is not available temporarily. Studies on this topic were developed also in the past, but application did not spread widely. Experiments in order to extract water from the air were carried out also in laboratories by means of commercial air-conditioning plants (dehumidifying unit) [2]. The feasibility of the method, fully proved by experiments, represented a costly system to extract water, therefore it was considered as an alternative in those places where water is very rare, expensive and is not required in large quantities.

However, for climatic conditions characterized by high temperature and relative humidity such as those in UAE coastal regions, the cooling and dehumidification processes, if optimized, can obtain appreciable amounts of fresh water, suitable for human consumption [3]. A solar-powered liquid desiccant system, to meet both building cooling and fresh water needs in Beirut humid climatic conditions, was proposed. The calculations were made for a typical residential space with conditioned area of 80 m^2 with the aim to produce 15 litres of drinking water a day and to meet air conditioning needs at minimum energy costs [4]. The researches highlight that the heat sink temperature is a critical optimization parameter and they indicate the appropriate regeneration temperature within the constraints of the system operations. A solar system can be designed basing on an absorption heat pump, to produce potable water while performing its air-conditioning duties. Such a system was calculated for the weather conditions of the Hurgada area, on the Red Sea coast of Egypt [5]. At the moment, several mobile/transportable equipment are commercialized to produce water from the air, to be used in the locations where water is needed for a limited period (i.e. emergency units powered by electrical sources, liquid or gaseous fuels) [6,7,8].

While in the past, the water extraction was studied to be performed by means of different technologies, in this research the humid air cooling process below the dew point, to cause the condensation of the vapour content in the air, is considered and it is applied to a combined system configuration for air conditioning and water production. A case study is taken into account to compare a "typical" HVAC system and a combined one, to show the advantages that can be achieved with the second one.

2. The analysis of an integrated system vs a typical air conditioning system – a case study

The aim of this paper is to discuss a case study represented by the HVAC system of a hotel, which is proposed to demonstrate the advantages of this solution in producing water from air, contemporarily using the cooled air for air refrigeration purposes. The comparison is made between a Typical HVAC System (TS) and an Integrated air conditioning System (IS), optimized for the production of water from the air, in order to highlight the advantages and capabilities of the second one in sub-tropical, arid climate. In the first case (typical HVAC system) the water produced by the vapour condensation during the dehumidification process is lost, while in the second case (integrated air conditioning system IS) the system is optimized to produce water to be used for the building needs.

The calculations of the daily water production and energy consumption for the two plant solutions is the starting point for analyzing the advantages and disadvantages from the economic point of view. In particular, the purpose of this analysis is to highlight the differences of the electrical energy costs, even if the aforesaid use is referred to very specific climatic conditions ($T_{outdoor}$= 35°C, $RH_{outdoor}$ = 60%; T_{indoor} = 20°C, RH_{indoor} = 60%) and for continuous operation at full load. The fabrication costs differences between the two considered plants are not considered in this study since they are closely bounded to design choices that cannot be separated from the hotel architecture and then are difficult to estimate and to quantify. As regards the technical aspects, both configurations refer to commercial components, normally used for HVAC systems.

The property is considered as distributed over 16 floors. On each floor, except for the first one in which the common areas are located, there are 20 rooms, on the two sides of the building and divided by a corridor: each room surface area is 36 m^2, the height is 3 m and it is designed for two guests. The first floor consists of a relevant number of common areas: the hall, 2 bar/breakfast rooms, 2 restaurants, 2 congress rooms (1000 guests), cinema, casino, shopping areas for a total of 10 000 m^2 (mean height 5 m).

The hotel HVAC system can be split into two parts: the first one is dedicated to private rooms (a), while the second one is devoted to common areas (b). In order to design the (a) HVAC system, heat loads of the 300 rooms were calculated with a different layout for 12 room representative configurations, taking into account exposition (for the solar radiation contributions) and relative position (unconditioned areas, external walls extension). The mean heat flux in the summer worst conditions was evaluated as 25.1 W/m^3.

The (b) HVAC system is divided into 5 units because common areas were divided into 5 macro zones, each one with its own air conditioning system. As heat loads result quite the same for all the five macro zones (they have been calculated in detail), it was decided to study one representative HVAC system configuration which is suitable for all the five zones. In order to design the main components of the conditioning system for common areas, 6 volumes per hour of air exchange with 50% of external air and 50% of recirculated air were considered. The cooling coil was sized taking into account the maximum occupation of common areas that represents the heaviest condition. The mean heat flux in the summer worst conditions was evaluated as 27.4 W/m^3.

(a) The HVAC system was designed with a chiller connected to fan coils, the air extraction by bathrooms. This section has the same features for both the Typical System TS and the Integrated System IS solution, therefore it is not sized, and no heat recovery is provided. For the primary air control, an Air Handling Unit (AHU) is connected to a second chiller. The air-handling unit dedicated to private rooms ensures air supply in neutral conditions: T_{inlet} = 20°C, RH_{inlet} = 60% (the thermal loads are compensated by the fan-coils). For the TS chiller cooling water inlet and outlet temperatures, T_{in} = 12°C and T_{out}=7°C were considered, while, as the IS AHU is designed to optimise the water production by means of an air heat-recovering unit, T_{in} = 7°C and T_{out} = 2°C are considered in the chiller unit.

(b) In order to design the representative system for each macro-zone, mean values of the calculated loads were considered: total heat load of 228.1 kW (165.7 kW sensible and 62.5 kW latent) and a design reference value multiplied with an increasing factor of 1.2 (273.7 kW).

2.1. Some TS AHU components features

The typical system energy consumption was calculated in the same working conditions as the IS (continuous operation). The results are resumed in Table 1. A scheme indication of the AHUs for rooms and common areas is represented in Fig.1.

Table 1 - Electric power, energy consumption, and water production for the air handling unit (cooling coil, post-heating coil, fans, and pumps)

	TS - Typical System		IS - Innovative System	
	Rooms	Common areas	Rooms	Common areas
External air [m^3/h]	30000	150000	30000	150000
Recirculated air [m^3/h]	0	150000	0	150000
Recovered heating power [kW]	0	361.5	215	1340
Cooling power battery packs [kW]	565.7	3463	517	3650
Post-heating battery pack [kW]	82.2	123.5	0	337.5
Electric power for refrigeration [kW]	177.9	1117.1	180.9	1248
Fans electric power [kW]	16.2	205.6	23.9	231.5
Chilled water pumps electric power [kW]	7.5	55	7.7	55
Post-heating water pump electric power [kW]	1.2	1.0	0	5,5
Condensed water [m^3/day]	11.0	66.4	12.4	72.2
Energy consumption [kWh/day]	4867	33089	5100	36960
TOTAL ENERGY CONSUMPTION	37956 kWh/day		42060 kWh/day	
TOTAL CONDENSED WATER	77.4 m^3/day		84.6 m^3/day	

With different indoor conditions (T = 25°C, RH = 50%), the condensate flow decreases (a) to 9.97 m^3/day and (b) to 61.68 m^3/day, the cooling power request is (a) 512 kW and (b) , the post heating power is (a) 114 kW and (b) 87.6 kW. Increasing the recirculated air flow, the condensate flow rate has a meaningless change.

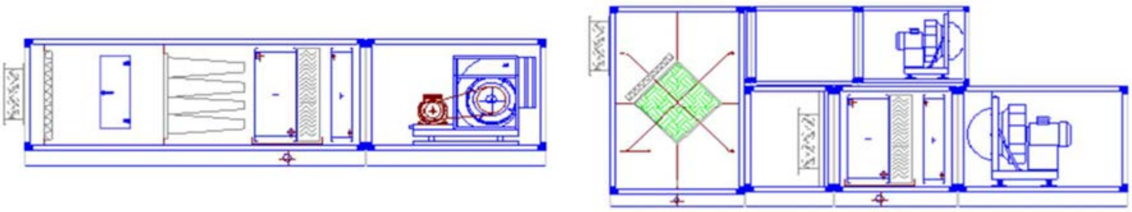

Fig. 1. (a) Rooms AHU; (b) Common areas AHU.

2.2. Some IS AHU components features

The integrated system energy consumption has been resumed in Table 1. A scheme indication of the two AHUs is represented in Fig.2 and Fig. 3. Some notes are resumed here:

(a) the air conditions at the exit of the heat exchanger are T = 30.6°C, RH = 26.1 %.

(b) the optimization of the first and the second heat recovery units have been performed with a series of simulations, in order to maximize the flow of condensed water and to minimize pressure losses, while maintaining high performances.

(c) by the calculation for the traditional air conditioning system and the combined one, the chillers EER value is about 3.1 in both cases. All the calculations were made in design conditions ($t_{outdoor}$ = 35°C and RH=60%) for air-cooled chillers (because of lack of water, it was not considered the use of water-cooled chillers).

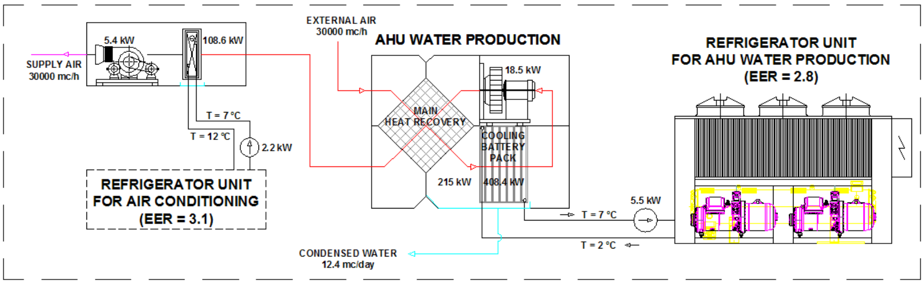

Fig. 2 – Rooms AHU

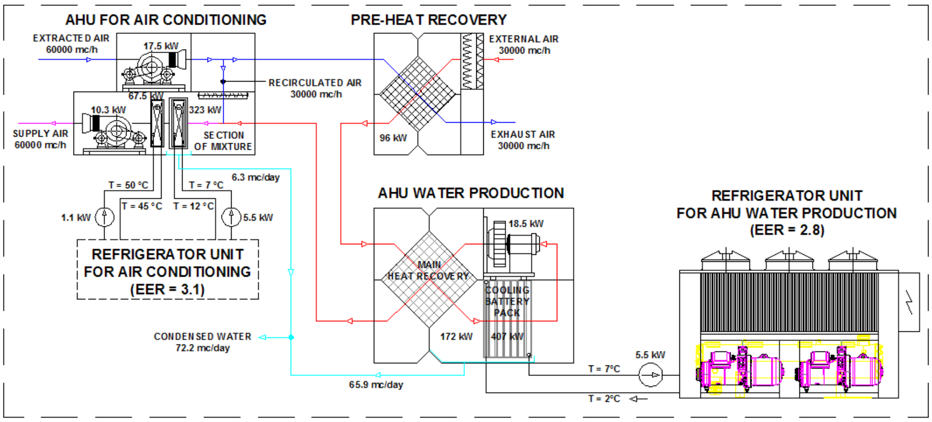

Fig. 3 - Common areas AHU

The energy needs have been calculated referring to the methodologies indicated by the International Standards on the energy performance of buildings. The simulations have been performed by means of a commercial software for HVAC systems components design, (that takes into account experimental data regarding heat exchangers, heat recovery systems, chillers, etc.). They allowed verifying system performances, the condensed water flow rate and the pressure losses of the heat recovery unit, varying some significant characteristics such as fin pitch, size, type, and temperature of the input air. The aim of these simulations was to optimize the choice of the two heat recovery units, maximizing the flow of condensed water and minimizing pressure losses, while maintaining high performances.

The main parameter for the heat recovery optimisation is the pressure drop: high pressure drop means more electric power absorbed by the fan and excessive values of differential pressure, low pressure drop involves non-uniformity in the flow field that adversely affect the performance and reliability of the calculated pressure drop. In the meantime, it is necessary to ensure greater flow of condensed water, good recovered power and output air conditions compatible with air conditioning needs.

The variation of the size of the heat recovery unit, both in terms of length (1200 - 1500 - 1600 mm) and of width (2200 - 2600 - 3000 mm), has been calculated to verify the variation of the pressure drops, the efficiency, the recovered heat rate, the condensed water flow rate and the cooling coil power. For the same purpose, it was necessary to vary the fin pitch and the input temperature of the fresh air for conditioning, and the output temperature from the cooling coil. The calculations highlighted also that the choice of the first heat recovery unit does not change substantially nor the performance of the second one nor the out air conditions at the exit of AHU and that, if recirculated airflow is increased, the flow of condensate has a meaningless change (external air flow fixed to 30000 m^3/h).

3. Typical to integrated system: a comparison between the two solutions

The calculations are based on the climatic conditions of Abu Dhabi, therefore, to carry on an economic evaluation, the local cost of electricity and water have been considered, referring to the local currency, United Arab Emirates (UAE) Dirham (AED).

Regulation and Supervision Bureau, in collaboration with Abu Dhabi Distribution Company and Al Ain Distribution Company, announced new water and electricity tariffs in Abu Dhabi for both Emiratis and expatriates with effect from January 1, 2015, apparently reducing government subsidies. In the past years, utility tariffs in Abu Dhabi were heavily subsided by the government: the state support in residential buildings was 55 - 90% for electricity and 79 -100 % for water. With those new tariffs, Emiratis people will pay for water (water was for free when upper limit of the previous tariff was applied) while the electricity costs will increase by 10%, only for higher consumption levels. It is interesting to highlight that water tariff for commercial and industrial uses will increase by 82 % [9, 10].

Supposing to use the tariffs imposed for high water and electricity consumption for residential Emiratis, the following references have been considered: 1.89 AED/m^3 water consumption cost and 0.055 AED/kWh electricity cost. Even if there are not available data about government support in these cases, a minimum percentage support was assumed to be maintained (respectively 55% and 79%). Therefore, the overall cost of water was supposed to be 9 AED/m^3. In any case, the calculations can be revisited, considering more appropriate and updated rates.

The consumption of the integrated system (air conditioning and drinking water production), as well as the typical system, is represented by electrical energy consumed by chillers, pumps and fans. The energy consumption and costs that must be sustained on a daily basis have been calculated (Table 2), referring only to the parts that differ both systems, since the common ones do not contribute to variations in the cost differences. The estimated hotel water consumption is 150 m^3/day.

Table 2 – Economic analysis

	Energy [kWh/day]	Condensate [m^3/day]	Water consumption [m3/day]	Energy cost [AED/day]		Water cost [AED/day]		Total cost [AED/day]	
				End user	Gov.supp. (55%)	End user	Gov.supp. (79%)	End user	Government
TS Total	37956	77.36	150*	2088	2551	284	1067	2371	3618
IS Total	42060	84.6	65.4	2313	2827	124	465	2437	3292
Difference IS/TS	4104		-84.6	226	276	-160	-602	65.8	-325.6
Sum				501.6 (extracost)		761.4 (saving)		+3%	-9%
*TS doesn't reuse condensate				259.8 (net saving)					

It is necessary to observe that the integrated plant produces water (it is optimized to this aim), as well as air conditioning. Even the typical plant produces a significant amount of condensate water, but in general, it is wasted. The integrated system water production is about 56.4% of the whole water daily hotel demand.

As can be seen, for both figures involved, the expense is not at all negligible. The cost difference for the whole HVAC systems + water is slightly higher for the end user but significantly lower for the government.

The results lead to additional observations:

(1) For the Government, it might be interesting to stimulate the autonomous production of drinking water. In particular, the achievable savings may be used to finance the extra costs of the integrated plant, or a review of the current economic support can be considered.

(2) The autonomous production of drinking water could be more attractive to the end user if the application of the integrated system could be considered as revamping of an existing typical plant, in order to achieve energy savings and water production, even if more detailed calculations must be performed to take into account that the TS doesn't work continuously. In the milder months, the control system will modulate the delivered power, resulting in less production of condensate water.

(3) Referring to the net saving cost, the overall cost of water is reduced by 19%. It is important to highlight that other costs must be considered in order to obtain drinking water due to water treatments, such as filtration. If a basic water treatment is considered with a cost of 1.14 AED/m^3, the overall cost reduction for drinking water becomes 7%. A Government control should guarantee water quality analysis.

(4) In a further development of calculations, the outdoor conditions variability must be considered: the energy consumption of both real plant solutions may be appreciably different from those calculated.

(5) The chiller has been designed to operate at full load, regardless of external weather conditions, to obtain the maximum water production.

(6) The use of this type of plant on a large scale could have positive effects from the environmental point of view.

Conclusions

The comparison analysis of two HVAC systems is presented: a typical one and an integrated one with the main aim of producing drinking water and contemporarily using the cooled air for refrigeration. A case study represented by a hotel placed in Abu Dhabi is considered to demonstrate the advantages of the system optimized for producing water from air. By the comparison between the two systems, it can be highlighted that the integrated system produces water and guarantees air conditioning with a global cost reduction for the HVAC system energy and the water supply of 7-19%, referring to the local rates.

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