OPTIMIZATION OF THE FAN COIL COOLING SYSTEM IN ACCORDANCE WITH THE PARAMETERS AFFECTING THE PERFORMANCE OF THE AIR SOURCE HEAT PUMP USING A MODERATED MEDIATION MODEL

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The data obtained from a heating and cooling system comprised of a fan coil unit integrated air source heat pump used in Istanbul, Turkey, as well as data on outdoor conditions, was analyzed in this study. The analysis was carried out with the help of the moderated mediation model, which is included as a process analysis in the "Statistical Package for the Social Sciences" application. In this study, a mathematical model of the moderated mediation model was created and the efficiency coefficients of the parameters effecting performance were calculated. It was discovered that the effect of medium and high relative humidity values on the outdoor temperature was about 4.81%. The heat pump fails to transmit heat to the environment outside as a result of medium and high relative humidity values increasing the outdoor temperature. As a result of this it has been found that relative humidity values have a negative effect on the water temperature entering the fan coil unit by approximately -1.18%. This result of the study shows that the outlet water temperature of the fan coil unit does not adequately cool the rooms in the summer. It has been discovered that while wind velocity negatively affects performance affecting parameters, low relative humidity values have no effect on them.

1. Introduction

The United Nations World Population Prospects study predicts that by adding 1.18 billion people over the two decades that follow, the world population would increase to around 8.5 billion in 2030 and approximately 9.7 billion in 2050 [1]. Also, according to the United Nations World Population Prospects report released in 2019, there will be 10.9 billion more people on the planet in 2100. The United Nations World Population Prospects report from 2019 kept its estimate of population growth current when it was republished in 2022 [2]. The population growth rate increases the requirement for housing, and industrial expansions increase energy consumption [3]. The total electricity production is predicted to increase by 3.2% year until 2030 and by 3.4% annually from 2030 to 2050 whenever the years from 2010 to 2021 are taken into consideration. Also, it is expected that by 2030 and 2050, respectively, the share of electricity in total energy consumption will have increased to 30% and 50%. According to energy data of Turkey, natural gas provided 33.22% of the 334,723.1 GWh of electrical energy produced in Turkey, imported coal provided 16.22%, and lignite provided 12.84% [4]. Increasing electricity use results in increased use of fossil fuels and serious environmental problems such as global warming [3].

According to statistical data, the world's energy demand has increased by 5.4% as a result of rapid economic growth [4]. The demand for renewable energy sources is growing daily as a result of the decreasing supply of fossil fuels utilized to meet the world's energy needs and the ecological damage they create [5]. Residential heating and cooling accounts for 6.7% of the world's energy demand [6]. The heating and cooling systems account for 54% of the building's energy usage [7]. Both decreasing global energy consumption and enhancing residential energy efficiency can be accomplished with a heat pump that has been produced correctly by the design conditions. Also, heat pumps effectively carry out heating and cooling operations simultaneously as well as these tasks at different times of the year [8]. Eco-friendly, energy savings, accountability, low operating costs compared to other pump types using wide application areas in heating systems, and integration into decentralized heating systems can be listed as the advantages of air source heat pumps [9]. Air source heat pump that is one of heat pumps are divided into three types according to their sources air, water, and ground are used in a wide range of applications in addition to having a higher efficiency in residential heating and cooling processes [11-12]. Compared to heat pumps employing other heat sources, the air source heat pump is more sensitive to air variations. However, air-source heat pumps are preferred, because the air source heat pumps are more cost-effective and have shorter payback periods [9].

The performance of the air source heat pump is seen to alter as the outdoor conditions' changes. This situation helps the analysis of the air source heat pump system's efficiency and the optimization of the systems in which the air source heat pump is integrated while helping to optimize the outdoor conditions and the parameters affecting them [10]. The air source heat pump can perform cooling operations by integrating into radiant cooling [13] and fan coil unit systems, as well as heating operations with underfloor heating, radiator, and fan coil units [14]. The air source heat pump that absorbs the heat or transfers heat to the water sent to the fan coil unit and fan coil unit serpentine placed in each area of the building is known as the center of the designed air conditioning systems [15].

Systems that transmit heat to the area such fan coil units, radiant floor or radiators, are used in conjunction with air source heat pumps [16]. Fan coil units employing a ducting direct expansion inverter system that is integrated into the air source heat pump and is based on the on/off operation of a single zone in the residential sector are more effective and use less energy than other terminal units. It is regarded as one of the first energy solutions [17]. The performance of the fan coil unit is influenced by the outdoor conditions, the fan velocity of the fan coil unit, and the outlet temperature air source heat pump and the outlet temperature fan coil unit [18]. Therefore, it develops optimization models for design, control systems, or different algorithms in operating mode, taking into account the parameter affecting the performance of the air source heat pump and fan coil unit [16].

The heat pump needs to have a large capacity to eliminate heat from the fluid with high outdoor temperatures. Otherwise, the heat is not absorbed at the required amount [19]. The inflow and outflow water temperatures of the fan coil unit can be affected either positively or negatively by the humidity in the environment, the volume of water, [20] the diameter of the pipe where the water is located in the fan coil unit, the distance between the pipes [21], and the parameters affecting the performance of the heat pump [19]. In this study, an optimization model was created based on parameters affecting fan coil unit and air source heat pump performance.

Condenser, evaporator, expansion valve, and compressor are the main components of heating and cooling systems. The compressor must either spend less or more energy to sustain the room temperature established during the design phase. The compressor uses more energy if the outside temperature increases in comparison to other outdoor conditions. When the compressor capacity is insufficient, an increase in outdoor temperature caused by other outdoor conditions means that the condenser can't transfer heat to the outer environment and the evaporator can't absorb heat from the fluid or the outer environment [22].

The performances of the heat pump and integrated systems (fan coil units, radiators, etc.) were increased by hourly electrical energy consumption trends obtained using a genetic algorithm model created for the optimization of heat pump heating systems in the study of Albertazzi et al. [9]. Licharz et al. found that the performance of the heat pump in houses is influenced by the heat source's temperature as well as the outdoor conditions [23]. In the study by Li et al. it was discovered that there was a negative interaction between outdoor temperature and relative humidity[24]. According to Song et al.'s study, a one-degree increase in outdoor temperature caused a 2.4% decrease in the performance of heat pumps [25]. According to Koçyit's study, an increase in outdoor temperature decreases the performance of the heat pump, and increasing the compressor capacity is needed to increase the performance in Diyarbakır/Turkey [26]. In the experimental study conducted by Bai et al. [27] and in the study created by Milovančević et al. [28], it was found that increasing the outdoor temperature negatively affects the performance of the heat pump, and the heat pump consumes more energy. The energy consumed by the water going to the fan coil unit has been decreased by 39% thanks to the algorithm and optimization model created by Lin et al. to analyze temperature and wind velocity [29]. The effect of outdoor conditions on the air source heat pump is optimized with an algorithm developed by Hernández et al., and the energy used by the fan coil unit is decreased [30]. It was found that the water temperature entering the fan coil unit was affected by changes in the outdoor temperature utilizing the optimization model created in the optimization study of Weitang et al. [33].

The low-carbon economy model has an impact on increasing energy efficiency and helps generate innovative ideas for the development of sustainable development with a moderated mediation model created by Zhang et al. [31]. It has been found that the use of renewable energy sources increases the comfort of people living in housing and the expectations of consumers for the protection of the environment, using a moderated mediation model created by Loaiza-Ramirez et al. [32]. The temperature and relative humidity of the room were controlled by adjusting the water flow rate with a fuzzy logic model developed by Attia et al. and the performance of the air conditioning system has improved [34].

It is aimed to help manufacturers or designers in designing heat pumps and fan coil units with greater energy efficiency by using the effect values and mathematical model generated by the optimization model in the literature. The moderated mediation model mathematically exposes the relationship between two or more variables related to energy and fluids and describes how or why this relationship may exist. Furthermore, unlike the regression model, it offers information on how another two or more moderator variables effect the relationship between two or more variables. [32, 35]. It is critical to consider when studying complex correlational or causal interactions between variables [36].

This model has disadvantages as well as advantages. If only changes that are not likely to be scientifically relevant are chosen, and measurements are not taken over a specific time period, the model produces incorrect results. This model is not applicable to data that does not have normalcy features [35]. Additionally, it is evident that the moderated mediation model is employed in the energy efficiency literature. This study utilizes a moderated mediation model to assess the performance of the heat pump and fan coil with the goal of guiding designers toward energy efficiency.

2. Methodology

Reducing heat losses and increasing energy efficiency are the two biggest challenges affecting buildings. Heat pumps are frequently utilized in buildings. Energy efficiency can be improved by using well designed heat pump technology along with different energy sources as air, ground, and water [37]. It has been discovered that outdoor temperatures [37] and relative humidity [38] effect the performance of the heat pump. The fan coil units integrated into the heat pump improves efficiency.supply indoor thermal comfort while utilizing energy effectively [39]. This study emerged with the idea of examining the effect of parameters that change the performance of the heat pump on the fan coil unit.

Optimization studies are being performed to lower the power consumption of a system with a fan coil unit combined with heat pump systems in order to develop mathematical equations. [40]. The aim of this research is to create a moderated mediation model to reveal the relationships between the parameters effecting air source heat pump performance and the fan coil unit. it is intended that the related mathematical equation will direct the designers or producers as a result of the moderated mediation model. The measurements were obtained hourly. The diagram of the system is shown in Fig. 1.

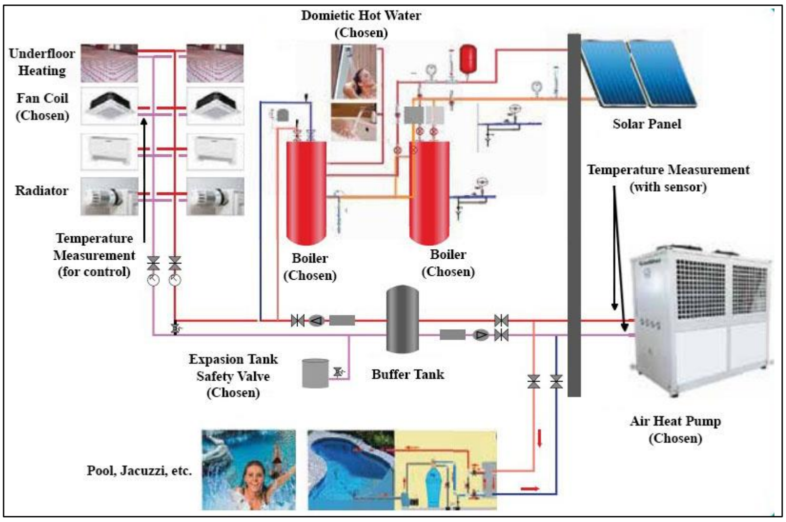

Fig. 1 The cooiling and heating system with ait heat pump entegted fancoil

The sensors were used for these measurements in the system. The air source heat pump produces domestic hot water in summer as well as winter. Heating and cooling modes are provided by the fan coil integrated into the air source heat pump. It can be used optionally by making the necessary connections in the future, because the capacity of the air source heat pump is sufficient to heat the pool and sauna. However, it is necessary to confirm that the data have normality properties before using the measured data in statistical models. IBM SPSS provides data-related models using a hypothesis-generation approach. Furthermore, it is appropriate for models of all sizes and levels of complexity, and it may assist systems in identifying new analysises, improving efficiency, and reducing risk. It prepares and analyzes data with an intuitive interface that eliminates the need to write code. Additionally, it provides visual data science tools to coders, noncoders, and analysts. The moderated mediation model are used to determine mathematical model and efficiency coefficients. IBM SPSS may be used to analyze all models. The result of this study is that the performance of the air source heat pump changes with the outdoor conditions. It resembles the results of Licharz et al.'s , Milovančević et al.'s and Li et al.'s study (the negative effect of increasing the outdoor temperature, In some cases, the negative relationship between relative humidity and the outdoor temperature, etc). In this study, the idea of mathematical equations and analysis with a model does not contradict Loaiza-Ramirez et al. 's and Zhang et al's study.

3. Materials and Methods

3.1. Data and Measurement Collection Process

The necessary measurements were gathered hourly (09:00 a.m., 10:00 a.m., 11:00 a.m., 12:00 p.m., 01:00 p.m., 02:00 p.m., 03:00 p.m., and 04:00 p.m.) for ten days. When the central limit theorem is applied to optimization and statistical analysis investigations [41], it is revealed that a sample size of 30 is enough [42]. In this study, the moderated mediation model was built using 80 measurements, and the normality analysis was carried out.

The variables of the outer environment conditions were relative humidity, outdoor temperature, and wind velocity for Çekmeköy/Üsküdar/İstanbul/Turkey in this study. The pressure values were measured at sea level and were not used in the study's model because no change in pressure values was noticed. The Turkish State Meteorological Service provided the data for the outer environment conditions variables. The data of the outer environment variables associated to the heat pump and fan coil belonging to the time period in which the measurement was taken were used. Therefore, the resulting moderated mediation model has a homogeneous structure and is statistically significant.

3.2. Normality Test

One of the most prevalent presumptions applied to the creation and use of statistical methodologies is that normality is at the foundation of many inference and prediction methods [43]. The terms skewness and kurtosis are used to express two normality criteria. The normal distribution's symmetry state of the variable acts as the foundation for the skewness criterion, while the normal distribution's peak of the variable serves as the basis for the kurtosis criterion. In the normal distribution analysis, if the skewness and kurtosis values are between -1.5 and +1.5, the hypothesis that the variable or variables have the normality property is accepted [44-45].

3.3. The Moderated Mediation Model (The Process Analysis)

The moderated mediation model, also known as process analysis, is used to examine how the relationship between variables changes depending on the variables' locations (e.g. changing the values of variables relating to external environmental conditions depending on location such as district, city, country), differences (e.g. an increase in temperature in some locations as relative humidity increases, an decrease in temperature in some locations as relative humidity increases) and the situation (e.g. the effect of variables on each other) in which they engage. It is also used to evaluate the extent to which the effect depends on these variables. The process analysis includes the moderation model and mediation model according to model selection. It creates a mathematical model that reveals the relationship between the dependent variable, the independent variable, the moderation variable, and the mediation variable while being statistically significant. Although process analysis was known as a relatively new statistical term, the idea of combining the moderation model and mediation model was not new since it entered the literature in 2013. To solve the issues that arise in complex optimization models, process analysis is used. It is also used to get results quickly and in a manner that is straightforward [46].

In the study, the seventh method of the the moderated mediation model model was employed to analyze data. When the number of variables increases or different correlations between variables are sought, different method of the the moderated mediation model model can be utilized. It has 92 different methods that reveal different relationships of variables. The diagram of process model 7 of the process analysis in the fundamental structure is shown in Fig. 2a and Fig. 2b [47]. In addition to all these models, the variable or variables that influence the mediator variable (M) and the dependent variable (Y) are included in the model as covariate variables and are shown in the model with C [48]. The moderated mediation model 7 was used in this study by adding the C variable which is defined as the wind velocity and its diagram is shown in Fig. 2c. This model can be described as the model connecting X to Y depending on a condition since the influence of the X variable on the Y variable via the M variable depends on another variable. In other words, the W variable changes the effect of the X variable on the M variable [47].

The regression equations for M and Y are used to determine the first path of the moderated mediation model 7. The equation describing the M variable and Y variable also explains how the influence of the X variable depends linearly on the W variables and describes the effect of the M variable on the Y variable with the efficiency coefficient. The mathematical equation of the the mediation model is shown in Eq. (1). Eq. (2) clearly shows the mathematical equation of the moderation model. If the covariate variable is included in the model, the mathematical equation is expressed with Eg. (3) [49].

$$\mathrm{M_P} = \mathrm{I_M} + \mathrm{a_{1_i}X} + \mathrm{a_{2_i}W} + \mathrm{a_{3_i}XW} + \mathrm{e_M} \tag{1}$$

$$\mathrm{Y_{P_1}} = \mathrm{i_Y} + \mathrm{c'X} + \mathrm{a_{a_i}M} + \mathrm{e_m} \tag{2}$$

$$\mathrm{Y_{P_2}} = \mathrm{i_y} + \mathrm{c'X} + \mathrm{a_{x_i}M} + \mathrm{c''C} + \mathrm{e_m} \tag{3}$$

The second path is the inclusion of the W variable and XW variable into process model 7 to reveal whether the direct effect of the X variable is linearly governed by the W variable. The detail is given in Fig. 2b [46]. The second path is the incorporation of the W variable and XW variable into process model 7 to determine whether the direct effect of the X variable is linearly dictated by the W variable. The direct effect and indirect effect are defined with the help of Eg.(4) and Eg. (5) [51]. At the last stage, it defines the effect of the covariate variables affecting the M variables and the Y variables [50].

$$\mathrm{M} = (\mathrm{a_{1_i}} + \mathrm{a_{2_i}W})\mathrm{b_i} \tag{4}$$

$$\mathrm{Y} = \mathrm{c'} \tag{5}$$

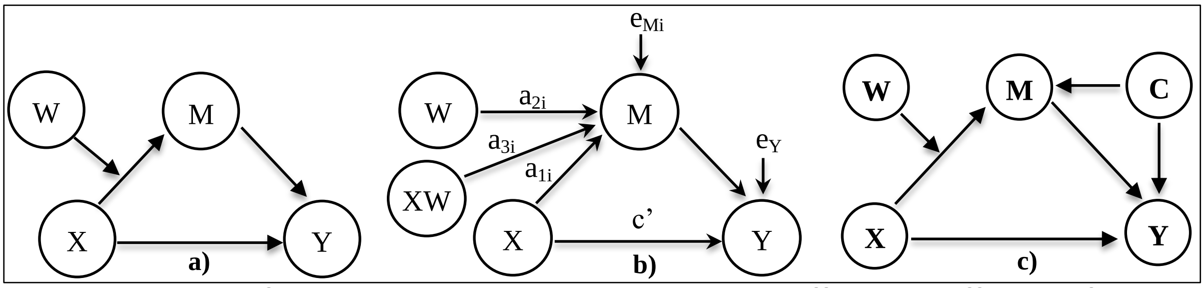

Fig. 2 a) Diagram of the moderated mediation model 7 b) The efficiency coefficients of model and c) The covariate variable of model.

The relative humidity (%) and the outdoor temperature (°C) values at the location of the villa are given in Fig. 3. The values of the outlet water temperature (°C) of the air source heat pump for cooling and the values of the outlet water temperatures (°C) of the fan coil unit after cooling, the wind velocity (m/s) values at the location of the villa are shown in Fig. 4 [52-53]. The location of the villa, where the air source heat pump and fan coil units are installed, is known as Çengelköy, Üsküdar, Istanbul, Turkey.

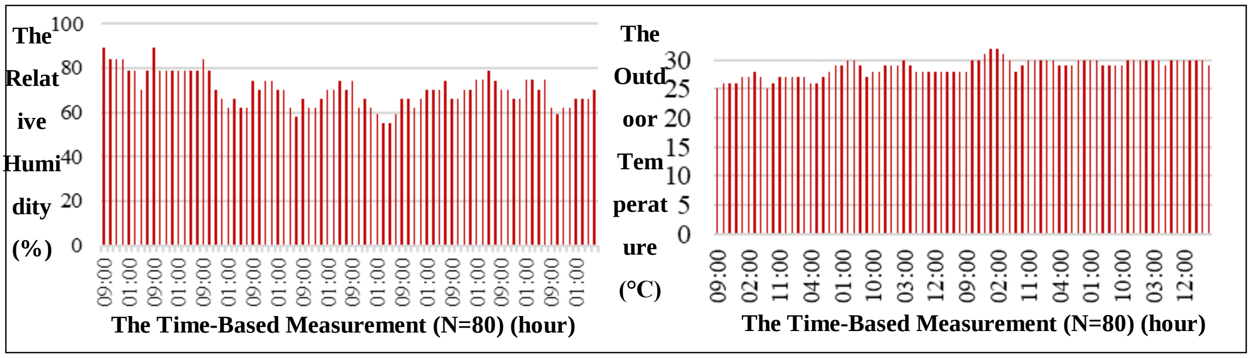

Fig. 3 The relative humidity (%) and the outdoor temperature (°C) values of Çengelköy region of Üsküdar district of Istanbul City of Turkey [52-53].

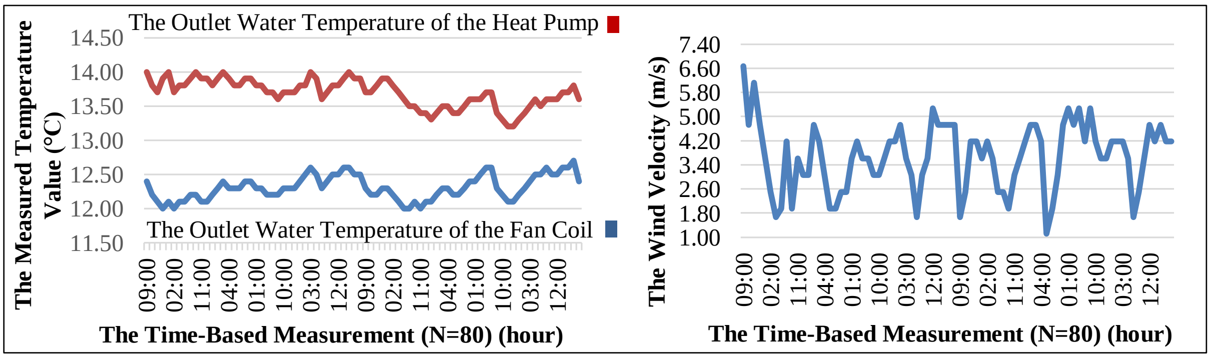

Fig. 4 The water temperature entering the fan coil, the water temperature entering the heat pump, and the wind velocity (m/s) values of Çengelköy/Üsküdar/Istanbul/Turkey [52-53].

4. Results

The moderated mediation model was investigated using IBM SPSS Statistics 26 program. In the moderated mediation model 7, the **X** variable represents the water temperature entering the air source heat pump (the outlet water temperature of the fan coil unit) (°C), the **Y** variable represents the outlet water temperature of the air source heat pump (the water temperature entering the fan coil unit) (°C), the **M** variable represents the outdoor temperature (°C), the **W** variable represents the relative humidity (%), and the **C** variable represents the wind velocity (m/s). The variables are used in the moderated mediation model as shown below (Fig. 2c). Scientifically, when the number of variables and the relationships between them are taken into account, the seventy model of analysis was used in the study. The moderated mediation model, as explained in section 3.3, is composed of two parts: the mediation model and the moderation model. The first part (symbolized by model 7-a) represents the mediation module, while the second part (symbolized by model 7-b) represents the moderation model.

The mean, the skewness values and kurtosis values of the variables used in moderated mediation model 7 are shown in Tab. 1. The skewness and kurtosis values of the variable of model were determined to be between -1.5 and +1.5 when these values were examined.

Tab. 1 Normality analysis results of variables used in the moderated mediation model

	X	**Y**	**M**	**W**	**C**
Mean	13.6913	12.3075	28.7125	70.3000	13.2125
Skewness	-0.5052	0.1753	-0.4454	0.3063	-0.1533
Kurtosis	-0.4405	-0.8306	-0.2786	-0.3792	-0.1783

The coefficients of the mathematical model and the relationships between M variable defined as a mediator, X variable, W variable in the external environment, and C variable defined as a covariate and interaction variable (Int-1) are shown in Tab. 2 The variables in Tab. 2 were used to create model 7-a in the first part of the moderated mediation model 7 (process model 7 analysis) .

Tab. 2 The results of model 7-a were created with the mediator variable outdoor temperature, the water temperature entering the air source heat pump and the grouped data of relative humidity.

Model Result – Model 7-a Outcome Variable: The Outdoor Temperature °C						
R	**R-square**	**MSE**	**F**	**df1**	**df2**	**p**
0.8843	0.7820	0.5417	67.2639	4.0000	75.0000	0.0000
	coeff	**se**	**t**	**P**	**LLCI****	**ULCI*****
Constant	27.7466	0.3012	92.1089	0.0000	27.1465	28.3467
X	-2.3562	0.4243	-5.5535	0.0000	-3.2014	-1.5110
W	-0.1207	0.0136	-8.8629	0.0000	-0.1479	-0.0936
Int-1*	-0.2950	0.0725	-4.0685	0.0001	-0.4395	-0.1506
C	0.0818	0.0215	3.8124	0.0003	0.0391	0.1246

* Interaction variable (Int-1): Water Temperature Entering the Air Source Heat Pump x Relative Humidity ** LLCI: Low Limit of Confidence Interval *** ULCI: Upper Limit of Confidence Interval

It was found that model 7-a is statistically significant in the 95% confidence interval (p=0.0000>0.05), and the variance analysis based on the F value is statistically significant (F=67.2639 > 0). The model 7-a explains meaningfully 78,20% (R-square=0,7820) of the study data. According to the model 7-a variables, $\mathbf{H_0}$ is explains that there is no significant relationship between X variable, W variable, M variable, and C variable, $\mathbf{H_1}$ is explains that there is a significant relationship between between X variable, W variable, M variable, and C variable, $\mathbf{H_2}$ is explains that there is no significant relationship between the Int-1 variable and M variable, and $\mathbf{H_3}$ is explains that there is a significant relationship between the Int-1 variable and M variable.

It was found It was found that the coefficient, lowest and highest effects for the constant value, the X variable, the W variable, the Int-1 variable, and the C variable in model 7-a are significant (p=0.000<0.05, b_X: -2.3562, b_Y: -0.1207, $b_{Int\text{-}1}$: 0.0818, b_C: -0.2950). If X variable is 0 °C, M variable is 27.7466 °C. The Int-1 variable is defined as the interaction between X variable and M variable. There is no zero between the lowest and highest effects of the X, M, W, C, and Int-1 variables ($LLCI_X$:

-3.2014, $ULCI_X$: -1.5110; $LLCI_Y$: -0.1479, $ULCI_Y$: -0.0936; LLCI $_{Int-1}$: 0.0391, ULCI $_{Int-1}$: 0.1246; $LLCI_C$: -0.4395 $ULCI_C$: -0.1506). So, H_1 and H_3 hypotheses can't be rejected, whereas H_0 and H_2 hypotheses are rejected. The mathematical equation of model 7-a which is established with the coefficients of variables in Tab. 1 is shown by Eg. (6). It is shown in Tab. 3 that W variable influences the relationship between X variable and mediator M variable by 4.81% (R^2-chng=0.0481, p=0.0001 <0.05). Since the prediction equation Eq. (6) ise obtained according to the "mean center for the construction of product criteria", there is no units in the equation.

$$M = 27.7488 + (-2.3562)X + (-0.1207)W + (-0.2950)XW \quad (6)$$

Tab. 3 The interaction effect of relative humidity is defined as the mediator variable in model 7-a.

	R^2-chng	F	df1	df2	p
XW	0.0481	16.5529	1.000	75.000	0.0001

The results of the covariance matrix shown in Tab. 4 indicate a negative correlation between the W variable and the X variable, a negative correlation between the C variable and the X variable, and a negative correlation between the C variable and the W variable. In addition, the change in variable x (0.1800) is greater than the change in W variable (0.0002) and the W variable (0.0005). Fig. 5 offers a visual representation of the variance and correlation graph of the variables based on the results of the covariance matrix.

Tab. 4 The covariance matrix of the moderated mediation model 7-a

	X	W	C
X	0.1800	-0.0014	-0.0002
W	-0.0014	0.0002	-0.0001
C	-0.0002	-0.0001	0.0005

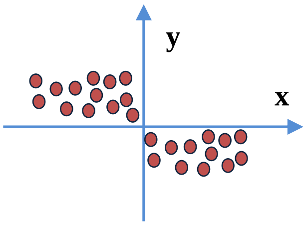

Fig. 5 Covariance matrix graph of the moderated mediation model 7-a

By taking into account the statistical conditioning value "-1SD, means, +1SD" and "mean center for the construction of product criteria" by model 7-a analysis, Tab. 5 shows the effect of W variable in location on the relationship between X variable and M variable. Since the -1SD value of W variable,is is not significant (p=0.8969, LLCI: -1.4262, ULCI: 1.2515), the H_4 hypothesis cannot be rejected. The H_5 and H_6 hypotheses cannot be rejected. Becauce the p-values of the means and +1SD values of relative humidity are significant (p<0.05 LLCI: -3.2014, ULCI: -1.5110 and LLCI: -6.0758, ULCI: -3.1744). According to effect of W variable in model 7-a, **H_4** hypothesis is the relationship between X variable and M variable is unchanged by the low W variable values, **H_5** hypothesis is the relationship between X variable and M variable is influenced by the medium W variable values, and **H_6** hypothesis is the relationship between X variable and M variable is influenced by high W variable values.

Tab. 5 Effect of relative humidity in model 7-a according to the order of the statistical conditioning value "-1SD, means, +1SD"

The Relative Humidity (%)	Effect	se	t	p	LLCI	ULCI
-7.6909 (-1 SD)	-0.0873	0.6721	-0.1300	0.8969	-1.4262	1.2515
0.0000 (0.0000)	-2.3562	0.4243	-5.5535	0.0000	-3.2014	-1.5110
7.6909 (+1 SD)	-4.6251	0.7282	-6.3512	0.0000	-6.0758	-3.1744

Tab. 6 shows the correlations between Y variable, the mediator M variable, X variable, and C variable functioning as a covariate. Model 7-b is the model that was developed using these variables.

Tab. 6 Results of model 7-b include the water temperature entering the fan coil unit, the outdoor temperature, the water temperature entering the air source heat pump and the wind.

Model Result – Model 7-b Outcome Variable: The outlet water temperature of the air source heat pump (The water temperature entering the fan coil unit) °C						
R	**R-square**	**MSE**	**F**	**df1**	**df2**	**p**
0.4998	0.2498	0.0246	8.4335	3.0000	76.0000	0.0001
	coeff	**se**	**t**	**P**	**LLCI***	**ULCI****
Constant	11.0141	0.3725	29.5707	0.0000	10.2722	11.7559
X	0.3602	0.0990	3.6370	0.0005	0.1630	0.5575
M	0.0399	0.0130	3.0665	0.0030	0.0140	0.0659
C	0.0111	0.0044	2.4991	0.0146	0.0023	0.0199

* LLCI: Low Limit of Confidence Interval-lowest effect ** ULCI: Upper Limit of Confidence Interval-high effect

The p-value and F value of model 7-b are significant ($p=0.0001<0.05$, $F=8,4335<0$ 95% confidence level). It was found that the coefficient, lowest effect and high effect for constant value , the X variable, the M variable and the C varlable are significant in the model 7-b ($p<0.05$, b_{CV}:11.0141, b_X:0.3605, b_M: 0.0399, b_C: 0.0111). There is no zero value between the low limit of confidence interval and the upper limit of confidence interval of all variables ($LLCI_{CV}$: 10.27.22, $ULCI_{CV}$: 11.7559; $LLCI_X$: 0.1630, $ULCI_X$: 0.5575; $LLCI_M$: 0.0140, $ULCI_M$: 0.0659 and $LLCI_C$: 0.0023, $ULCI_C$: 0.0199). So, H_7, H_8, and H_9 hypotheses cannot be rejected. According to the model 7-b, $\mathbf{H_7}$ hypothesis is Y variable is influenced by the mediator variable of M variable, $\mathbf{H_8}$ hypothesis is Y variable is influenced by the covariate variable (C variable), and $\mathbf{H_9}$ hypothesis is Y variable is influenced by X variable.

Eq. (7) clearly shows the mathematical equation for model 7-b, which reveals the effect of the mediator M variable, the covariate C variable, and X variable on the temperature of Y variable. Since the prediction equations Eq. (7) and Eq. (8) are obtained according to the "mean center for the construction of product criteria", there are no units in the equations.

$$Y = 11.0141 + 0.3602\,X + 0.0399\,M + 0.0111\,C \tag{7}$$

Tab. 7 and Eq. (8) show the direct effect of the water temperature entering the air source heat pump on the outlet water temperature of the air source heat pump. The coefficient, lowest value, and high value of direct effect are significant (p=0.0005, LLCI: 0.1630, ULCI:0.5575).

$$Y = 0.3602\,X \tag{8}$$

Tab. 7 The direct effect of the water temperature entering the air source heat pump on the water temperature entering the fan coil unit

Effect	se	t	p	LLCI	ULCI
0.3602	0.0990	3.6370	0.0005	0.1630	0.5575

By considering the statistical conditioning value "-1SD, means, +1SD" and "mean center for the construction of product criteria" by model 7-b analysis, Tab. 8 shows the indirect effect of relative humidity in the location between the water temperature entering the air source heat pump and the outlet water temperature of the air source heat pump.

The H_{10} hypothesis is rejected because in fact that there is zero value between the low limit of confidence interval and the upper limit of confidence interval (LLCI: -0.0763<0< ULCI: 0.0438) of the low values of relative humidity. The H_{11} and H_{12} hypothesis could not be rejected because in fact that there is not zero value between the low limit of confidence interval ($LLCI_{LRH}$: -0.2059, $LLCI_{MRH}$: -0.3658) and the upper limit of confidence interval ($ULCI_{LRH}$: -0.0225, $ULCI_{MRH}$: -0.0494) of the medium values of relative humidity (The indirect effect: -0,0941) and the high values of relative humidity (The indirect effect: -0.1848). According to indirect effect of W variable in the model $\mathbf{H_{10}}$ hypothesis is the relationship between X variable and Y variable is effected by the low W variable values, $\mathbf{H_{11}}$ hypothesis is the relationship between X variable and Y variable is effected by W variable value, and $\mathbf{H_{12}}$ hypothesis is the relationship between X variable and Y variable is effected by W variable values.

Tab. 8 The indirect effect of relative humidity in the model

The Relative Humidity (%)	Effect	se	LLCI	ULCI
-7.6909	-0.0035	0.0296	-0.0763	0.0436
0.0000	-0.0941	0.0465	-0.2059	-0.0225
7.6909	-0.1848	0.0798	-0.3658	-0.0494

*The water temperature entering the air source heat pump °C -> The outdoor temperature °C -> The water temperature entering fan coil unit °C

The 95% confidence interval for the index of moderated mediation did not contain zero (b=0.0118, SE=0.0050, 95% CI: [-0.0222, -0.0034]), suggesting that there were differences between the indirect effects between the different levels of the moderator. The moderated mediation effect of relative humidity on the model is negative. The values are shown in Tab. 9.

Tab. 9 The moderated mediation effect of relative humidity in process analysis model

Effect	se	LLCI	ULCI
-0.0118	0.0050	-0.0222	-0.0034

The relationships between the mediator variable (outdoor temperature), the moderator variable (relative humidity), and X variable were revealed by the moderated mediation model. The graph of the interaction between the variables using (Sytax/SPSS) the codes obtained as a result of the analysis is shown in Fig.6. IBM SPSS produced the code based on the model analysis results, taking into account the relationships between variables, the error rate, and the standard deviations of the data.

```
DATA LIST FREE/
  HPEWT RH OUT_TEMP.
BEGIN DATA.
   -,2026   -7,6909   29,7739
    ,0000   -7,6909   29,7562
    ,2026   -7,6909   29,7385
   -,2026     ,0000   29,3050
    ,0000     ,0000   28,8276
    ,2026     ,0000   28,3501
   -,2026    7,6909   28,8362
    ,0000    7,6909   27,8990
    ,2026    7,6909   26,9618
END DATA.
GRAPH/SCATTERPLOT=
 HPEWT WITH OUT_TEMP BY RH.
```

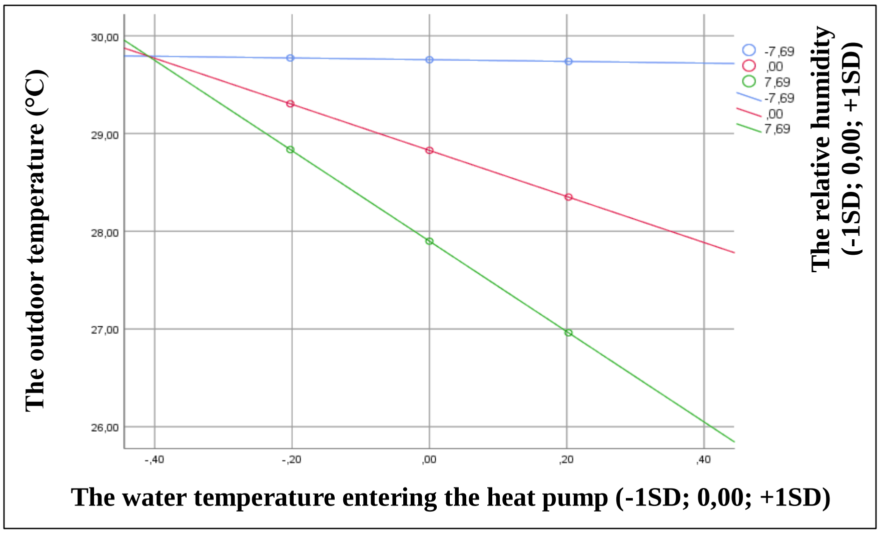

Fig. 6 The graph of the interaction between the mediator variable outdoor temperature, the water temperature entering the air source heat pump and the moderator variable relative humidity

The moderated mediation model was analyzed as using SPSS. The resulting mathematical results are shown in Fig. 7.

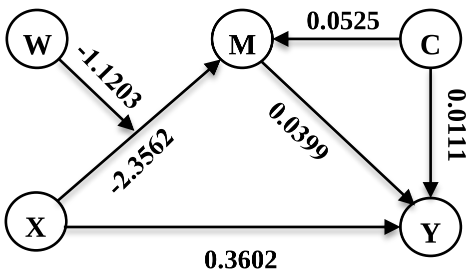

Fig. 7 The representation of mathematical coefficients obtained using SPSS on the diagram

5. Discussion

The relationship between the water temperature entering the air source heat pump and the outdoor temperature is unaffected by low values of relative humidity. However, It is discovered that the indirect effect medium values of relative humidity and high values of relative humidity have a significant effect on the relationship between the water temperature entering the air source heat pump and the water temperature entering the fan coil. It is observed that the effect of a high relative humidity value is greater. While creating or selecting the air source heat pump and fan coil unit, this effect should be taken into consideration.

The increment in the outdoor temperature causes a negative effect on the water temperature entering the air source heat pump from the fan coil unit according to moderated mediation model due to the fact that its temperature has a mediated effect on the relationship between the outlet water temperature of the air source heat pump and the water temperature entering the air source heat pump

The increment in the wind velocity, the outdoor temperature, and the water temperature entering the air source heat pump cause the increase in the water temperature transmitting the fan coil units from the air source heat pump. Due to the rise in outdoor temperature, the outlet water temperature of the fan coil unit doesn't quite sufficiently cool the rooms of villa. If it did, the outlet water temperature of the fan coil unit would be higher because it would be absorbing the heat from the rooms of the villa.

The increase in relative humidity changes the outdoor temperature in a way that negatively affects the efficiency of the air source heat pump. However, it was observed that the increase in the wind velocity at the location of the measurements enhanced the outdoor temperature. this is due to the increase in evaporation as wind velocity increases. The increase in evaporation decreases the relative humidity. This meteorological information explains the negative relationship between wind and relative humidity. Due to this interaction, it is observed that the water temperature entering the air source heat pump will not increase as quickly as is required.

The fact that relative humidity negatively effects the relationship between the water temperature entering the air source heat pump and the outdoor temperature and the mathematical equation that can be used to guide the design should not be disregarded by the designers or engineers.

It is seen that wind velocity, the indirect effect of medium and high relative humidity values negatively affects the relationship between the temperature of the water entering the air source heat pump and the temperature of the outlet water temperature of the air source heat pump. So, it is essential to consider the effects of the outdoor temperature, the wind velocity, and the relative humidity to design and select the air source heat pump component (evaporator) that absorbs heat from the water used to cool the rooms of the villa.

If there weren't any additional variables in the model, the observed effect of the water temperature entering the air source heat pump on the water temperature exiting the air source heat pump would be higher. Because the results of the model produced with two variables will be scientifically inaccurate, such a study is not suggested.

The relative humidity and wind velocity have a negative effect on the outdoor temperature, which prevents the heat pump from providing heat within the planned design conditions. The compressor, evaporator, and condenser capacity must be increased in order to reduce this negative effect. However, because increasing capacity requires more electrical energy, it may be a solution to produce electricity from solar energy when solar radiation is suitable and use this electricity in a heat pump. Additionally, electricity can be produced from waste heat in areas where there is waste heat by using the ORC System (Energy Production from Waste Heat).

6. Conclusions

The effect of relative humidity, defined as a mediator variable, on the relationship between the water temperature entering the air source heat pump and the water temperature entering the fan coil unit was found to be -1.18%. In other words, because the relative humidity increases, the water temperature entering the air source heat pump and the water temperature entering the fan coil unit cannot reach the temperatures under the design conditions and are negatively affected. An increase in relative humidity corresponds to an increase in sensible temperature, and the heat absorbed from the fluid cannot be transferred to the source by the air source heat pump. So, the water temperature entering the fan coil unit is negatively affected by this condition.

According to studies in the literature, the compressor cannot remove heat from the system in high outdoor temperatures, and the evaporator cannot absorb heat effectively. As the data in Tab. 2, and Tab. 6 of this study are examined, it is concluded that an increase in relative humidity has a negative effect on the water temperature entering and leaving the air source heat pump. The outdoor temperature, relative humidity, and wind velocity must be considered while designing the air source heat pump's fan coil unit, evaporator and condenser according to the information acquired and analysis carried out.

The relative humidity effects the relationship between the water temperature entering the air source heat pump and outside temperatures by approximately 4.81%. Due to the effect of relative humidity, it turns out that the water temperature entering and leaving of the heat pump rise differently from the design conditions, and the air source heat pump cannot transfer sufficient energy to the external environment. The fan coil unit cannot therefore cool the rooms of the villa in accordance with the design parameters.

It has been found that changing one of the parameters in the outdoor conditions causes a change in the water temperature entering the air source heat pump value and the water temperature entering the fan coil unit value. Thanks to the mathematical equation (Eq. 2) created with the moderated mediation model, outdoor conditions, the water temperature entering the air source heat pump values, and the water temperature entering the fan coil unit values can be estimated. According to the model results, an increase in relative humidity decreases (negative effect) outdoor temperature whereas an increase in wind velocity raises (positive effect) outdoor temperature ($p < 0.005$, b_{RH}: -1.1203, b_{WV}: 0.0525). Mathematical equation created as a consequence of the investigation can be used to generate homogeneous and statistically accurate results with the outdoor environment data in different locations. As a result, utilizing outdoor data, it is possible to estimate the temperature of the water entering the heat pump and the temperature of the water entering the fan coil for different locations.

It has been found that low relative humidity levels have no effect on the temperature of the water entering and leaving the fan coil and heat pump (LLCI: -0.046 < 0 < ULCI: 0.0438). It was found that medium (b=-0.941, CI: [-0.2054, -0.0250]), and high (b=-0.1848, CI: [-0.3608, -0.0534]) relative humidity prevent the water temperature entering and leaving the heat pump and fan coil from reaching the design conditions and negatively affect the outdoor temperature (b=-1.1203, CI: [-1.4183, -0.8223]). It is observed that the effect of high relative humidity values is twice as great as the effect of medium relative humidity values.

Abbreviations and Indices

IBM	International Business Machines
SPSS	Statistical Package for the Social Sciences
LLCI	Low Limit of Confidence Interval
ULCI	Upper Limit of Confidence Interval
Coeff	Coefficient
t	T-Test Value
p	Significance Value
%	Percent
GWh	Giga Watt Hours
COVID-19	Coronavirus 2019
SME	Small and Medium Enterprises
°C	Degrees Celsius
m	metre
s	second
R	Correlation Value
MSE	Mean Squared Error
se	Standart Error
F	F-test Value
df	Degress of Freedom
SD	Standard Deviation
HVAC	Heating, Ventilation, and Air Conditioning
LRH	Low Relative Humidity
MRH	Medium Relative Humidity
CO_2	Karbondioksit
RH	Relative Humidity
WV	Wind Velocity

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