

**ENERGETIC PERFORMANCE ASSESSMENT OF A COMBINED EVAPORATIVE COOLING SYSTEM FOR RESIDENTIAL BUILDINGS IN HOT AND DRY CLIMATE CONDITIONS****Ibragimov Umidjon Khikmatullayevich**

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**Abstract.** This study evaluates the energetic performance of a combined evaporative cooling system (CECS) implemented in a residential building under the climatic conditions of Karshi city. The system performance was analyzed based on cooling load assessment and airflow balance calculations for a representative summer day. The experimental results showed a maximum cooling load of 9.42 kW, with system cooling effectiveness reaching 61.35% and a COP of up to 2.44. Seasonal analysis indicated electricity savings of 1368 kWh, equivalent to 168.3 kg of standard fuel, over a 152-day cooling period. The findings confirm the energy-saving potential of CECS in hot and dry climates.

**Keywords:** combined evaporative cooling system; energy efficiency; residential buildings; cooling load; coefficient of performance (COP); standard fuel savings; sustainable cooling technologies; hot climate conditions.

**Introduction.** Global growth in energy consumption has led to the depletion of existing energy resources and a significant increase in environmental impacts. Over the past two decades, worldwide primary energy consumption has increased by 49%, while carbon dioxide ( $CO_2$ ) emissions have risen by 43% [1]. In parallel, energy demand for space cooling and air-conditioning systems in buildings has grown sharply in recent decades. This trend has further accelerated the depletion of energy reserves and intensified challenges associated with global climate change. Addressing these issues requires the implementation of energy-efficient solutions in building cooling and air-conditioning systems. From this perspective, the application of evaporative cooling technologies in buildings represents a promising and increasingly relevant approach for reducing energy consumption and mitigating environmental impacts [2]. Energy efficiency issues associated with evaporative cooling systems (ECS) have been extensively investigated by numerous researchers. Moien and Ghassemlar [3] examined approaches to enhance ECS performance. Their findings indicate that multi-stage configurations are more efficient and cost-effective than two-stage systems, with the multi-stage design demonstrating up to 79% higher energy-saving potential. Ebrahim [4] integrated an ECS with a window-mounted air-conditioning condenser to improve its thermal performance. The results showed that the proposed system reduced energy consumption by 16% and increased the coefficient of performance (COP) by 55%. Maheshwari and Al-Ragom [5] conducted field experiments on an ECS with an airflow capacity of 1180 L/s. The cooling capacity and energy consumption of the ECS were compared with those of a conventional electrically driven local air-conditioning unit of similar size. Their results revealed that, over a single cooling season, the ECS achieved electricity savings of 12,418 kWh compared to the conventional unit. Heidarinejad et al. [6] investigated a two-stage ECS operating under various climatic conditions in Iran, focusing on thermal comfort, energy savings, and water consumption. The study demonstrated that,

compared with a conventional vapor-compression air-conditioning system of equivalent capacity, the ECS achieved up to 60% energy savings. However, water consumption in the ECS was found to be approximately 55% higher. Delfani et al. [7] conducted an experimental investigation of an evaporative cooling system (ECS) for commercial and residential spaces. The minimum air temperature achieved by the ECS was 14.7°C, while the average temperature was 17.7°C. The wet-bulb effectiveness ranged from 93% to 106%, whereas the dew-point effectiveness varied between 65% and 83%. The reported annual energy savings reached 55-60%. Khandelwal et al. [8] examined the potential of a regenerative evaporative cooling system for building energy conservation. Their results indicated that the maximum energy-saving potential of the regenerative ECS reached 15.69%, compared to 12.05% for a conventional ECS. El-Dessouky et al. [9] developed a membrane-based air dehumidification system integrated with a conventional ECS. The membrane dehumidifier was used to remove moisture from the air stream prior to evaporative cooling. When the proposed system was combined with a mechanical vapor compression unit, electricity savings of up to 50% were achieved. The above-reviewed studies demonstrate the significant energy-saving potential of evaporative cooling technologies. However, the comprehensive assessment of the energetic, environmental, and economic performance of a combined evaporative cooling system (CECS) has not been sufficiently addressed in the existing literature. Considering this research gap, the present study evaluates the energetic, environmental, and economic performance of implementing a CECS in residential buildings.

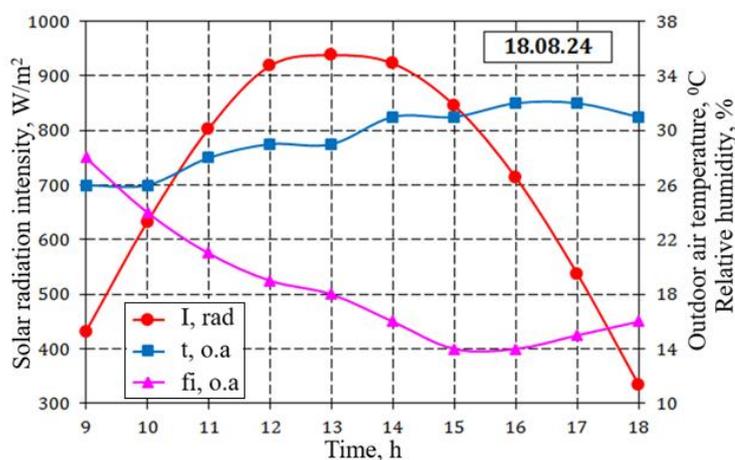
### Results and discussion.

The energy savings achieved through the implementation of the combined evaporative cooling system (CECS) were quantified based on the equivalent standard fuel savings methodology [10]:

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

where,  $Q_{CECS}$  represents the annual energy savings achieved through the implementation of the CECS, expressed in  $kWh/year$  (or  $MJ/year$ );  $Q_L^{HV}$  denotes the lower heating value (LHV) of the standard fuel on a working mass basis ( $29.31 MJ/kg$ ), and  $\eta_b$  is the efficiency of the boiler unit, typically assumed within the range of 0.55-0.75.

The estimation of the energy savings achieved by implementing the CECS in the experimental house was carried out using a representative climatic day, namely August 18, 2024. The diurnal variations of outdoor air temperature, relative humidity, and solar radiation intensity on that day are presented in Figure 1.



### Figure 1. Diurnal variation of outdoor air temperature, relative humidity, and solar radiation intensity

According to the results presented in Figure 1, on August 18, 2024, between 09:00 and 18:00, the outdoor air temperature varied within the range of 26-32°C, relative humidity ranged from 14% to 28%, and solar radiation intensity fluctuated between 334.6 and 937.7  $W/m^2$ . The cooling load of the experimental house was determined, and the calculation results are presented in Table 1. According to the data in Table 1, on August 18 the total cooling load of the experimental house was 9.42 kW. The contributions to this load were 3.42 kW through the walls, 1.10 kW through the roof, 4.79 kW due to solar radiation, and 2.04 kW due to air infiltration. To offset the cooling load generated in the experimental house on this day, the required cooling capacity of the ECS in terms of supplied cooled air was determined. The corresponding results are presented in Table 2. According to Table 2, in order to maintain the indoor air temperature at 24°C on August 18, the supply airflow rate varied between 205.5 and 281.5  $m^3/h$ , with a total required supply airflow of 2391.7  $m^3/h$ . The exhaust airflow rate ranged from 173.1 to 249.1  $m^3/h$ , resulting in a total discharged airflow of 2067.7  $m^3/h$ . The performance parameters of the ECS, including cooling effectiveness, cooling capacity, cooling water consumption, and COP, required to offset the excess heat load in the experimental house are presented in Table 3.

**Table 1. Cooling load of the experimental house**

Vaqt	$t_{amb}$	$Q_w$	$Q_c$	$Q_s$	$Q_i$	$Q_{tot}$
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
<b>Total:</b>		<b>1,51</b>	<b>1,12</b>	<b>4,71</b>	<b>2,08</b>	<b>9,42</b>

**Table 2. Supply and exhaust airflow rates of the experimental house**

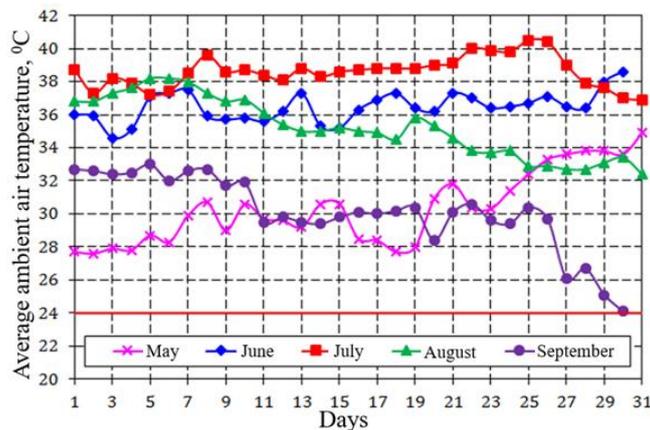
Time	$V_{ca}$	$V_{oa}$
9	228,2	195,8
10	281,5	249,1

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
<b>Total</b> :	<b>2391,7</b>	<b>2067,7</b>

Table 3. Performance parameters of the ECS

e	Tim	$t_{im}$ °C	$\varphi_{im}$ %	$\varphi_{oub}$ %	$W_w$ kg/h	$Q_{ECS}$ kVt	$\varepsilon_{ECS}$	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 assuming an indoor air temperature of 24°C in the experimental house. According to the results obtained for August 18, the outlet air relative humidity ranged from 39.9% to 46.7%, while the cooling water consumption varied between 0.3 and 1.1 kg/h. The cooling capacity of the ECS ranged from 0.15 to 0.65 kW, the cooling effectiveness varied between 35.71% and 61.35%, and the COP ranged from 0.57 to 2.44. To assess the demand for air-conditioning in residential buildings under the climatic conditions of Karshi city, the average ambient temperature values over the past decade are presented in Figure 2.



**Figure 2. Average ambient air temperature over the last decade (2015–2024)**

As shown in Figure 2, a cooling demand is observed from May 1 to September 29 (152 days). Assuming an average daily cooling load of 9 *kW*, the total energy savings achieved through the implementation of the CECS were calculated, and the results are summarized in Table 4.

**Table 4. Energy performance indicators of the CECS**

Description	Month					Total
	V	VI	VII	VIII	IX	
Number of days	31	30	31	31	29	152
Energy savings, <i>kWh</i>	279	270	279	279	261	1368
Equivalent standard fuel savings, <i>kg</i>	34,32	33,21	34,32	34,32	32,1	168,3

Therefore, the implementation of the proposed CECS makes it possible to save 1368 *kWh* of electricity, equivalent to 168.3 *kg* of standard fuel, during a single cooling season.

**Conclusions.** The present study confirms the technical and energetic feasibility of implementing a combined evaporative cooling system (CECS) in residential buildings under hot climatic conditions.

First, the experimental analysis showed that the total cooling load of the building reached 9.42 *kW* on the representative summer day, with solar radiation accounting for the dominant share of the heat gain.

Second, the evaporative cooling system achieved a cooling capacity of up to 0.65 *kW*, with cooling effectiveness reaching 61.35% and a maximum COP of 2.44, demonstrating stable and efficient operational performance.

Third, seasonal evaluation revealed that the proposed CECS can save 1368 *kWh* of electricity during a 152-day cooling season, equivalent to 168.3 *kg* of standard fuel, highlighting its substantial energy-saving potential.

Overall, the obtained results demonstrate that the CECS represents an effective and energy-efficient solution for reducing electricity consumption in residential buildings located in hot and dry climates.

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