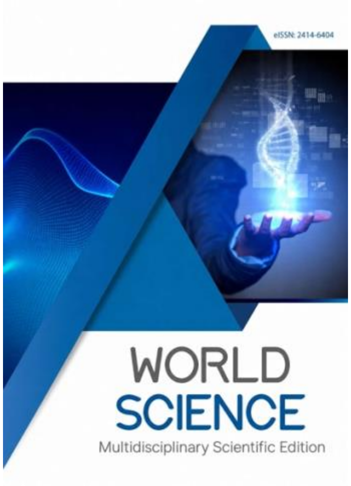

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EXPERIMENTAL RESULTS OF AIR-TO-WATER HEAT PUMP APPLICATION IN A HEATING SYSTEM

Damdin Batkhuyag
Master student, Mongolian University of Life Sciences, Ulaanbaatar, Mongolia

Baatarkhuu Dorjsuren
Ph.D, Associate Professor, School of Engineering and Technology, Mongolian University of Life Sciences, Ulaanbaatar, Mongolia

Munkh-Erdene Bat-Erdene
M.Sc, Lecturer, School of Engineering and Technology, Mongolian University of Life Sciences, Ulaanbaatar, Mongolia

Ganbold Dagvadorj
Ph.D, Senior Lecturer, School of Engineering and Technology, Mongolian University of Life Sciences, Ulaanbaatar, Mongolia

Amgalanzul Jargalsaikhan
Ph.D, Senior Lecturer, School of Engineering and Technology, Mongolian University of Life Sciences, Ulaanbaatar, Mongolia
ORCID ID: 0000-0003-1739-474X

ABSTRACT

This study aims to determine the feasibility, efficiency, and performance of utilizing an air-to-water heat pump (AWHP) within a space heating system under the harsh continental climatic conditions of Mongolia. For the field experiment, an F-015 model AWHP was integrated into a single-family residential house located in the Songinokhairkhan district of Ulaanbaatar, featuring a total floor area of 48.8m2 and a calculated peak thermal load of 4.29kW. Continuous data collection was conducted in March 2026 utilizing a cloud-based Smart Data Logger system monitoring parameters at 1-minute intervals. During the experimental period, the ambient outdoor temperature fluctuated within the range of -6.47...10.380C. Under these conditions, the thermal capacity generated by the heat pump ranged from 3.54 to 5.07kW, while the corresponding electrical power consumption varied between 1.16 and 1.25kW. Mathematical and statistical analysis of the experimental dataset revealed that the Coefficient of Performance (COP) of the heat pump fluctuated between 2.98 and 4.14 as a direct function of the outdoor air temperature. The system demonstrated highly stable operation with a low coefficient of variation (V = 8.84%). The findings confirm that AWHP systems operate reliably under moderate winter-to-spring transitional conditions and present a viable alternative to traditional coal-fired heating methods in cold regions.

KEYWORDS

Coefficient of Performance (COP), Electrical Power, Thermal Energy, Refrigerant

CITATION

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Introduction

Within the strategic framework of Mongolia's long-term development policy, "Vision-2050," the reduction of greenhouse gas emissions, mitigation of air pollution, and enforcement of energy efficiency require the urgent deployment of advanced, highly efficient renewable energy technologies to replace traditional carbon-intensive coal-based heating solutions (Government of Mongolia 2020). Investigating the practical feasibility, operational efficiency, and environmental impacts of air-to-water heat pumps (AWHPs) through empirical field testing under Mongolia's extreme climate is highly consistent with these national strategic goals (Tsolmon N. 2025).

Although air-to-water and water-to-water heat pump systems have been progressively introduced to Mongolia's decentralized heat supply sector since 2010, historical theoretical studies suggested that AWHPs cannot fully sustain the heating load of buildings independently throughout the entire duration of the prolonged heating season due to extreme continental drops in temperature, thus requiring bivalent or hybrid auxiliary heat sources (Tsolmon N. 2025). Prior experimental assessments indicated that when applied to standard building hydronic systems designed for supply temperatures above 50^0C, AWHPs maintain reasonable efficiency only within an outdoor temperature range of 10^0C to 12^0C, yielding a COP between 2.2 and 3.6. Globally, a vast body of literature addresses the optimization, seasonal performance factors, and low-temperature limitations of AWHP systems across regions such as the Russian Federation, the USA, the European Union, Japan, Greece, Canada, and South Korea (Dongellini, Naldi, and Morini 2015; Januševičius and Streckienė 2015; Koury et al. 2013; O'Hegarty et al. 2022; Sun et al. 2021; Wang et al. 2013). A key consensus among international researchers emphasizes that laboratory-measured COPs must be validated through empirical, real-world field evaluations to establish accurate Seasonal Performance Factors (SPF). In cold climates, ambient air temperature remains the most critical determinant of AWHP dynamics. For instance, Januševičius and Streckienė combined field measurements with TRNSYS dynamic simulations to confirm that declining outdoor temperatures severely degrade efficiency, noting that power consumption surges during cyclical frost-defrost operations (Januševičius and Streckienė 2015). Similarly, Wang et al. verified that prolonged defrost cycles substantially penalize the seasonal COP (Wang et al. 2013). While global research extensively covers capacity sizing, environmental impacts, and temperature-dependent COP variations, comprehensive empirical field testing under extreme Mongolian conditions remains insufficient. Consequently, assessing AWHP functionality in a region characterized by exceptionally long heating seasons provides critical scientific and practical insights aimed at lowering operational costs, saving fuel, and mitigating urban air pollution.

Research materials and methodology

The thermal load and space heating losses of the residential building are calculated to determine the required capacity and select the appropriate air-to-water heat pump (AWHP) unit. Following the system installation, a cloud-integrated Smart Data Logger system is deployed to record high-frequency measurements at 1-minute intervals, capturing key parameters including outdoor and indoor ambient temperatures, supply and return temperatures of the heat pump circuit, supply and return temperatures of the thermal buffer tank circuit, as well as the instantaneous electrical current and power consumption of the compressor unit.

The resulting time-series dataset is subjected to rigorous mathematical and statistical processing to identify potential outliers, evaluate dataset homogeneity, and verify conformity to normal distribution laws. Furthermore, cross-parameter correlation analysis is performed to establish statistical interdependencies between the measured variables. Based on the empirical thermodynamic and electrical data, the instantaneous and average Coefficient of Performance (COP) of the heat pump system is evaluated. The peak building heat loss and thermal load are quantified based on the geometric configurations, material properties, and layer thicknesses of the building envelope components, including external walls, windows, ceilings, and floors.

Heat dissipation from a building is characterized by two distinct pathways. Specifically, conductive heat loss through the building envelope components—including walls, windows, ceilings, and floors—is mathematically defined by the governing heat conduction equation (Namkhainyam B. 2001).

$$Q_{cond} = \sum U_\iota A_\iota (t_{in} - t_{out});\ \text{W} \tag{1}$$

Where: U_ι is the heat transfer coefficient (U-value) of the i-th building envelope component (walls, windows, ceilings, and floors), expressed in W/m^{20}C; A_ι is the heat-transmitting surface area of the i-th building envelope component (walls, windows, ceilings, and floors), expressed in m^2; $t_{in}\ and\ t_{out}$ are the design indoor and outdoor ambient air temperatures, respectively, expressed in ^{0}C

The thermal load due to air infiltration through gaps and ventilation is calculated via:

$$Q_{inf} = C_{\rho}\rho n\mathcal{V}(t_{in} - t_{out});\ \text{W} \tag{2}$$

Where: C_{ρ} – air heat capacity, $C_{\rho} = 0.33\ J/kg°C$; ρ – air density, $\rho = 1.2, \frac{kg}{m^3}$; n – air change rate per hour, $n = 0.3$; $\mathcal{V}$ – total internal volume of the building, m^3

The combined peak heat loss is expressed as:

$$Q_{total.loss} = Q_{cond} + Q_{inf};\ W \tag{3}$$

The instantaneous Coefficient of Performance (COP) of the heat pump system is defined by the ratio of generated thermal energy output to net electrical power input (Munkhbayar B. 2005):

$$COP = \frac{Q}{P} \tag{4}$$

Where: Q is the thermal energy (heat capacity) generated by the heat pump system, expressed in kW.

$$Q = c_p m\Delta T \tag{5}$$

Where: c_p is the specific heat capacity of the antifreeze solution (coolant), equal to 3151J/kg°C; m is the mass flow rate of the antifreeze solution, expressed in kg/s; ΔT is the temperature difference between the supply and return lines of the heat pump fluid circuit, expressed in °C

Results of the research

The empirical field experiment was conducted on a residential building located in the 6th sub-district (khoroo) of the Songinokhairkhan district, Ulaanbaatar. The building features a total usable floor area of 48.8m^2, an internal volume of 117.1m^3, and a calculated peak structural heat loss of 4.29kW. F-015 model AWHP was integrated into the building's hydronic heating network. Continuous measurement logs were recorded daily from March 6, 2026, to March 16, 2026.

Table 1. Measured Thermodynamic and Electrical Performance Parameters of the AWHP System

No.	HP Current (A)	HP Power (kW)	HP Outlet Temp., ^{0}C	HP Inlet Temp., ^{0}C	Outdoor Air Temp., ^{0}C	Indoor Room Temp., ^{0}C	HS Inlet Temp., ^{0}C	HS Outdoor Temp., ^{0}C	Q, kW	COP
1	5.445	1.222	45.380	43.641	-4.669	21.971	38.450	29.747	4.895	4.005
2	5.441	1.225	45.693	43.944	-5.203	21.515	38.600	29.802	4.922	4.020
3	5.408	1.221	45.510	43.774	-5.438	21.315	38.537	29.740	4.886	4.001
4	5.381	1.220	45.381	43.650	-5.783	21.028	38.405	29.633	4.871	3.995
5	5.342	1.208	44.924	43.270	-5.794	20.741	38.244	29.536	4.653	3.836
6	5.198	1.176	42.615	41.151	-6.381	20.498	36.830	28.688	4.120	3.486
7	5.180	1.175	42.616	41.099	-6.477	20.201	36.454	28.221	4.269	3.609
8	5.135	1.161	42.645	41.093	-6.144	20.104	36.287	27.998	4.366	3.736
9	5.392	1.223	44.848	43.046	-2.893	19.874	37.371	28.555	5.071	4.147
10	5.508	1.254	46.150	44.715	4.844	19.935	38.305	29.215	4.038	3.217
11	5.418	1.217	43.272	41.722	9.832	21.444	37.698	29.599	4.364	3.568
12	5.523	1.221	42.953	41.309	10.386	22.774	37.407	29.468	4.628	3.787
13	5.514	1.223	42.507	41.008	10.164	22.248	37.413	29.642	4.216	3.444
14	5.441	1.218	42.070	40.746	9.725	22.670	37.570	29.810	3.726	3.055
15	5.507	1.221	42.935	41.623	9.156	24.045	37.780	29.948	3.693	3.007
16	5.233	1.164	42.676	41.417	8.027	23.336	37.810	29.980	3.542	2.985
17	5.492	1.224	42.928	41.268	7.422	23.158	37.646	30.151	4.671	3.812
18	5.454	1.208	43.233	41.671	5.521	24.259	37.737	30.183	4.396	3.610
19	5.544	1.224	43.352	41.783	3.888	24.325	37.749	30.203	4.417	3.600
20	5.555	1.215	43.637	41.980	1.864	23.388	37.803	30.215	4.662	3.833
21	5.541	1.210	43.857	42.243	0.383	22.967	37.149	30.277	4.543	3.751
22	5.506	1.211	44.160	42.605	-1.177	23.576	38.347	30.428	4.377	3.608
23	5.510	1.210	44.160	42.605	-1.000	23.120	38.580	30.585	4.512	3.702
24	5.527	1.229	45.375	43.697	-2.859	22.817	39.045	30.747	4.720	3.834

Statistical processing of the calculated COP values yielded a coefficient of variation of V = 8.84, which is significantly below the standard threshold, indicating a highly uniform, homogeneous, and consistent performance distribution across the test intervals. Outlier analysis using critical t-testing values proved that $t_x > t_m$ did not occur abnormally, validating that the dataset contains no statistical anomalies or measurement errors.

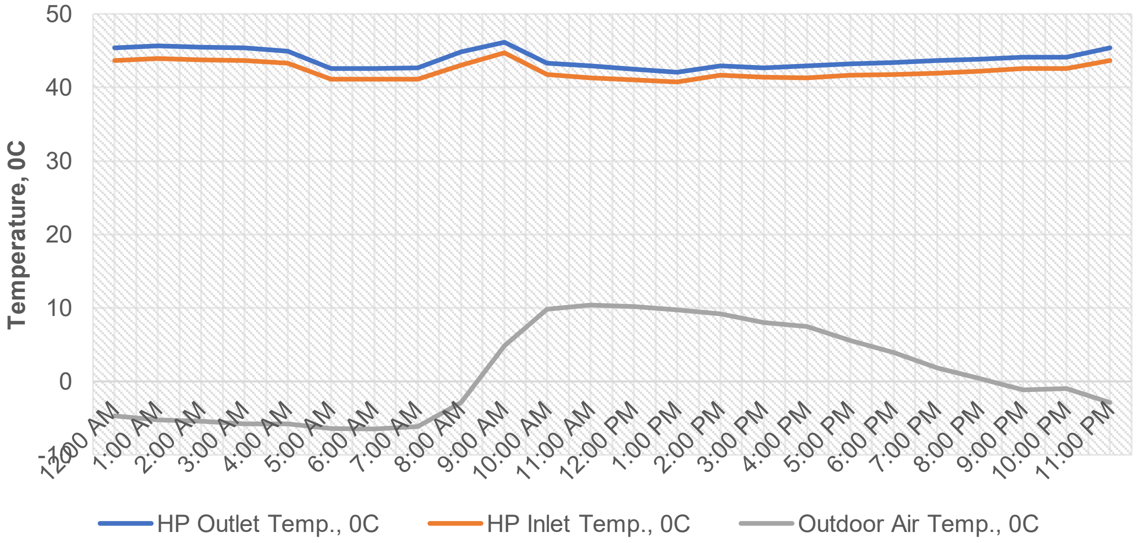

Fig. 1. *Heat pump refrigerant and ambient temperature variation*

Indoor ambient temperature sensors placed in the center of the living zone (40 cm below the ceiling) recorded an average indoor temperature of 21.5^{0}C, peaking at 24^{0}C and dropping to a minimum of 19^{0}C. This indicates excellent compliance with residential thermal comfort standards. Concurrently, shaded outdoor sensors registered a low boundary temperature of -6.47^{0}C during the March transitional cycle.

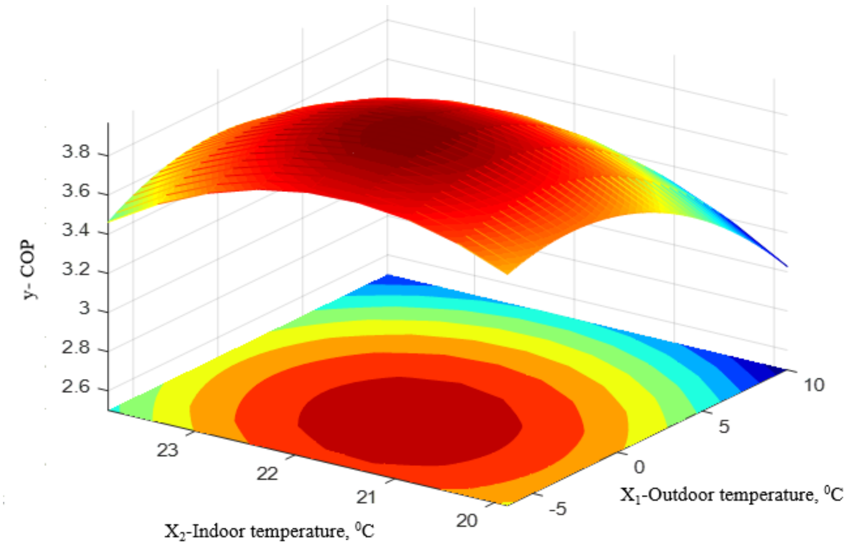

Fig. 2. *Correlation between outdoor/indoor air temperatures and COP values*

The relationship between the outdoor ambient air temperature and the heat pump coefficient of performance (COP) is illustrated in the following figure.

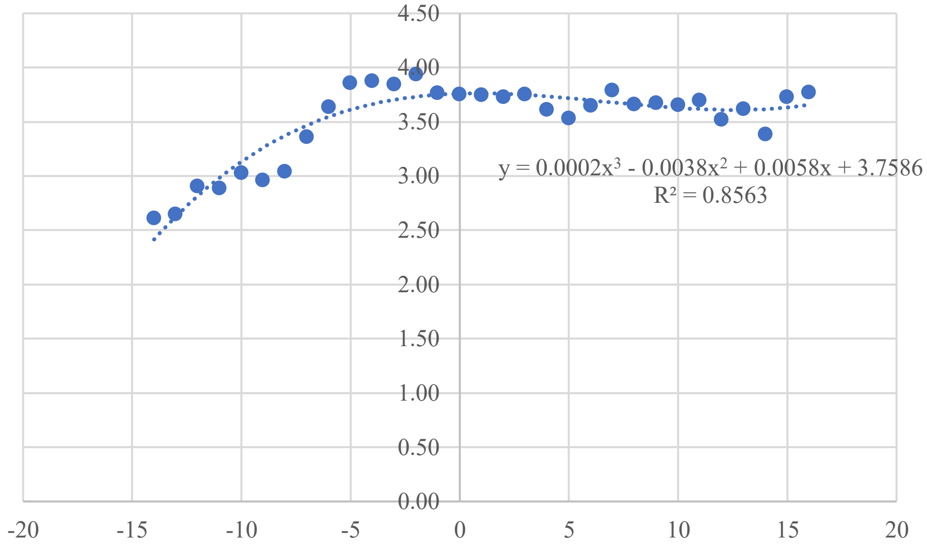

Fig. 3. *COP value as a function of outdoor air temperature*

Within the measured outdoor ambient band of -6.47^{0}C to 10.38^{0}C, the system's operational COP fluctuated between 3.007 and 4.147. A direct inverse correlation between high thermal lift requirements and the COP was observed; as ambient air temperatures dropped, the instantaneous efficiency decreased predictably due to vapor density variations and minor frost accumulation on the evaporator coils.

Conclusions

The structural and infiltration heat loss calculations for the 48.8m^2 prototype residence yielded a total design thermal load of 4.29kW. The chosen F-015 air-to-water heat pump fully satisfied the building's thermal energy requirements during the spring transitional testing window.

The system successfully maintained a stable indoor thermal environment with an average room temperature of 21.5^{0}C. Within the ambient testing envelope of -6.47^{0}C to 10.38^{0}C, the system exhibited an operational COP range of 2.98 to 4.14, demonstrating high thermodynamic efficacy under transitional conditions.

Statistical validation confirmed a low coefficient of variation (V = 8.84) for the COP data string, proving that the heat pump delivers stable, predictable, and highly uniform performance in space-heating configurations.

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