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RESEARCH ARTICLE

Modelling of evaporator and condenser temperature mathematical equation based the parametres of outdoor environment

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Abstract

This study investigates how outdoor environmental factors and wind direction influence the performance of air-source heat pumps in cooling mode. Air-source heat pumps are a critical clean-energy technology promoted by countries to address rising energy demand and reduce carbon emissions. Using the 21st model of moderated mediation analysis in SPSS Process Macro, the research found that external temperature, wind direction, and relative humidity impact the condenser's condensation temperature by 23.78%, 7.38%, and 4.20% (It has been obtained through value as an effect, rather than through an increase or decrease), respectively. The analysis also revealed negative indirect effects, with wind speed reducing the evaporator's evaporation temperature by 2.55% and outdoor temperature lowering it by 20.76%. Furthermore, wind direction decreased the evaporator temperature by 0.13%. The weather is clear, with no clouds and no precipitation. The mathematical model developed for the cooling mode provides a tool for forecasting future evaporator temperatures. This approach offers valuable insights for air-source heat pump manufacturers and for designers of condensers and evaporators, and it contributes to carbon emission reduction strategies. Although the results were derived for Istanbul, Turkey, the effect coefficients estimated from the data can be applied to other significant locations.

Keywords: Moderated mediation analysis, modelling, air heat source heat pump

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1.Introduction

Energy utilization is rising rapidly owing to increased energy demand in people's living spaces and the industrial sector. As energy use increases, carbon emissions also increase. Among the greatest challenges facing humanity today are energy deprivation and restricted access to affordable, clean energy. With energy being an essential part of our everyday lives, having access to inexpensive, safe, clean, and secure energy is an essential benchmark for evaluating our quality of life [1-2]. Countries encourage the green economy model, which strives for sustainable development without harming the environment, by providing incentives for technologies such as heat pumps that use renewable energy sources to reduce greenhouse gas emissions and the carbon footprint of products. [3]. Building-related carbon emissions and energy consumption worldwide totaled 8.8 billion tons of CO_2 and 6 billion tons of conventional coal, respectively [4]. In accordance with the Paris Agreement, which many countries have accepted, it is aimed at achieving the zero emission target with the Kyoto Protocol by supporting devices such as heat pumps that use renewable energy sources by 2050 [5]. A heat pump produced under proper design conditions can reduce carbon emissions while simultaneously enhancing energy efficiency. Air source heat pumps provide significant benefits by reducing increases in carbon emissions from residential buildings. These systems operate with high energy efficiency, consuming less electricity and thus producing lower carbon emissions. They can be combined with renewable energy sources, thereby reducing fossil fuel consumption and offering heating and cooling with zero emissions. Additionally, their low operating costs and long lifespans reduce energy consumption, further lowering the carbon footprint. Air Source Heat Pumps have gained popularity in the past decade due to their energy-efficient, environmentally-friendly, low operating expense compared to different types of pumps, manageability and different applica-

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tion location in cooling-heating systems [6]. Changes in outdoor environmental parameters affect the performance of air-to-water heat pumps. In addition, the condenser, evaporator, compressor, and other core components of the heat pump, along with the condensation temperature of the condenser and the evaporation temperature of the evaporator, are all affected by variations in the external environment, whether they are positive or negative [7].

An experimental study by Zou et al. revealed that the performance of the air-to-water source heat pump deteriorates as the outdoor temperature rises. The study also found that as the outdoor temperature increases, the air-source heat pump with a condenser requires more energy from the compressor to transfer heat to the outdoor environment. [8]. Wang et al.'s research on the operation of an air-to-water source heat pump found that higher outdoor temperatures led to increased wind speed. The research determined that elevated wind speeds, outdoor temperatures, and relative humidity levels negatively affect the heat pump's performance, making it more challenging for the condenser to release heat into the surrounding air [9]. According to an experimental study by Atmaca et al., the performance of the condenser and evaporator was enhanced at decreasing outdoor temperatures with minimal relative humidity, as well as at increased outdoor temperatures with decreasing relative humidity [10]. By analyzing the night-day and summer-winter temperature changes, Gado et al.'s study on energy-saving in heat pumps found that the compressor uses less energy in the winter than in the summer and that the heat pump's performance declines at high temperatures [11]. Din et al. created a machine-learning model to changes in variables affecting heat-pump performance by classifying input variables using K-means clustering. The machine learning model was used to create an artificial intelligence algorithm. This enables the calculation of the interactions between factors with varying values that impact the air to water source heat pump's performance (such as outdoor conditions, operating costs, etc.) [12]. A mathematical model was developed by Chung et al. by performing numerical modeling to assess the effect of relative humidity on the functioning of the heat pump. Future predictions regarding the impact of relative humidity on the air-to-water source heat pump can be made using the derived mathematical model. [13]. A drop in outdoor temperature favorably impacts heat pump performance when the source is air, according to Zhou et al.'s work on heat pump modeling. [14]. According to Bai et al.'s model study on air source heat pump performance, the performance of the air source heat pump increases at medium and low outdoor temperature values [15]. A mathematical model, including variables that affect the performance of an air-to-water heat pump, was developed as part of Uroš et al.'s research on the device. The interactions between the obtained mathematical equation and the variables have been identified, allowing for the possibility of making future predictions [16]. In the work on estimating the heat pump's (source:air) performance based on meterology data, a model of the heat pump's (source:air) was developed, and Stamatellos et al. conducted a simulation of this model. The heat pump's (source:air) performance and its foundation equipment, including the compressor, evaporator, and condenser condensation temperature, has been found to be adversely affected by an increase in the outside temperature[17]. In research on energy optimization aimed at eliminating environmental impacts, the moderated, moderation, and moderated-mediation models for the effectiveness of renewable energy sources were compared in light of parameters affecting these sources. Thus, by revealing the effects of the parameters influencing renewable energy sources on different models, it has been found that the data from the moderated mediation models are more effective in determining the actual values [18]. In research conducted by Shi et., the effect of different wind directions on a heat exchanger was modeled using FLUENT software. As an outcome of this modeling, it has been found that easterly winds raise the condenser temperature [19]. Zhu et al. developed a model to determine the effect of wind (speed and direction) on air coolers. Based on the effect values in this model, it was found that changes in wind speed and direction affect the performance of the condenser and air coolers [20].

The evaporator absorbs heat from the surrounding air. The direction of the wind either supports or hinders this process. The condenser may, depending on the circumstances, have a positive or negative impact on heat transfer from the evaporator to the refrigerant when wind direction and speed vary. This can reduce the efficiency of the evaporation process because the evaporator struggles to release heat from the system. Because the system must work harder to achieve the desired cooling effect, a negative wind direction increases energy consumption. The compressor might need to operate longer or at a higher capacity to compensate for the inefficiency caused by the reduced evaporation ratio. Since the system must work harder to achieve the desired cooling effect, a negative wind direction increases the system's energy consumption. The compressor might need to operate longer or at higher capacity to compensate for the inefficiency caused by the reduced evaporation rate. [22].

It is possible to determine when the heat pump will consume less energy by examining the impact values between the outdoor environment and its primary components. These impact values can identify areas where the air-source heat pump will operate more effectively. As a result, less power is consumed and less carbon dioxide is emitted during energy production. The effectiveness of these technologies depends on the outdoor environment. Less energy is required for heating and cooling when the heat pump operates in response to outdoor conditions. [21].

The reasons for selecting the moderated mediation analysis in the study are as follows:

Examining moderation and mediation relationships simultaneously, the moderated-mediation model is a powerful analytical method that assesses the effect of one variable (for example, outdoor temperature) on another through mediation (such as evaporator temperature) and shows how this mediation is altered by a moderator variable (for example, humidity or wind speed). In this way, the impact of external factors (like temperature and relative humidity) on the condenser and evaporator temperatures can be modeled not only directly but also by considering how these interactions change through the processes of mediation and moderation [31].

Forward-Looking Predictions and Optimization: The moderated mediation model is useful for modeling how a system responds to environmental factors and how these factors interact to produce outcomes. This allows prediction of the system's performance across external variables and identification of an optimal operating temperature range for specific conditions (such as high temperature or low relative humidity). Such predictions are highly valuable for the efficient design and management of cooling systems [31].

Detailed Examination of the Effects of External Variables: This model provides the opportunity to examine how one parameter (e.g., external ambient temperature) affects another parameter (e.g., evaporator temperature) and how this effect varies under specific conditions (e.g., when humidity is high or low). In other words, it allows more detailed modeling of the effects of external parameters, both directly and indirectly (through mediation). This is particularly critical for cooling systems where external conditions need to be adjusted [31].

Understanding the effects of outdoor environmental parameters on air-source heat pumps is a critical step in optimizing the efficiency of these systems. Variables such as relative humidity, outdoor temperature, wind speed, and seasonal variations directly affect the heat pump's energy effectiveness; therefore, analyzing these parameters correctly ensures that the system transfers more heat with less energy. This understanding allows proper system selection and adjustments, minimizing energy consumption, reducing operating costs, reducing environmental impact, and extending the lifespan of the device. As a result, considering external conditions enables the use of more efficient, sustainable, and long-lasting heat pumps, both economically and environmentally [22].

By including wind direction among the parameters influencing the performance of the heat pump (source: air), the 21st model of the moderated mediation analysis was utilized to determine the impacts of these variables on evaporator temperature values, condenser temperature values, and their mathematical equations. Its objective is to support the research of producers or developers of heat pumps (source: air) and heat exchangers (e.g., condensers and evaporators) by utilizing mathematical formulas and assessing the influence of model variables on condenser and evaporator temperature values.

A review of the literature shows that the effects of one or two external environmental conditions on the condenser and evaporator, the key components of the heat pump (source: air), have been examined. This study, however, reveals both the interactions among all outdoor conditions reported in the literature and their effects on the condenser and evaporator. Additionally, the mathematical equation describing these interactions has been derived, enabling future predictions.

2. Methodology

If technologies using clean energy are not sufficiently supported, it is forecasted that global energy utilization will go up by 55% compared to 2024 levels by 2050, with the rate expected to exceed 30% by 2030 [23]. Its goal is to lower carbon emissions and to meet the energy needs of homes, which account for the largest portion of this rise, by using clean energy technologies such as heat pumps. Due to its cost-effectiveness, ease of installation, and efficiency, the heat pump (source:air) is recommended [22]. The condenser and evaporator, the two essential parts of an heat pump (source:air-condensation and evaporation temperature), exhibit either positive or negative performance changes depending on the outdoor environment parameters (like outdoor temperature, wind speed and relative humidity) [24]. In this study, wind direction was added to the model along with outdoor temperature, relative humidity, and wind speed to examine the effect of outdoor factors on the performance of evaporator and condenser in heat pump (source:air). It is therefore intended to assist individuals or organizations that manufacture, design, or acquire an air-source heat pump.

2.1. Data and measurement collection process

In modeling, optimization, and statistical studies using the IBM SPSS Process Macro, a minimum sample size of 50 is required for a moderated moderation model. If the sample size is larger, the margin of error will inevitably decrease. The evaporator evaporation and condenser condensation temperature of the heat pump (source:air), whose project and installation have been completed, have been obtained with the sensors in the device with reference to the refrigerant [25]. The outdoor environmental parameters that impact the performance of core components of an air-source heat pump (the compressor, evaporator, and condenser), such as wind speed, relative humidity, wind direction, and outdoor temperature, were acquired from the Turkish State Meteorological Service. Since the wind directions were retrieved as verbal entries from the meteorology database, nominal codes were assigned in IBM SPSS for model analysis. Nominal codes for wind directions are shown in Table 1.

Table 1. The nominal codes of the wind directions produced for the moderated mediation analysis

Code	Wind Direction	Code	Wind Direction
1	North	10	South-Southeast
2	Northeast	11	East
3	Northwest	12	East-Northeast
4	North-Northwest	13	East-Southeast
5	North-Northeast	14	West
6	South	15	West-Northwest
7	Southwest	16	West-Southwest
8	South-Southwest	17	Flexile
9	Southeast	18	No Wind

***Code:** SPSS Nominal Code for the moderated mediation analysis

Since wind directions are expressed verbally, specific numerical values must be assigned to expressions indicating wind direction to enable their use in training the model, according to Table 1. For example, in the coding system, the northeast wind direction is encoded as code 2. If the ambient temperature value is recorded in the learning dataset and code 2 is assigned to the other column, then when that ambient temperature value is provided to the system, the model will infer that the wind is blowing from the northeast.

The measurement and the outdoor environment parameters data that are the subject of the study were recorded concurrently and instantaneously for 10 days (for every day in mornig /09:00/10:00/11:00/, in noon /12:00/ and in afternoon /13:00/14:00/15:00/16:00) as a total of 80 values. Figure 1 shows the condenser temperature used in the moderated mediation analysis. The condensing temperatures that develop for the R410A refrigerant used in the heat pump (source: air) and that are required to release heat to the outside can also be described by the values displayed in Figure 1.

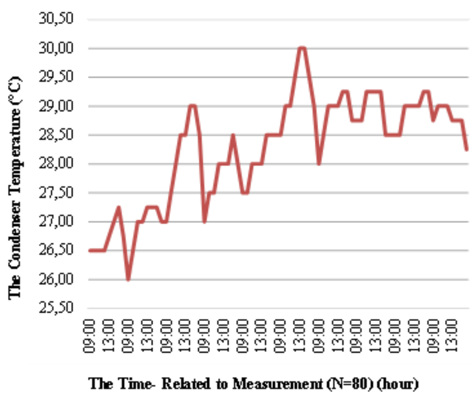


Figure 1. The condensing temperature (°C) values related to heat pump (source:air)

The evaporator evaporation temperature used in the moderated mediation analysis is shown in Figure 2. The values shown in Figure 2 can also be defined as the evaporation temperatures that develop in a heat pump using R410A (source: air) and that are necessary to absorb heat from the water coming from the fan coil.

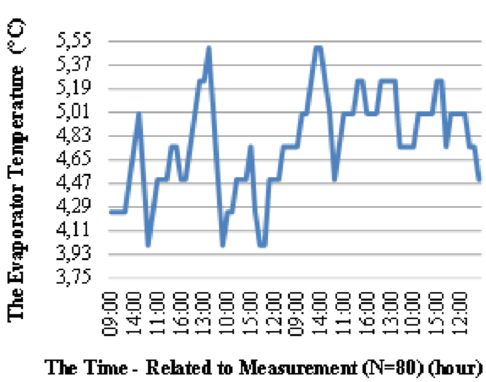


Figure 2. The evaporation temperature (°C) values related to the heat pump (source:air)

The outdoor temperature values of Istanbul city, where the heat pump (source:air) is located, are displayed in Figure 3. Studies in the literature show that the condenser temperature values of a heat pump (source: air) are affected by outdoor temperature. Therefore, the most important variable in this study's model is outdoor temperature, and the value shown in Figure 3 is included to the model.

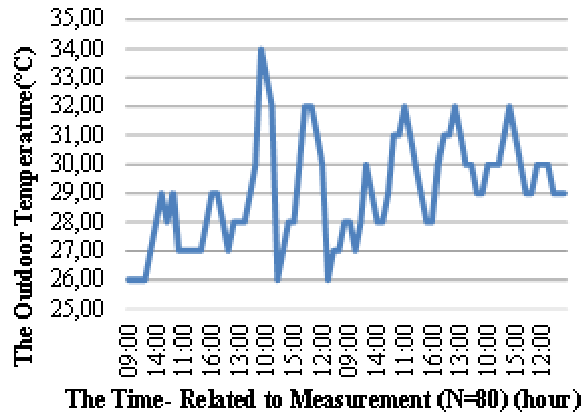


Figure 3. The outdoor temperature (°C) values related to Istanbul city of Turkey [26]

The relative humidity (%) in the city of Istanbul, where the heat pump (source: air) is located, is shown in Figure 3. The second variable used in the moderated mediation model is relative humidity. The relative humidity value corresponding to each outdoor temperature, as shown in Figure 4, is added to the model.

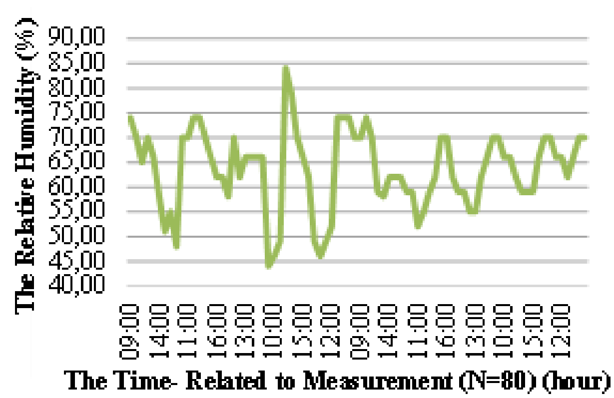


Figure 4. The relative humidity (%) values related to Istanbul city of Turkey [26]

Figure 5 displays the wind speed values (m/s) for Istanbul, the location of the heat pump (source: air). Since wind speed is another factor influencing the performance of the pump's (source:air) fundamental components, the model is provided with wind speed values measured at the heat pump's (source:air) location in meters per second.

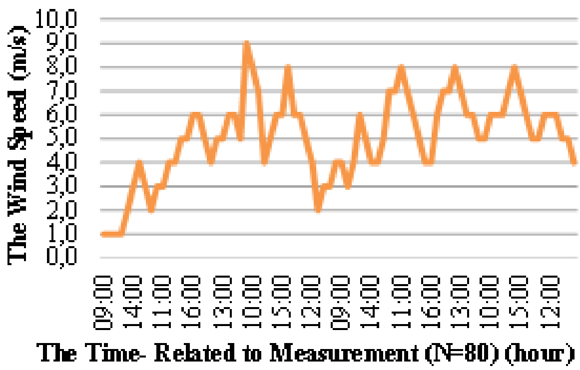


Figure 5. The wind speed (m/s) values related to Istanbul city of Turkey [26]

The wind-direction code for the city of Istanbul, where the heat pump (source: air) is located, is displayed in Figure 6. IBM SPSS Process Macro or other machine-learning optimisation programmes can perform verbal valuation. For this purpose, the relevant code assignments were made to define the verbal expressions and the wind-direction values according to which other variables change, as determined in Figure 6.

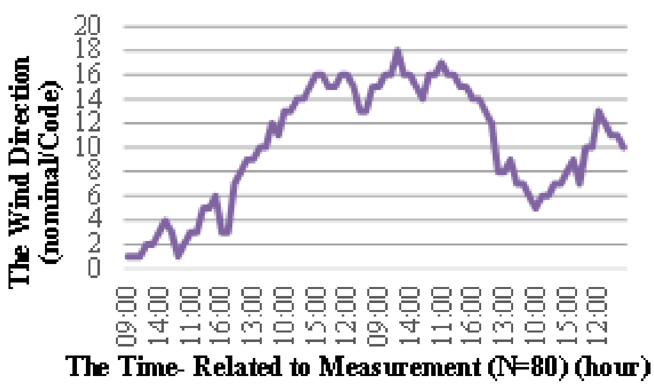


Figure 6. The wind dirrection (code) values of Istanbul city of Turkey [26]

The data related to outdoor environmental parameters and the evaporator and the condenser of the heat pump (source: air) located in Çengelköy/Üsküdar/İstanbul were analyzed using IBM SPSS software with a moderated moderation model. Thus, in addition to studying the effects of the outdoor environmental parameters on the condenser and the evaporator, a mathematical equation for the evaporator was derived.

Several reasons support selecting wind direction as an additional variable in the model. Wind direction determines not only the wind speed but also the direction of wind movement. This has the capacity to either increase or decrease the overall efficiency of the system. Wind direction can affect the temperature balance of the system. If the wind blocks the incoming airflow, the heat pump may absorb less heat from the surrounding environment, potentially disrupting system stability. Wind direction can directly impact the system's efficiency and differs from other parameters. For example, even if the temperature is the same, the wind direction and fluid dynamics can prevent the heat pump from efficiently absorbing and releasing heat [27]. The steps and progress of the study are shown in Figure 7.

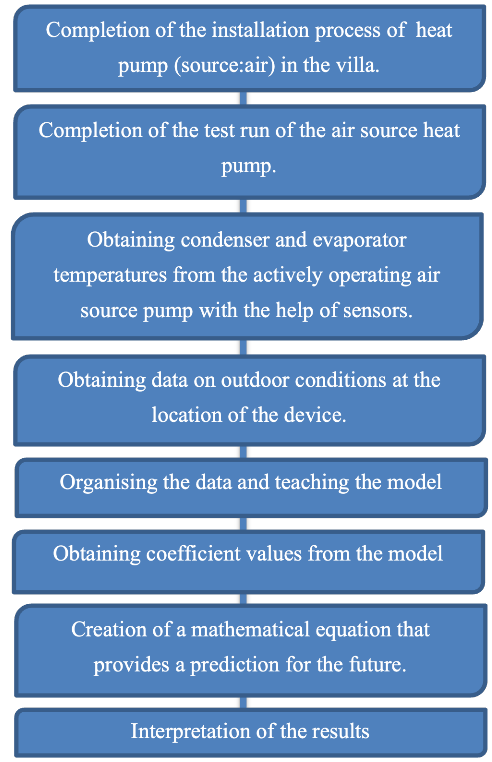


Figure 7. The cycle and steps of the study

3. Materials and methods

3.1. Normality test

The results are more realistic when the data obtained instantly and found to be normally distributed by the Normality Test are used in statistical research, modeling studies, and optimization applications. The Kolmogorov-Smirnov (K-S) test and the Shapiro-Wilk test are considered the two most effective tests for assessing normality. Kolmogorov-Smirnov (K-S) test and Shapiro-Wilk test can be performed by following the normality test procedure included in the IBM SPSS program [28].

The skewness and kurtosis parameters used to determine whether variables are normally distributed are the "warp and woof" of the normality test. Skewness measures the extent to which variables deviate from symmetry, indicating negative (-) or positive (+) skew in the normality test. The kurtosis measures the extent to which variables deviate from the average (-) or (+) direction in the normality test [29]. The premise that the variables follow a normal distribution is accepted if the skewness and/or kurtosis results of the local variables utilized in the model are under examination fall between -1.5 and +1.5 [30].

In data analysis, normality is a key assumption for many statistical methods, and skewness and kurtosis are two common metrics used to assess how closely a data set follows a normal distribution [30].

Skewness measures the asymmetry of a distribution. Skewness = 0: The distribution is perfectly symmetrical (an ideal normal distribution). Positive skew: The distribution exhibits a longer right tail, indicating that data points are more spread out on the right. Negative skew: The distribution has a longer left tail(data points are more spread out on the left side)[30].

Kurtosis measures the "tailedness" of a distribution. Kurtosis = 0(excess kurtosis)indicates a normal distribution. Positive kurtosis (leptokurtic): The distribution exhibits more pronounced tails and a sharper peak, indicating more outliers. Negative kurtosis(Platykurtic):The distribution has lighter tails and a flatter peak(fewer outliers)[30].

Interpretation of kurtosis (-1.5 to +1.5) is generally considered acceptable, suggesting the data have a similar shape to a normal distribution (in terms of peak and tails). Interpretation of Skewness (-1.5 and +1.5): values within this range are generally considered acceptable for normality. The distribution is close enough to symmetric, and this is often within the threshold for many statistical tests [30].

3.2. The moderated mediation analysis

The moderated mediation analysis was obtained by combining moderation and mediation analyses. The moderated mediation analysis illustrates the relationships among variables X, M, and Y and shows how the fourth variable, W, indirectly influences those relationships. It is defined as the effect of X on Y. The true magnitude of the effect of variable X on variable Y is revealed when variable M, defined as a mediator, is included in the model. The W variable, defined as the moderator, represents the indirect effect in the model by indicating how the moderator influences the relationships among variables. The first analysis section of the model expresses the impact of X on Y vover the mediator, M, even if the percentages of effect and mathematical coefficients in the moderated mediation analysis vary based on the model selected. In addition, indirect effects are revealed when the W variable is added to the first part of the analysis. The moderated mediation analysis examines the indirect effects on the associations among the W, X, and Y variables; between the X and M variables; and between the M and Y variables, depending on the model type selected from the 92 models identified in the moderated mediation analysis. The general mathematical equation expressed in the first part of the model is shown in Equation(1) [31].

$$M_P = i_M + a_{1_i}X + a_{2_i}W + a_{3_i}XW + e_M \quad (1)$$

The second portion of the model, chosen based on the applicability of the data set to be examined, provides the overall mathematical equation containing the X, Y, and M variables that will direct the designs created. This general mathematical equation, which enables prediction, is given by Equation (2). In addition, by adding the C variable, defined as a covariate, to the part of the model containing the X, M (mediator), and Y variables, the direct effect of the C variable on the M (mediator) and Y variables can be revealed. The new general mathematical equations formed by adding a covariate variable (C variable — for improved precision of the model) are shown in Equations (3) and (4) [32].

$$Y_P = i_Y + c'X + b_{xi}M + e_Y \quad (2)$$

$$M_{new} = i_M + a_{1_i}X + a_{2_i}W + a_{3_i}XW + a_{4_i}C + e_M \quad (3)$$

$$Y_{new} = i_Y + c'X + b_{x_{1i}}M + b_{x_{2i}}C + e_Y \quad (4)$$

The general mathematical equations of the 21st model are expressed by Equation (5) and Equation (6) [32].

$$Y = i_Y + c'X + b_{1_i}M + b_{2_i}Z + b_{3_i}MZ + b_{4_i}C + e_Y \quad (5)$$

$$M = i_M + a_{1_i}X + a_{2_i}W + a_{3_i}XW + a_{4_i}C + e_M \quad (6)$$

The moderator variable W and the In-1 XW variable are included in the selected model, in accordance with the moderated mediation analysis, to determine whether the influence of X on Y is affected by W. Finally, the interactions between M and Y are explained in the model [33]. Figure 8 displays the conceptual diagram of 21st optimisation model of the moderated mediation analysis. The conceptual diagram in Figure 8 is a visual representation that illustrates the relationships and interactions between different concepts, components, or elements of the 21st optimisation model. It is often used to provide a high-level overview or framework of how various parts of the 21st optimisation model are connected or how a process works [34].

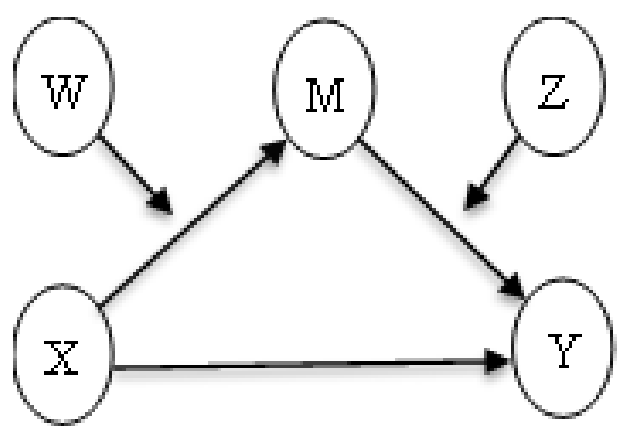


Figure 8. The conceptual diagram of the 21st optimisation model of the moderated mediation analysis [34]

Figure 9 shows the statistical diagram of the 21st optimisation model of the moderated mediation analysis. In terms of the 21st optimisation model, the statistical diagram typically refers to a visual representation used to illustrate the data, relationships, or results derived from a statistical or mathematical model. The statistical diagram is used to communicate key insights, trends, and patterns from the data and help in understanding the behavior of the 21st optimisation model or the system being analyzed [34]

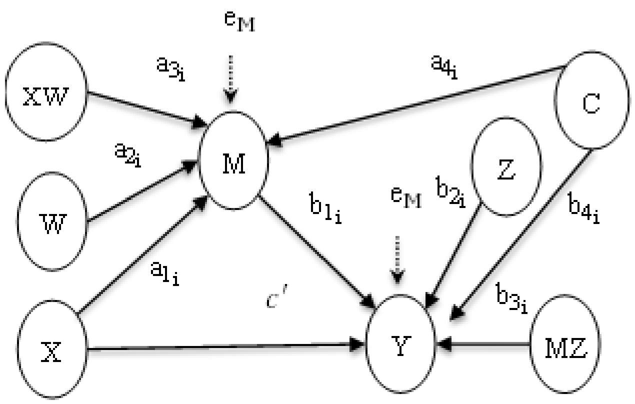


Figure 9. The statistical diagram of the 21st optimisation model of the moderated mediation analysis [34]

The 21st optimisation model may refer to the 21st century approach to moderating the mediation process in a more complex and realistic way, integrating the roles of multiple variable. This particular model is frequently applied to situations in which a moderator (W) influences the mediation process and a mediator (M) mediates the relationship between an independent variable (X) and a dependent variable (Y). Model 21 of moderated mediation analysis examines how a moderator affects the type or magnitude of the indirect effect in a mediation model. It is particularly useful for understanding complex interactions in which the effect of an independent variable on a dependent variable but varies with the presence or magnitude of another variable. More detailed understanding of how and when specific effects occur in various circumstances is made possible by this model [33].

Mean-centering and conditioning-value techniques are essential for resolving multicollinearity and enhancing model interpretability in a moderated mediation model. By subtracting the mean from the independent variable (X), the mediator (M), and the moderator (W), mean centering stabilizes regression coefficients and clarifies the moderation effect by lowering the correlation between the main effects (X and W) and the interaction term (e.g., X * W). Following mean-centering, multicollinearity is identified using collinearity diagnostics such as the Variance Inflation Factor (VIF) or the condition index, which quantify the extent to which correlations among predictors inflate the variance of estimated coefficients. To ensure consistent and reliable estimated coefficients, it may be necessary to exclude or combine predictors when multicollinearity is problematic, as indicated by high VIF values or a high condition index. When combined, these techniques reduce multicollinearity, enhance model stability, and ensure accurate interpretation of moderation within the mediation process. The IBM SPSS Process macro was used to implement the techniques [33].

The lower limit confidence interval(LLCI) is the minimum value found by the model in the validation iteration across 5000 effect values, while the upper limit confidence interval (ULCI) is the maximum value found by the model in the validation iteration across 5000 effect values. For the model to be significant, there should be zero between these values [34].

4. Theory and hypotheses

Condenser, evaporator, and compressor performance, as well as the air-source heat pump's coefficient of performance, change in response to changes in the outdoor environment. The condenser appears to be the heat-pump component most affected by external environmental parameters (e.g., wind speed, relative humidity, and outdoor temperature), depending on the fluid temperature and the condenser's condensation temperature. In addition, the evaporator performance also varies depending on the performance of the condenser [33]. The literature review conducted in this research revealed how the condenser and evaporator temperatures, which are components of the heat pump under study, are affected by outdoor environmental parameters. In order to reveal these effects, H_1, and H_2 hypotheses have been developed.

H_1: The condenser condensation temperature is directly impacted by the outdoor temperature..

H_2: The evaporator evaporation temperature is indirectly impacted by the outdoor temperature.

4.1. The mediator M variable

In heat pumps using a vapor-compression cycle, a change in the condenser's performance (condenser condensation temperature) causes a change in the evaporator's performance (evaporator evaporation temperature). The condenser, the heat pump's fundamental component, is most affected by external environmental factors, such as temperature and relative humidity. It is feasible to uncover the impact on the heat pump's performance by building a model using data on its constituent parts [35]. The air source heat pump uses a vapor compression cycle, just like other types of heat pumps, so variations in the condenser's performance also impact the evaporator's performance [36]. In this reseach, a model was constructed in light of the studies on the heat pump in the literature, and the condenser condensation temperature was determined as the mediator(M) variable in this study to analyze the effect of the condenser on the evaporator and create a mathematical equation. In order to reveal this effect, H_3 hypotheses have been developed.

H_3: The condenser condensation temperature has a direct effect on the evaporator evaporation temperature.

4.2. Moderator W variable and Z variable

Additionally, there is a positive or negative impact on the condenser's performance(the condenser condensation temperature)and, indirectly, on the evaporator's performance(the evaporator evaporation temperature)due to changes in outdoor environment parameters like wind speed, relative humidity, and outdoor temperature that affect the fluid temperature used in the vapor compression cycle [36]. The performance of heat pumps (source:air) is impacted by changes in outside environment parameters, particularly the outdoor temperature and wind speed, according to a reseach on the modeling of (source:air) performance by Yamaguchi et al. [37]. Changes in the performance of the air-source heat pump are driven by the performance of its condenser and evaporator, two of its fundamental components [38]. To examine the influence of wind direction on the condenser condensation temperature and the indirect influence of wind speed on the evaporator evaporation temperature, the H_4, H_5, H_6, and H_7 hypotheses were developed.

H_4: The wind direction has a direct effect on the condenser condensation temperature.

H_5: The condenser condensation temperature is directly impacted by the direction of the wind through the outdoor temperature.

H_6: The wind speed has an indirect effect on the evaporator evaporation temperature.

H_7: The wind speed through the condenser condensation temperature has an indirect effect on the evaporator evaporation temperature.

4.3. Covariate C variable

Outdoor temperature and relative humidity affect both condenser performance and the evaporator's evaporation temperature, according to research by Zhang et al. on the subject and Thongluang et al. on the effect of outdoor environment parameters on condenser performance. Furthermore, the evaporator evaporation temperature and the condenser condensation temperature are adversely affected by increases in ambient temperature and relative humidity [39–40]. In order to examine the impact of relative humidity on the evaporator evaporation temperature and the condenser condensation temperature, the H_8 and H_9 hypotheses were created for this study.

H_8: The condenser condensation temperature is directly impacted by the relative humidity.

H_9: The evaporator evaporation temperature is indirectly impacted by the relative humidity.

Since the wind direction (W) is categorized as a nominal variable, it is essential to understand how such variables are handled in analysis. Nominal variables do not have any inherent ranking or numerical value; they simply represent different categories. For example, wind direction can be expressed in categories such as east, west, north, or south. If wind direction (W) is considered a moderator variable, interaction terms between W and other variables can be included in the model. Nominal variables, such as wind direction (W), are typically incorporated into the analysis by creating dummy variables. This approach enables the model to estimate the effect of each category of the nominal variable individually. If wind direction is used as a moderator, its impact can be analyzed in terms of its interaction with other variables. Proper modeling of nominal variables is crucial, particularly in interaction analyses, for accurate interpretation of results.

The direct and indirect effects of external environmental parameters on the condenser condensation temperature and the evaporator evaporation temperature were estimated using moderated mediation analysis. The effects are presented as percentages in the model results. However, this percentage denotes the variable's proportional impact on a change, rather than the change itself.

5. Result

According to the 21^{st} models of moderated mediation analysis, X defines the outdoor temperature (°C), Y defines the evaporator evaporation temperature (°C), M (mediator) defines the condenser condensation temperature (°C), Z (moderator) defines the wind speed (m/s), W (moderator) defines the wind direction (nominal), and C (covariate) defines the relative humidity (%). In this research, the 21^{st} optimization model of the moderated mediation analysis consists of two parts called model 21a and model 21b. The mean-centering method and conditioning-value method are applied to variables in model 21a and model 21b to more clearly reveal the effect of outdoor environment parameters on condenser and evaporator temperatures and to eliminate multicollinearity. The direct impact of the outdoor parameters on the condensation temperature and indirect impact on the evaporation temperature were obtained using the 21^{st} model. The mathematical equations associated with the model have also been revealed.

The data must possess normality property to evaluate data related to the variables contained in the 21^{st} model of moderated mediation analysis. As a result, the variables were subjected to tests for normality using IBM SPSS 26, and the results are shown in Table 1. The skewness and kurtosis values of the X, Y, M, W, Z, and C variables In the 21^{st} model of the moderated mediation analysis were found to be between -1.5 and +1.5, based on the outcomes of the normality analysis in Table 2. The X, Y, M, Z, and C variables also approximate normality, as indicated by skewness and kurtosis values between +1.0 and +1.0. Since the W variable represents wind direction, its values are set to "nominal" in IBM SPSS.

Table 2. The 21st model's variables' normality analysis results

Variables	Skewness	Kurtosis
X	-0.187	-0.618
Y	0.289	-0.375
M	-0.526	-0.672
W	-0.332	-1.175
Z	-0.365	-0.043
C	-0,345	-0,034

The effect results obtained from Model 21a (the first part of the 21st optimization model of moderated mediation analysis), which were found to be significant (p< 0.05) within the 95% confidence interval, are shown in Table 3.

Table 3. The results of model 21a was created with variables defined in the model

	Const.	X	W	C	Int-1
Coeff	-2.5649	0.2378	0.0738	0.0420	-0.0369
se	0.9267	0.0645	0.0152	0.0144	0.0085
t	-27.677	36.883	48.252	29.189	-43.493
p	0.0071	0.0004	0.0000	0.0046	0.0000
LLCI	-4.4111	0.1094	0.0435	0.0133	-0.0537
ULCI	-0.7188	0.3662	0.1042	0.0707	-0.0200

Int-1: The effect of wind direction on the condenser condensation temperature together with the outdoor temperature LLCI: The lower limit confidence interval, ULCI: The upper limit confidence interval

The variables were outdoor temperature (p<0.05, b=0.2378, LCI= 0.1094 and 0.3362), wind direction (p<0.05, b=0.0738, CI= 0.0435 and 0.1042), relative humidity (p<0.05, b=0.0420, CI= 0.0133 and 0.0707), and the Int-1 variable (p<0.05, b=-0.0369, CI= -0.0537 and -0.0200). The results indicate that Model 21a accurately represents 61.46% of the effects of these variables. Additionally, the error margins for the variables X, W, C, and Int-1 in explaining the remaining 38.54% of the data were 6.45%, 1.52%, 1.44%, and 0.85%, respectively. In Model 21a, the Int-1 (interaction variable) represents the combined effect of wind direction and outdoor temperature on the condenser's condensation temperature (interaction effect). As a result, the hypotheses H_1, H_4, H_5, and H_8 cannot be rejectedThe ideal value for the mathematical equation can be found by comparing the values of the lower and upper confidence limits (interaction effect). It is impossible to provide values for the variables from which the model data will be obtained using the coefficients of the mathematical equation and the interaction between the variables that the teaching will predict in the future.

Equation(7) displays the mathematical formula derived from the impacts of the variables of relative humidity, wind direction, and outdoor temperature on condenser.

It was found that the Int-$1_{model21a}$ (Interaction variable, XW) variable in model 21a describes the effect (Effect:0.0972) of wind direction together with the outdoor temperature on the condenser condensation temperature shown in Table 4 is a significant (p=0.0000<0.005) Interaction Effect (9.72%).

Table 4. The effect of wind direction together with the outdoor temperature on the condenser condensation temperature

Variable	Int-$1_{model21a}$ (XW)
Effect	0.0972
F	18.9165
df1	1.0000
df2	75.000
p	0.0000

Results from Model 21a indicated that the "South-North" (effect: 0.4224, CI: 0.2688 and 0.5676) and "East-West" (effect: 0.2478, CI: 0.1194 and 0.3772) wind directions had a significant effect (p = 0.00 < 0.05) on the condenser condensation temperature. Because the confidence intervals do not include 0, it was concluded that the influence of wind direction is quite substantial, as shown in Table 5. Additionally, the "change" and "no change" wind directions were not found to affect the condenser's condensation temperature. It is impossible to include the condenser temperature—that is, the effect of wind direction on the condenser temperature— together with the outdoor temperature. These effects do not correspond to simple increases or decreases; rather, they reflect the effect of wind direction on the percentiles that influence increases and decreases in the condenser temperature.

Table 5. The impact of the change in the wind direction on the condenser condensation temperature

	-1SD	Mean	+1SD
Wind Direction	-5.0033	0.0000	5.0033
Effect	0.4224	0.2478	0.0554
se	0.06	0.0654	0.0664
t	63.125	37.983	0.7527
P	0.0000	0.0005	0.5454
LLIC	0.2688	0.1194	-0.1647
ULCI	0.5676	0.3772	0.2325

The mathematical equation , generated from the coefficients of variables obtained from Model 21b (presented in Table 6), is used to estimate the evaporator temperature based on changes in outdoor temperature, condenser temperature, wind speed, and relative humidity.

Table 6. The coefficient values of mathematical equations according to the Model 21b

	Coeff	se	t	P	LLCI*	ULCI*
Cons	6.2541	0.2178	23.49238	0.0001	5.9656	6.8969
X	-0.2086	0.0299	-7.8986	0.0001	-0.2765	-0.1748
M	0.4076	0.0229	16.3927	0.0000	0.3164	0.5458
Z	0.1039	0.0228	4.4285	0.0000	0.0657	0.1152
C	-0.0229	0.0039	-5.6789	0.0015	0.0413	0.0568
Int-1*	0.0349	0.0103	3.3682	0.0000	-0.0318	-0.0149
R: 0.9329 **R-sq:** 0.8454 **F:** 76,02010 **P:** 0,0000						

The mathematical equation of Model 21b, which accurately describes 84.54% of the evaporator's evaporation temperature data, was found to be significant (p= 0.0000 < 0.05) at the 95% confidence level. Additionally, the error margins for the variables explaining the remaining 15.46% of the data in the mathematical equation were 2.99%, 2.29%, 2.28%, 0.39%, and 0.039%, respectively. Based on these results, the H_2, H_3, and H_6 hypotheses cannot be rejected. Equation (8) presents the mathematical equation of Model 21b.

As the condenser condensation temperature increased, wind speed significantly (p=0.0015 < 0.05 in the 95% confidence interval) increased the evaporator evaporation temperature by 2.59%. This effect is shown in Table 7.

Table 7. The indirect effect of the wind speed together with the condenser temperature indirectly on the evaporator temperature according to the Model 21b

Indirect Effect	T	df1	df2	P
0.0259	12.4350	1.0000	75.0000	0.0015

Because of the direct effect of condenser condensation temperature on the evaporator evaporation temperature, the analysis results of Model 21b in Table 8 revealed that outdoor temperature negatively affected the evaporator evaporation temperature by 20.76%, with a 3.00% error margin. Furthermore, this effect was significant (p = 0.00 < 0.05, CI: -0.2674 and -0.1478). The model determines how external temperature affects evaporator temperature owing to the direct relationship between condenser and evaporator temperatures.

Table 8. The Indirect effect of the change in the outdoor temperature on the evaporator evaporation temperature

Definition	Values
Indirect Effect	-0.2076
se	0.0300
t	-69.186
P	0.0000
LLIC	-0.2674
ULCI	-0.1478

Results from Model 21b indicated that low (effect: -0.0128, CI: -0.0191 to -0.0075), medium (effect: -0.0151, CI: -0.0233 to -0.0086), and high (effect: -0.0047, CI: -0.0279 to -0.0097) wind speeds had a significant indirect effect on the evaporator temperature through the condenser temperature. Since the confidence intervals did not include 0, it was concluded that wind speed has a significant impact, as shown in Table 9. The error margins for these results are 0.30%, 0.38%, and 0.47%, respectively. Because the model results indicate an indirect effect, values for the variables cannot be provided.

Table 9. The total indirect effect of the wind speed on the evaporator evaporation temperature (Index of moderated mediation)

	-1SD	Mean	+1SD
Wind Speed	-1.7782	0.0000	1.7782
Indiret	-0.0128	-0.0151	-0.0173
BootSE	0.0030	0.0038	0.0047
BootLLCI	-0.0191	-0.0233	-0.0279
BootULCI	-0.0075	-0.0086	-0.0097

A graphical representation of the interactions among m, z, and y and among x, w, and m has been developed using codes obtained from the 21st models of moderated mediation analysis. Figure 10 shows the effect of outdoor temperature and wind direction on condenser (condensing) temperature. The effects of condenser (condensing) temperature and wind speed on the evaporator temperature are shown in Figure 11. As a result of training the model using the data set, codes that provide a clearer graphical understanding of the interaction between the variables were obtained. These interactions are shown in detail in Figures 10 and 11.

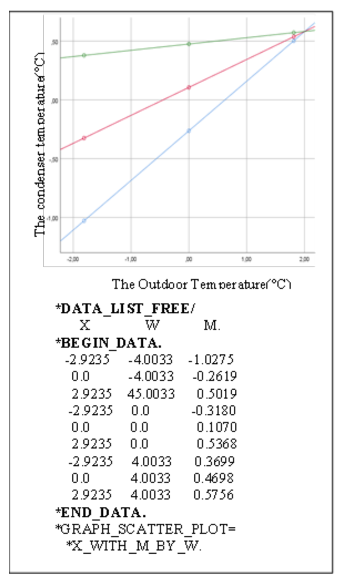
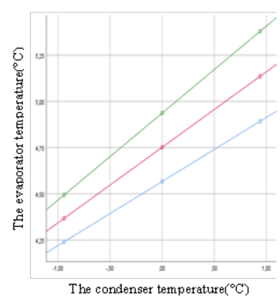


Figure 10. The effect of outdoor temperature and wind direction on the condenser temperature

It was found that, when the outdoor temperature is low, the condenser's condensation temperature increases as the wind direction shifts from north to south and from east to west. Additionally, as the outdoor temperature rises, the condenser's condensation temperature changes more significantly when the wind direction shifts to the south or west. Similarly, the evaporation temperature of the evaporator increases as the wind direction shifts from north to south and from east to west when the condenser temperature is low. However, as the condenser temperature rises, the change in evaporator temperature becomes more pronounced when the wind speed shifts toward the south and west. Figure 11 displays the effect of wind speed and condenser temperature on the evaporator temperature.




```
*DATA_LIST_FREE/
   M          Z          Y.
*BEGIN_DATA.
  -0.9635   -2.8762   4.1906
   0.0      -2.8762   4.5995
   0.9635   -2.8762   4.7834
  -0.9635    0.0      4.2993
   0.0       0.0      4.69125
   0.9635    0.0      5.1916
  -0.9635    2.8762   4.4790
   0.0       2.8762   4.8994
   0.9635    2.8762   5.2998
*END_DATA.
*GRAPH_SCATTER_PLOT=
  *M_WITH_Y BY_Z.
```

Figure 11. The effect of wind speed and condenser temperature and on the evaporator temperature

Table 10 shows the indirect effect of wind direction on the evaporator's evaporation temperature. Furthermore, this effect was significant (95% CI: -0.0027 to -0.0007). The wind direction was found to affect the evaporator's evaporation temperature by 0.15%, with a 0.05% error margin.

Tablo 10. The indirect effect of the wind direction on the evaporator evaporation temperature

Wind Direction	BootSE	BootLLCI	BootULCI
-0.0015	0.0005	-0.0027	-0.0007

6. Conclusion and discussion

The results of the study on modelling the effects of outdoor conditions on the basic elements of the air-source heat pump and on the creation of the mathematical equation are presented below.

1. Changing the wind direction from north to south and from east to west raised the condenser's condensation temperature by 7.38%, while a 23.78% increase in outdoor temperature and an increase in relative humidity together raised the condenser's condensation temperature by 4.20%. Additionally, the change in wind direction reduced the effect of outdoor temperature on the condensation temperature by 3.69%.
2. The effect of changing the wind direction from north to south on the condenser condensation temperature (0.4222) was 43.68% greater than that of changing the wind direction from east to west (0.2378).
3. Wind speed has an indirect effect of 2.59% on the evaporator evaporation temperature, owing to the direct effect of the condenser condensation temperature on that temperature, with other outdoor environmental parameters held constant except for outdoor temperature. Additionally, wind speed was found to reduce the evaporator temperature by 1.28% at low, 1.51% at moderate, and 1.73% at high wind speeds, when other outdoor environmental parameters were altered.
4. It was discovered that the direct relationship between the condenser and the evaporator temperatures resulted in a 20.76% decrease in the evaporation temperature at the evaporator for every increase in outside temperature. In addition, it was found that the condenser condensation temperature has a negative indirect effect of 0.13% on the evaporator evaporation temperature, since it changes with wind direction (from north to south or from east to west), which directly affects the evaporator evaporation temperature.

Zhu et al. demonstrated the impact of wind direction and speed on the condenser, whereas Zou et al. examined the impact of external temperature on the air source heat pump. When these effects and their interactions are examined simultaneously, without contradicting findings in the literature, it is observed that outdoor temperature has the greatest direct effect on the condenser condensation temperature among outdoor environmental parameters. However, the impact of changing wind direction, influenced by temperature variations and high- and low-pressure air currents, on the condensation temperature is greater than that of relative humidity. Wind direction moderates outdoor temperature on condensation temperature.

A novel scientific contribution of this study is that additional directions, such as northeast, are effective, the condenser temperature differs among the north, south, west, and east directions without contradicting the conclusion of Shi et al. that. In addition, instantaneous changes in wind direction and periods of constant wind direction are also observed. Changing the wind direction from north to south has a greater effect on the condenser's condensation temperature than changing it from east to west. When wind direction remains unchanged or fluctuates frequently, there is no significant impact on condenser performance. Highlighting the effect of changes in wind direction from north to south constitutes an additional contribution of this study. Even when the outdoor temperature is low, changes in wind direction from north to south or from east to west negatively affect the condenser's condensation temperature. In such cases, the condenser fails to transfer heatto the outdoor environment as designed. An increase in the condenser's condensation temperature should lead to higher compressor power consumption. Consequently, the efficiency coefficient of the air-to-water source heat pump decreases.

Uroš et al. and Stamatellos et al. developed mathematical formulas to forecast factors influencing the heat pump's (source: air) future performance. A mathematical equation was also derived in this study. However, unlike previous studies, this equation incorporates all outdoor parametersas well as condenser and evaporator temperatures, thereby providing more precise data. The mathematical model, which estimates 83.34% of the evaporator temperature data using outdoor environmental parameters and condenser condensation temperature variables with high accuracy, will serve as a guide for those involved in the production or design of the heat pumps subject to this study and their key components.

Because the direct effect of the condenser condensation temperature on the evaporator evaporation temperature, it was found that, when other outdoor environmental parameters remain constant except for outdoor temperature, an increase in wind speed raises the evaporator evaporation temperature, depending on the outdoor temperature. This suggests that it may not be possible to transfer the appropriate amount of heat from the rooms. However, observations indicate that the effect of wind speed on the evaporator's evaporation temperature decreases when other outdoor environmental parameters vary. Even with this reduction, the effect on the evaporator evaporation temperature gradually increases because the changing wind speed, together with the rising outdoor temperature, negatively affects the condenser condensation temperature as the latter rises from low to high values.

Because the condenser condensation temperature directly affects the evaporator evaporation temperature, the observed negative effect of increasing outdoor temperature on the evaporator evaporation temperature implies that the desired heat transfer cannot be achieved. Additionally, when wind direction changes from north to south or from east to west, it negatively affects evaporator performance by exerting a very slight, indirect effect on the evaporator's evaporation temperature. These results represent new scientific contributions regarding the evaporator.

The percentages of the effects of the variables used in the model can be explained by four headings, in terms of practical or operational changes in air-source heat pumps: efficiency improvement and low energy consumption; heat pump operating time and performance; control systems; and outdoor weather compatibility.

By examining the percentage changes in variables related to efficiency improvement and reduced energy consumption, it is possible to predict when the heat pump will provide greater cooling with lower energy consumption. Devices that consume less energy are not overloaded. Thus, the maintenance requirements of more efficient systems can also be reduced, thereby saving costs in the long term. The effect values obtained from the model can facilitate future prediction and optimisation studies and enable more precise operation of the device's control systems. The sensitivity of the air-to-water source heat pump to external factors is shown..

Based on the impact values obtained in this study, the most effective operating mode of the air-to-water heat pump can be determined.

Author contributions

For research articles with several authors, the following statements should be used "Conceptualization, Mehmet Özdemir.; methodology, Mehmet Özdemir.; software, Mehmet Özdemir.; validation, Mehmet Özdemir and Ayhan Onat.; formal analysis, Mehmet Özdemir; investigation, Mehmet Özdemir and Ayhan Onat; resources, Mehmet Özdemir; data curation, Mehmet Özdemir; writing—original draft preparation, Mehmet Özdemir; writing—review and editing, Ayhan Onat; visualization, Mehmet Özdemir; supervision, Ayhan Onat.; project administration, Mehmet Özdemir and Ayhan Onat.; All authors have read and agreed to the published version of the manuscript."

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Data availability statement

The databases from which the study's data were sourced are both open to the public and paid. Some data were gathered through measurements. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of interest

The authors declare no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors declare that they did not use any generative AI or AI-assisted technologies (such as ChatGPT, Claude, etc.) in the preparation of this article. The research and writing process were carried out entirely through the original contributions of the authors.

Abbreviations and indices

CO_2	Carbon Dioxide
IBM SPSS	International Business Machines Statistical Package for the Social Sciences
N	Measuring Number
CI	Confidence Interval (For Upper and Low Limit
Coeff	Coefficient
t	T-Test Value
p	Significance Value
%	Percent
°C	Degrees Celsius
m/s	metre/second
R	Correlation Value
R-sq	R square
MSE	Mean Squared Error
se	Standart Error
F	F-test Value
df	Degress of Freedom
SD	Standard Deviation

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