Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 55(3) (2023) 67-70
DOI: 10.22060/mej.2023.21864.7525

Techno-economic feasibility study of using heat pipe heat exchanger to improve dehumidification in air-handling unit

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ABSTRACT: Techno-economic feasibility study of using wrap around heat pipe heat exchanger (WAHP) to improve dehumidification in air-handling units (AHU) was carried out. Hot and humid climate conditions of north of Iran were applied. Two types of buildings, i.e. with 100% and 25% fresh air were studied. Coupled calculations of cooling coil and WAHP are presented. Corresponding results were validated with outputs of a software belonged to a reputable WAHP manufacturer. Performances of WAHP-AHU and conventional AHU are compared. For economic analyses, two scenarios are considered; first, WAHP is installed as a part of a brand new AHU in the factory. Second, WAHP is installed as a retrofit on an existing an under-operation AHU. Results show that 5% and 25% of electricity savings are obtained by using WAHP on AHU of buildings with 100% and 25% fresh air, respectively. Also, regardless of energy consumption, the brand new WAHP-AHU is more than 20% cheaper than the conventional AHU. For energy tariffs, there are two perspectives: a consumer perspective (with subsidies) and a governmental perspective (including no subsidy). From the governmental perspective, adding a WAHP to under-operation AHUs is profitable, i.e. an IRR of 45% and a 5 years investment return is achievable.

Review History:

Received: Oct. 17, 2022
Revised: Feb. 08, 2023
Accepted: Mar. 06, 2023
Available Online: Apr. 11, 2023

Keywords:

Heat pipe
air-handling unit
dehumidification
feasibility study
heat exchanger

1- Introduction

In hot and humid climates it is essential to dehumidify the conditioned air significantly, otherwise, not only the occupant's comfort and health conditions are violated but also the building material and the accommodated electrical and mechanical apparatuses are exposed to the risk of damage. In order to enhance air dehumidification in buildings equipped with air handling units (AHU), in a conventional approach, the air flow is highly cooled, using larger cooling coils, to increase condensation. Consequently, the air temperature falls below the acceptable range, therefore, a reheat coil must warm the air flow again. An alternative approach is application of a wrap-around heat pipe heat exchanger (WAHP). Its evaporator section located before the cooling coil precools the air flow and its condenser section located after the coil reheats the air flow. Many studies have been done in the field of simulation, design, construction and utilization of heat pipe heat exchangers [1-3]. Also, many researches have been done on the application of them to enhance air flow dehumidification in AHU [4-7]. In this article, the design calculations related to the direct expansion (DX) cooling coil and WAHP used in AHU, as well as the energy saving calculations and economic evaluation, are presented. That way, techno-economic feasibility of utilizing WAHP is studied.

2- Methodology

Coil and WAHP calculations

In this subsection, first, the temperature and humidity conditions inside and outside of the building are specified. Then, heat and mass transfer and energy balance calculations related to WAHP coupled with the DX cooling coil are presented. Results are also compared on the psychrometric chart.

Validation

To validate the calculations, the corresponding results were compared with the results of a software of a manufacturer of WAHP. Compared data include temperature and humidity ratio before and after DX coil and WAHP, WAHP effectiveness and WAHP heat transfer rate. Such a comparison for the case of 25% fresh air is presented in table 1. As shown in table 1, a very good agreement was observed between the results of this work and the software outputs.

Energy saving

The amount of energy consumption of AHU in conventional method and that with WAHP are calculated and compared.

Considering that the use of WAHP is proposed as an alternative to the conventional method, therefore, comparing the energy consumption of these two modes can be a decisive criterion in choosing the appropriate method. In order to

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Table 1. Comparison of calculation results and the software outputs for WAHP-AHU with 25% fresh air

	ε_{WAHP}	q_{WAHP} (kW)	ω_4	T_4
calculations	0.33	36.7	0.007	15.3
software	0.31	36	0.007	14.9

calculate energy consumption, two different applications are considered: 100% fresh air, e.g. in a hospital, and 25% fresh air, e.g. for a restaurant. All calculations are done for buildings with 3000 m^3 of space. Assuming that the height of the floor to the ceiling is about three meters, the area is about 1000 m^2. Regarding the application of a restaurant, this size is reasonable, however, for a hospital that is very small. For a hospital for example with 10000 m^2, the amount of energy consumed can be considered 10 times of what is calculated here.

Economic analysis

Considering the price of energy in Iran and based on the cost of fabrication a brand new AHU as well as fabricating and installing a WAHP on an under-operation AHU, economic analyses based on internal rate of return (IRR) and net present value (NPV) are performed. It is obvious that for the price of energy, both consumer's point of view (including subsidies) and the government's point of view (real price) should be considered.

3- Results and Discussion

Calculations related to DX coil and WAHP were performed for different geometry specifications (including number of rows and number of fins per inch) and different DX coil surface temperatures. Finally, the selected set of characteristics for the coil and WAHP, as well as the temperature and humidity conditions of the outlet and the heat transfer rate of the WAHP is determined as shown in Table 2. In the conventional AHU, usually two middle-sized DX coils are used instead of a very big DX coil. The different points in the air flow path for the conventional AHU are 1', 2', 3' and 4' which represent positions at DX #1 inlet, between DX #1 and DX #2, DX #2 outlet (i.e. reheat oil inlet) and reheat coil outlet, respectively. Also in the WAHP-AHU, points 1, 2, 3 and 4 respectively represent the WAHP evaporator inlet, between evaporator and DX coil, after DX coil (i.e. WAHP condenser inlet), and condenser outlet. The conditions corresponding to these points are demonstrated on the psychrometric chart in figure 1. As can be seen, replacing the cooling coil number two and the reheating coil with WAHP resulted in the outlet air with almost the same conditions (points 4 and 4'), while the amount of energy required to cool it (enthalpy difference from point 2 to 3) is less than the amount of energy required for cooling in the conventional method (enthalpy difference from point 1' to point 3').

Table 2. selected DX coil and WAHP properties

DX coil	**evap. Temp.**	**6.5**
	V (ft/min)	526
	number of rows	6
	number of tubes per row	38
	fin per inch	12
WAHP	number of rows	2
	number of tubes per row	38
	fin per inch	14
	w1	0.01213
	T1	26.7
	w2	0.01213
	T2	21
	w3	0.00726
	T3	9.6
outputs	*w4*	0.00726
	T4	15.3
	RH 4	68%
	WAHP heat rate (kW)	36.7

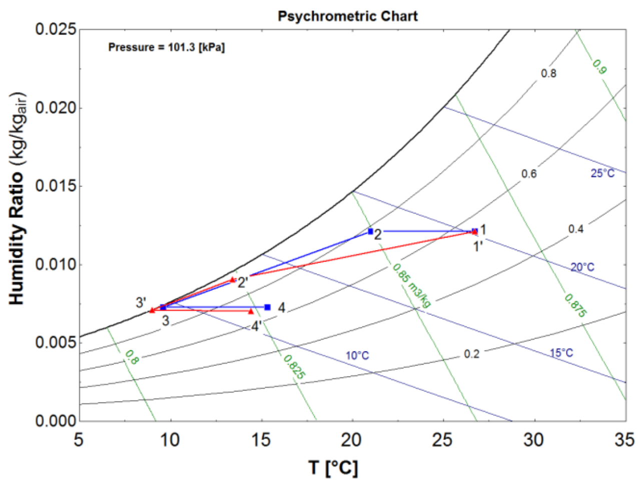

Fig. 1. variation of air flow conditions while flowing in conventional AHU (1'-4') and WAHP-AHU (1-4)

4- Conclusions

In this article, a techno-economic feasibility study of the use of WAHP dehumidification booster on AHU was performed. Heat and mass transfer relations were formulated and the calculations results were validated with outputs of a software belonged to one of the world's largest WAHP manufacturers. Also, energy conservation and economic savings calculations for the weather conditions of north of Iran were carried out.

Based on the results of energy saving calculations, using

WAHP in an AHU with 25% fresh air reduces electricity consumption by 25%, while in an AHU with 100% fresh air, electricity consumption is reduced by only 5%.

According to the economic analyses, it can be concluded that the use of WAHP as a retrofit for under-operation AHUs is cost-effective only from the government's point of view, in which no energy subsidy is allocated. However, due to the fact that the cost of a brand new AHU equipped with WAHP is lower than that for a conventional brand new AHU, regardless of energy saving issues, the use of heat pipe technology in this case is also cost-effective for the consumer.

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HOW TO CITE THIS ARTICLE

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