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Energy efficiency assessment of a combined evaporative cooling system

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ABSTRACT: Currently, household air conditioners used in air cooling and humidification systems in buildings consume a large amount of electricity and increase the specific energy consumption of the system. In order to reduce energy consumption in cooling buildings, a combined evaporative cooling system that operates entirely on solar energy, is environmentally friendly, inexpensive and easy to operate. When the proposed system is implemented in the air cooling and humidification system of a residential building with an area of 12 m^2, 1368 kWh of electricity and 168.3 kg of conventional fuel are saved per cooling season.

KEYWORDS: evaporative cooling, temperature, relative humidity, outdoor air, cold water, air volume

I. INTRODUCTION

The increasing global energy consumption is leading to a depletion of available energy resources and a significant increase in environmental impact. Over the past two decades, primary energy consumption in the world has increased by 49% and carbon dioxide emissions by 43% [1]. Also, over the past few decades, energy consumption in building cooling and air conditioning systems has increased dramatically worldwide, which further exacerbates the problems associated with the depletion of energy resources and global warming. These problems can be solved by saving energy in building cooling and air conditioning systems. In this regard, the use of evaporative cooling systems in buildings is one of the urgent issues.

The energy saving issues related to evaporative cooling system (ECS) have been studied by many researchers. Moien and Ghassem [2] conducted a study on improving the efficiency of ECS. They stated that a multi-stage system is more efficient and economical than a two-stage system, and it was found that the energy saving potential of the multi-stage system is 79% higher. Ebrahim [3] used ECS to improve the efficiency of a window-mounted condenser. According to the results, the new system reduced energy consumption by 16% and increased the COP by 55%. Maheshwari and Al-Ragom [4] tested a ECS with an air flow rate of 1180 l/s in field conditions. The study compared the cooling performance and energy consumption of ECS and a similar-sized domestic air conditioner powered by electricity. According to their results, ECS saved 12418 kWh of electricity over one season compared to the domestic air conditioner. Heidarinejad et al. [5] studied a two-stage ECS used in different climatic regions of Iran, focusing on thermal comfort, energy saving, and water consumption. The results showed that ECS achieved energy savings of up to 60% compared to a conventional mechanical steam compressor system of the same capacity, but the system had a 55% higher water consumption.

Delfani et al. [6] conducted a study on ECS for commercial and residential premises. The lowest temperature obtained using ECS was 14.7°C, and the average temperature was 17.7°C. The wet bulb efficiency ranged from 93 to 106%, and the saturation point efficiency ranged from 65 to 83%. The annual energy savings reached 55 to 60%. Khandelwal et al. [7] studied energy savings in buildings using regenerative ECS. According to their results, the energy savings potential was up to 15.69%, compared to 12.05% for conventional ECS. El-Dessouky et al. [8] developed a membrane air dryer and combined it with a conventional ECS. The dryer serves to dry the air passing through the ECS. They achieved up to 50% electricity savings when combining the system with a mechanical vapor compression system. As can be seen from the above analysis, the energy, environmental and economic efficiencies of implementing a ECS have not been evaluated. Taking this into account, this dissertation study evaluated the energy, environmental and economic efficiencies of implementing a ECS in residential buildings.

II. MATERIALS AND METHODS

The amount of energy saved as a result of the introduction of the combined ECS (CECS) was estimated based on the conditional fuel saved [9]:

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$$B = \frac{3{,}6Q_{CECS}}{Q_l^W \eta_b} \quad (1)$$

where Q_{CECS}-the amount of energy saved when implementing CECS, kWh/year (MJ/year); Q_l^W-the lower combustion heat of the fuel in the working mass (29.31 MJ/year); η_b-the FEC of the boiler plant (usually taken to be 0.55...0.75).

The energy savings achieved by implementing CECS in the experimental house were determined as follows, with the typical day of August 18, 2024, selected. The results of the daily changes in outdoor temperature and relative humidity, as well as solar radiation intensity on August 18, 2024, are shown in Fig. 1.

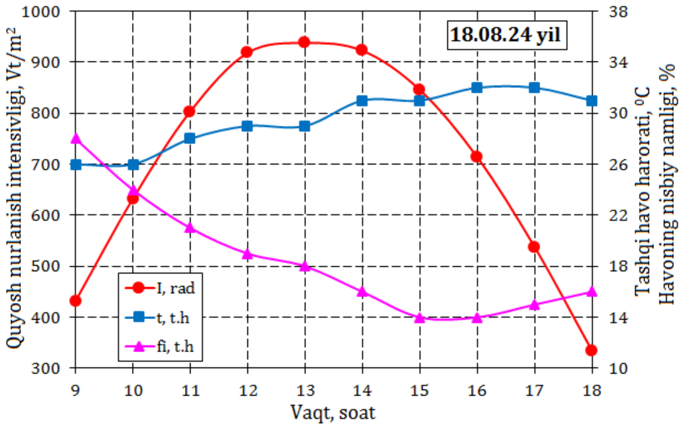

Fig. 1. Daily changes in outdoor temperature, relative humidity, and solar radiation intensity.

According to the results in Fig. 1 above, on August 18, 2024, between 9^{00} and 18^{00}, the outdoor air temperature varied between 26...32°C, the relative humidity between 14...28%, and the solar radiation intensity between 334.6...937.7 W/m^2.

III. RESULTS AND DISCUSSION

The heat load was determined when the windows and doors of the experimental house were not covered with curtains and when they were, and the calculation results are presented in Table 1.

Table 1. Thermal load of the experimental house

Time	$t_{o.a}$	Q_w	Q_c	Q_s	Q_i	Q_{gen}
9	26,0	0,05	0,04	0,31	0,07	0,48
10	27,0	0,08	0,06	0,43	0,11	0,68
11	28,0	0,11	0,08	0,45	0,15	0,78
12	29,0	0,13	0,10	0,47	0,18	0,89
13	29,0	0,13	0,10	0,47	0,18	0,89
14	31,0	0,19	0,14	0,51	0,26	1,10
15	31,0	0,19	0,14	0,51	0,26	1,10
16	32,0	0,22	0,16	0,53	0,30	1,20
17	32,0	0,22	0,16	0,53	0,30	1,20
18	31,0	0,19	0,14	0,51	0,26	1,10
Total, kW:		**1,51**	**1,12**	**4,71**	**2,08**	**9,42**

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According to the results in Table 1, the total heat load of the experimental house on August 18 was 9.42 kW, and the values that make up this load are as follows: 3.42 kW through the wall, 1.10 kW through the ceiling, 4.79 kW through solar radiation, and 2.04 kW through infiltration.

On this day, the cold air efficiency of the ECS was determined to eliminate the heat load that occurred in the experimental house, and the results obtained are presented in Table 2.

Table 2. Consumption of cooling and exhaust air to the experimental house

Time	$V_{c.a}$	$V_{h.a}$
9	228,2	195,8
10	281,5	249,1
11	246,3	213,9
12	222,2	189,8
13	205,5	173,1
14	244,5	212,1
15	236,0	203,6
16	249,8	217,4
17	249,8	217,4
18	228,0	195,6
Total, m^3/h:	**2391,7**	**2067,7**

According to Table 3, to maintain the room temperature at 24℃, the cooling air consumption varied between 205.5...281.5 m^3/h, and a total of 2391.7 m^3/h of cooling air was required. The exhaust air consumption varied between 173.1...249.1 m^3/h, and a total of 2067.7 m^3/h of hot air was exhausted. The results of the cooling efficiency, cooling capacity, cooling water consumption, and COP values of the ECS, which provides the necessary cooling air to eliminate excess heat in the experimental house, are presented in Table 3.

Table 3. ECS parameter value

Time	$t_{a.i}$, ℃	$\varphi_{a.i}$, %	$\varphi_{a.o}$, %	$W_{c.w}, kg/h$	Q_{ECS}, kW	ε_{ECS}	COP
9	26	28	40,6	0,3	0,15	35,71	0,57
10	26	24	39,9	0,6	0,28	40,65	1,05
11	28	21	40,1	0,6	0,32	45,11	1,22
12	29	19	41,3	0,6	0,36	49,65	1,37
13	29	18	39,9	0,6	0,33	48,95	1,27
14	31	16	44,6	0,9	0,55	57,69	2,10
15	31	14	41,4	0,9	0,53	55,90	2,03
16	32	14	45,1	1,1	0,65	60,61	2,44
17	32	15	46,7	1,1	0,65	61,35	2,44
18	31	16	44,6	0,9	0,52	57,69	1,96

The calculations were performed at an air temperature of 24℃ inside the experimental house. According to the calculation results, the relative humidity of the air at the outlet was 39.9...46.7%, the amount of cooling water was 0.3...1.1 kg/h, the cooling capacity of the ECS varied between 0.15...0.65 kW, the cooling efficiency was 35.71...61.35%, and the COP value was 0.57...2.44. According to the analysis results, 7.6 kg of cooling water is required to ensure comfortable climatic conditions in the experimental house with an area of 12 m^2 and a volume of 32.4 m^3, if the doors and windows are not covered with curtains. In this case, the COP value of the BST is on average 1.65, and with a total heat load of 9.42 kW, the total cooling capacity of the BST is 4.34 kW and the average cooling efficiency is 51.33%. The electrical power generated by the FEM is 3.52 kWh, and the energy supply of the ECS is completely covered by the solar FEM and an additional 0.98 kWh of energy is stored in the battery. Based on this stored energy, it was determined that there is a possibility of using the KBST for an additional 2 hours.

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Vol. 12, Issue 3, March 2025

To determine the need for air conditioning in residential buildings in the climatic conditions of the city of Karshi, the average temperature values over the last decade are shown in Fig. 2.

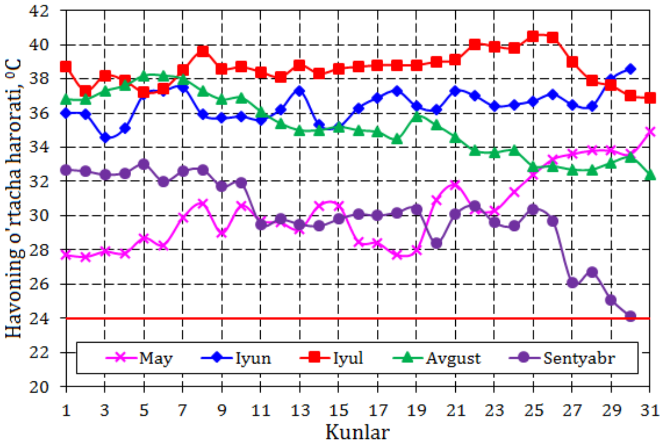

Fig. 2. Average air temperature over the last decade (2015-2024)

According to Fig. 2 above, there is a heat load from May 1 to September 29 (152 days), and if we assume an average daily heat load of 9 kW, then the amount of energy saved is as follows (Table 4).

Table 4. Energy efficiency indicators of the KBST

Naming	Months					Total
	V	VI	VII	VIII	IX	
Number of days	31	30	31	31	29	152
Amount of energy saved, kWh	279	270	279	279	261	1368
Conditional fuel saved, kg c.f.	34,32	33,21	34,32	34,32	32,1	168,3

Therefore, based on the implementation of the proposed CECS, there is a potential to save 1368 kWh of electricity or 168.3 kg c.f. cooling season.

IV. CONCLUSION

It was determined that the total heat load of the experimental house on August 18, 2024 was 9.42 kW, and 7.6 kg of water was required to cool 2391.7 m^3/h of air, and that the total cooling capacity of the BST was 4.34 kW, the average cooling efficiency was 51.33%, and the average COP value was 1.65.

It was determined that in the climatic conditions of the city of Karshi, one cooling season lasts 152 days, and a total of 1368 kWh of electricity or 168.3 kg. c.f is saved during one season of operation of the CECS.

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