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Designing a passive-cooling, sustainable windcatcher in hot, dry area

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ABSTRACT

This research article presents possibility of designing a sustainable windcatcher within the concept of earth-"air heat exchange" (EAHE) natural ventilation and passive cooling in hot, dry climate (Baghdad city) and to examine the impact of increasing area of the windcatcher and movement of air through buried pipe that end inside the building, and it is used for natural air movement the building is located in Baghdad. An experimental device was assigned to determine the temperature at different points during the airway that appeared from the introduction of an airflow, measured in July 2019. The results were compared with a computer simulation program (Trnsys 16), the presence of similarities was confirmed. To improve performance heat exchange (EAHE), various variables were simulated, including tube length, diameter, vertical path length, and burial depth. The heat exchange has proven important in a hot, dry climate, and passive cooling one of the most acceptable concepts and it's economical too. The proposed design achieves thermal comfort and natural ventilation for a sustainable building and a source of renewable energy.

Keywords: Natural Ventilation, Environment, Heat Exchanger, Passive Evaporative, EAHE.

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1. Introduction

The increasing energy demand in buildings is a major issue around the world nowadays. It has been recognized by many researchers and experts as one of the modernization's main challenges in the 21st century [1]. The importance of this challenge should not be underestimated, especially with the increasing demand for housing and the great pollution that affects all aspects of the environment around us [2-4]. More than 65 per cent of the global power is consumed in buildings. As a result, more than 30 per cent of greenhouse gases is associated with the buildings' operation [1-3]. One of the main energy sources consumptions in buildings is associated with achieving human thermal comfort specifically cooling and heating systems.

Therefore, an important topic in today's academia is how to reduce energy dependence, thus energy expenditure, in buildings while achieving thermal comfort for the users [5]. Because passive cooling systems can have a significant impact on reducing energy consumption in buildings, especially in hot and dry climates, such systems should be examined thoroughly in Iraq. Moreover, passive cooling specifically traditional windcatchers have been in-use in Iraq centuries before the introduction of electricity and active air conditioning and ventilation systems [6]. Finally, natural ventilation often led to better indoor air quality IAQ compared to close loop air-conditioning systems, thus overcoming problems caused by mold and fungi that contaminate the cooling coils and air impellers that cause many diseases, including depression and lethargy due to prolonged exposure [2].

One of the promising passive design options for minimizing energy use of ventilation and cooling in buildings is "Earth-Air Heat Exchanger" ("EAHE") system beside modern windcatchers. This system's effectiveness relies on temperature variation between earth heat and outside air, which is related to depth of the soil and its physical properties [3].

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Many researchers from different countries have touched on the development of heat exchanges with multiple technologies. "Al Ajmi and al". [4]. Try to use simulated apartment buildings in the desert climates of EAHE cooling system results show that "heat exchange" reduced the internal temperature by a slight difference through peak summer time. As for "D. Belatrache and al". [7]. Advanced an exchange "simulation" (EAHE). For home air conditioning, the system is distinguished and energy saving. And well Agrawal, K.K and al. [8]. A comprehensive review of the literature and developing of the EAHE system as a promising passive technology utilizing soil temperature. In order to integrate the system's economics and enhance acceptability. Either study N. Rosa and al. [9]. By the influence's numerical evaluation of pipe diameter parameters, spacing between tubes and velocity of air flowing on EAHE thermal performance of residential buildings, it is shown that "thermal performance" system decreased as the air velocity increased.

These and other studies [10-11] have demonstrated the development of "Earth-to-Air Heat Exchanges" ("EAHE") technologies. To improve passive evaporative cooling, increase ventilation efficiency. However, no experimental study of a building's heat exchange has been conducted by employing windcatchers for this purpose. The basic concept of that study is suggesting a field study and "numerical simulation" "earth-to-air heat exchange" (EAHE) by increasing the section of windcatcher and that part of the windcatchers are underground, i.e. increasing air movement and achieving heat exchange with wet walls and buried pipes, which can reduce the air temperature. The air's movement through the entry windcatchers' hole and its transfer to vertical passages and underground pipes due to the difference in the air's pressure column between the outside and the inside, contributes to increasing heat exchange, and to bring refreshing cool air indoors in summer, improving thermal comfort for residents and reducing energy dependence.

2. Proposed thermal system

The proposed thermal system represents the traditional windcatcher system development consisting of vertical passage and tubes buried underground. The vertical corridor is the vertical part of the air suspension with a larger cross-sectional area. The air vent facing the prevailing air movement is equipped with a foamed synthetic rubber filter to purify the incoming air, then vertical passages represented by two parts. The first continues to the ground level and lined with porous bricks. It contains a spraying system water on the walls to continue wetting it with water. The second part is a continuation of the first part, which is inside the ground with a depth of 2 m then to two sets of tubes made of buried clay buried underground, ending with an opening inside the building equipped with a fan to inflate the air in, the air moves due to the difference in air column pressure between outside and the inside. The vertical passage and the tube buried underground play role the ground-air heat exchange. Through vertical corridors and horizontal pipes Fig. 1. This study considers that "the surrounding land has an unchanging and uniform thermos physical property".

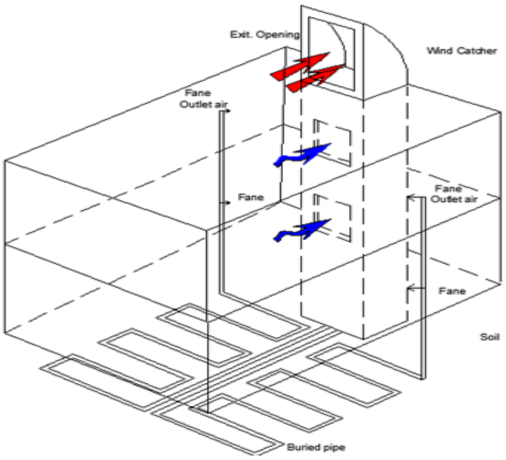

Figure 1. Model of heat exchanger (EAHE) and air movement

2.1. Model soil temperature

To determine the heat exchange between air and earth, we have to analyze the study site's soil that receives part of the vertical passage of air movement and the buried underground tubes through which the energy exchange takes place. Integrated with Trnsys 16 Blog in its dynamic accounts [12]. Which gives a calculation of the earth's temperature with a difference in depth, the mathematical model is instituted on thermal conductivity property of heat diffusion within a solid mass, the ground temperature is determined with the next equations:

$$T(Z,t) = Ts + As * [Exp - (Z)\sqrt{\pi / 365\alpha}] * Cos\{2\pi/365 * [(t - to) - (Z/2) * \sqrt{365/\pi\alpha}]\} \qquad (1)$$

If you consider Z = ∞, be the equation on the following image:

$$T(\infty,t) = Ts \qquad (2)$$

If we consider Z = 0, equation for a difference soil surface temperature is as follows:

$$T(0,t) = Ts + As * Cos\{2\pi/365 * (t - t\,o)\} \qquad (3)$$

Through the equations, various indicators can be defined to determine the evaluation of the earth's activity determined by the climatic zone, soil depth, soil surface temperature, frequency and spread, as shown in Figure 2 [13] .

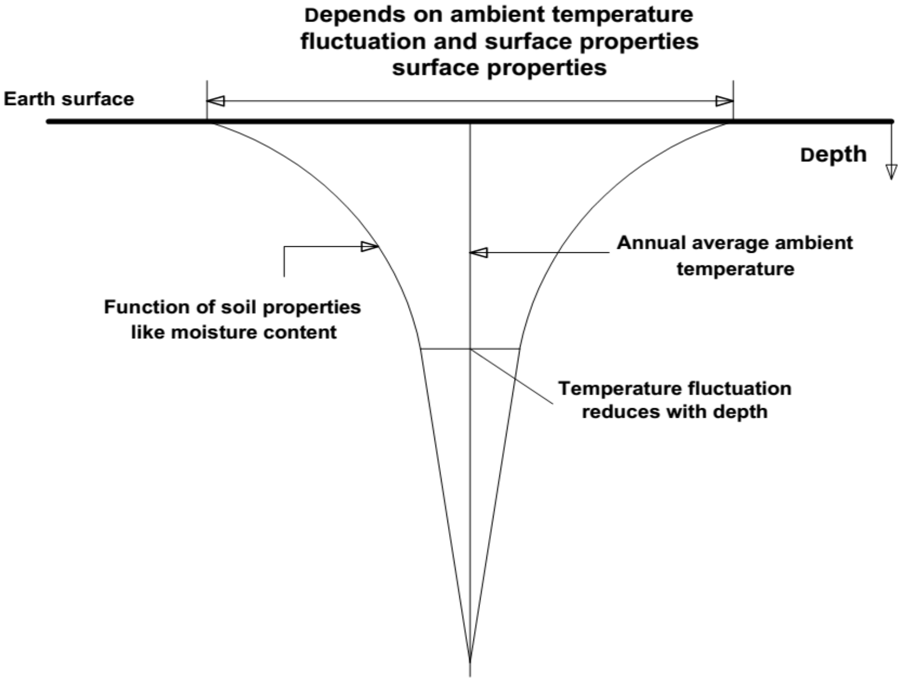

Figure 2. As the depth of the earth changes, the temperature of the earth changes [13]

2.1.1. Climate properties on the earth temperature

Earth thermal storage is a catalyst for the geothermal aid development, for this it is necessary to conduct a preliminary assessment of the climatic indicators of the study area, depending on the surrounding environment temperature, wind speed and solar radiation, the earth's temperature for the specified depth and the nature of the earth. The Baghdad city was chosen within the Iraqi central regions. It has a semi-desert climate (hot, dry summer). The average daily radiation intensity 7.30 kw/m^2. The average daily temperature is 40°C and it reaches 51°C at midday in July, it drops to 19°C at night or more. The winds are northwest, relative humidity (RH) inter 24% in July and 73% in December [14]. Table 1 and Figure 3 illustrates the wind

For the study area. Summer cooling is desirable, while heating in winter is not effective, so research requires about energy alternatives to reduce dependence on electricity, including utilizing ground water and soil temperature to reduce temperature and improve natural ventilation.

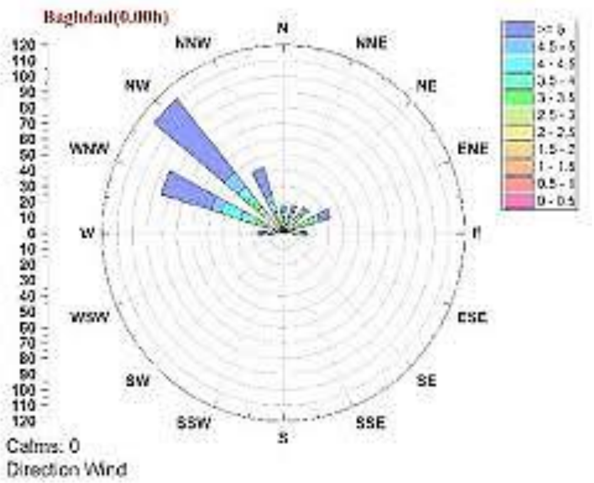

Figure 3. The chart shows the wind direction in study region [14]

Table 1. Wind properties at study area [15]

Monthly averages of wind velocity (m / s) and wind direction in the study area													
Baghdad	**Jan**	**Fed**	**Marc**	**Apri**	**May**	**Jun**	**July**	**Augu**	**Septe**	**Octo**	**Nove**	**Dece**	**Annual rates**
	2.8	**3.2**	**3.6**	**3.4**	**3.6**	**4.3**	**4.6**	**4.1**	**3.1**	**2.7**	**2.5**	**2.6**	3.4
Wind direction in proportion													
	N	**N-E**	**E**	**S-E**	**S**	**S-W**	**W**	**N-W**					
January	**7.7**	**2.6**	**6.1**	**14.8**	**4.9**	**4.6**	**13.8**	**21.0**					
July	**90**	**0.9**	**0.6**	**0.8**	**1.0**	**2.3**	**28.3**	**47.1**					

2.1.2 Ground thermal characteristics simulation

Physical thermal properties of the study sites soil at depth of 2.5 m. Fig. 4 shows the soil temperature ranging between 27.5°C and 12.5°C with the amplitude of 15.0°C. This deviation is justified by the gradient solar radiation and high temperatures. The difference between soil temperatures and ambient air temperature depends on the heat flow provided by soil to geothermal system. In fact, the soil's nature in Baghdad is muddy-sandy. The heat capacity of sandy clay soil is higher than other soils, which affects the soil's thermal penetration.

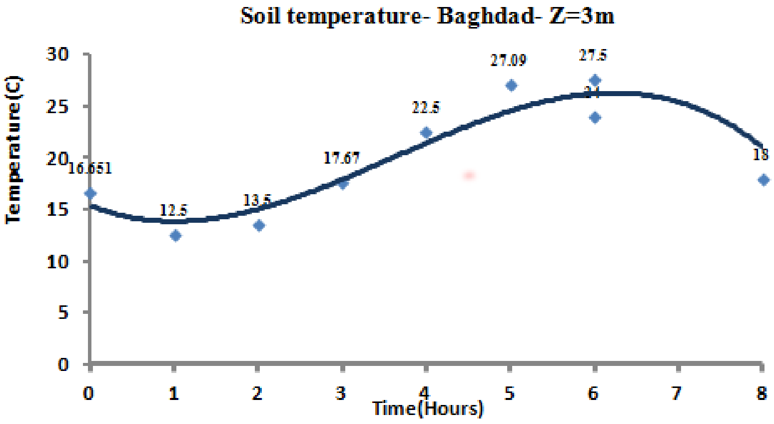

Figure 4. Soil temperature profile at a 2.5m depth (Baghdad)

2.2. Model heat exchanger EAHE

The heat exchange allows air to pass through a buried tube 2 m underground for cooling and heating purposes. In general, at this depth in winter, it is warmer and cooler than outside in summer [16]. The

Trnsys.16 program dealt with the proposed EAHE thermal model, the presence of the vertical corridor surrounded by the earth and the clay tubes buried in soil. The heat transfer inter walls of vertical corridor and the horizontal tubes can be considered symmetric. Through the passage and tubes, the dynamic system of air temperature, velocity and heat exchange is dealt with relying on the energy conservation's principle, gained heat energy from air flowing maybe expresses as follows:

$$\emptyset = \dot{m}_{air} * Cp_{air} * dT(x) = \frac{dx}{Rcnv+Rpipe+Rsoil} * [(T(Z,t) - T(X)] \qquad (4)$$

$$R\ convection = 1/2.\ \pi.\ r2.\ Hconv \qquad (5)$$

$$R\ pipe = \ln\ (r1/r2)\ /\ 2.\ \pi\ .\ \lambda\ pipe \qquad (6)$$

$$R\ soil = \ln\ (r'1\ /r'2)\ /\ 2.\ \pi\ .\ \lambda\ soil \qquad (7)$$

3. Characterization of experimental setup:

3.1. Test cell

An pilot study was conducted in a two-store house with an inner courtyard, walls constructed of lightweight concrete with a thickness of 25 cm (isolated from regular building materials twice), the area of the windcatcher is 2.2 m^2 and the wind direction is northwest. The basic model of the windcatcher was advanced by adding a vertical underground tunnel that represents a continuation of the windcatcher, the windcatcher hatch 1.50 m above the building level, the air intake fan was placed to increase the air flow during the dormant period with an air filter to purify the air and prevent the dust entry, there is a set from the underground pipes, the horizontal pipe diameter is 50 cm, the net height of the air locker is 13.40 m, as in Fig. 1. The thermal design of the test model is based on reducing the heat loss from the wall and floor elements by using insulating materials. As in Table 2.

Table 2. Thermal and physical parameters used in simulation

Matter	Thermal Conductivity (W/m K")	"Density (Kg/m^3)	Specific heat Capacity (J/kg K) "
Air	0.0242	1.225	1006
Soil	0.52	2050	1840
Pottery therapist	0.405	1600	1436
PVC	1.16	1380	900

3.2 Assessment of cooling energy needs

Figure 5 illustrates covering energy needs based heating and cooling energy requirements of test area to be combined to achieve thermal comfort, thus achieving the cooling tank in the ground and the underground water tank. The test model power was evaluated through numerical simulation. An important need during the summer months of August and July, the acceptable temperature is 26°C, and the cooling requirements for Room 1 on the ground floor are 456.5 kw/h. It is lower than Test Room 2, as it is located on the first floor and is exposed to solar radiation.

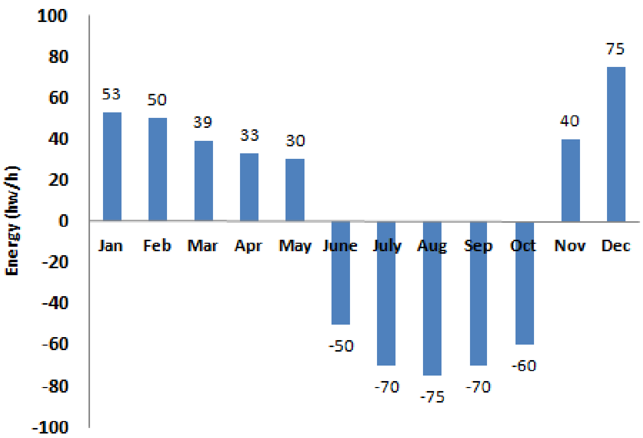

Figure 5. Energy supplied to the proposed system by walls and buried air duct over a year

3.3 Experimental system description

Design the heat exchange system as follows:

- The vertical corridor is the skylight's employment in the building and its continuation underground with a depth of up to 2 m.
- At the vertical corridor's base, two networks of tubes are connected inside the soil with lengths (41 m) (46 m) with a diameter of 50 cm made of high-density fossilized clay chemically treated to prevent fungus growth and bacteria and resistance to weather labourer to surety the quality of heat exchange, the layer surrounding the sand material tubes.
- There is a horizontal slope of 3% to prevent pooling of water inside the pipes.
- Vertical paths of pipe end inside the housing spaces.
- The air intake port is equipped with a fan that works in static wind conditions.
- The air outlet inside the rooms contains a clamp (metal wire) and includes a fan pushes the incoming air has an equal flow rate 90 m^3/hour.
- The lining of the hook air is built from high density bricks (840-1350) it is bespoke not to use reddish-colored low porosity bricks, because it deteriorates and crumbles when used.
- Provides a water spray system on the lining of air locker in the highest part above ground level in the plastic tubes form with a diameter of 40mm containing holes with a diameter of 4mm per 10 cm, providing the system with a water tank to control the flowing water amount.

The air moves from top to bottom to the windcatcher's cavity and the liner moistened with water droplets, and the wet tubes' network due to the soil's groundwater, and the cold air moves in the dwelling space due to difference in the air column's pressure. Fig. 1

4. Results and discussions

4.1. Experimental results

Temperatures were recorded in a room on the ground floor No. (1) and the other on the first floor (2) at the entrance to the windcatcher and the pipes' outlet during the hot period, July 2019, during the period of expressing cooling needs. Fig. 7 shows the air temperatures' evolution for the study model. We note that the heat exchange provides a temperature drop of 6-7°C for room No. (1) and 4-5°C for room No. (2). These readings are for different hours, and it can be said that the heat exchange between air and earth embracing tubes can explain that the heat exchange with the tubes and the soil continues during the night time efficiently during the daytime period. Fig. 6.

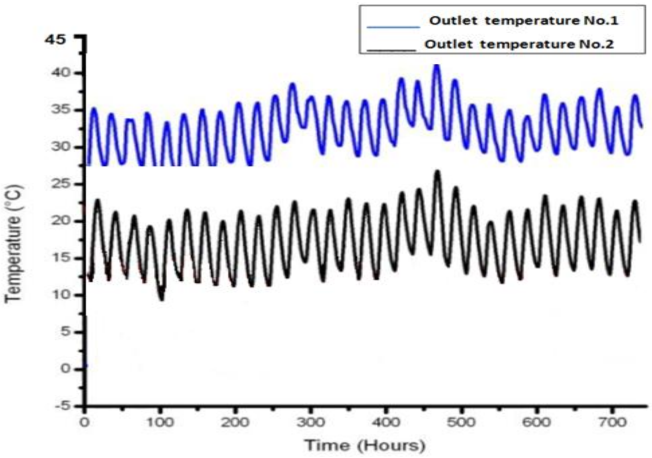

Figure. 6. Air temperature evolution for the two test models at the outlet of the heat exchanger, July 2019

4.2. Simulation and verification through Trnsys16

The proposed simulation was carried out for the two test rooms, taking into account all conditions of the experimental investigation in the air movement presence during the day, for the simulation conditions with experimental investigation of the heat transfer values coefficient. To verify the simulation and the experimental results obtained from measuring the air temperature from the air exit port during the study period, the average temperature recorded for this period is 37.5°C, we note there is an agreement between simulation results and recorded experimental results_with a difference of 0.6°C. Fig. 7 shows difference in air temperature from exit port for experimental simulation from 16.8°C to 25.8°C, and the simulation temperature readings between 16.1°C and 25.2°C.

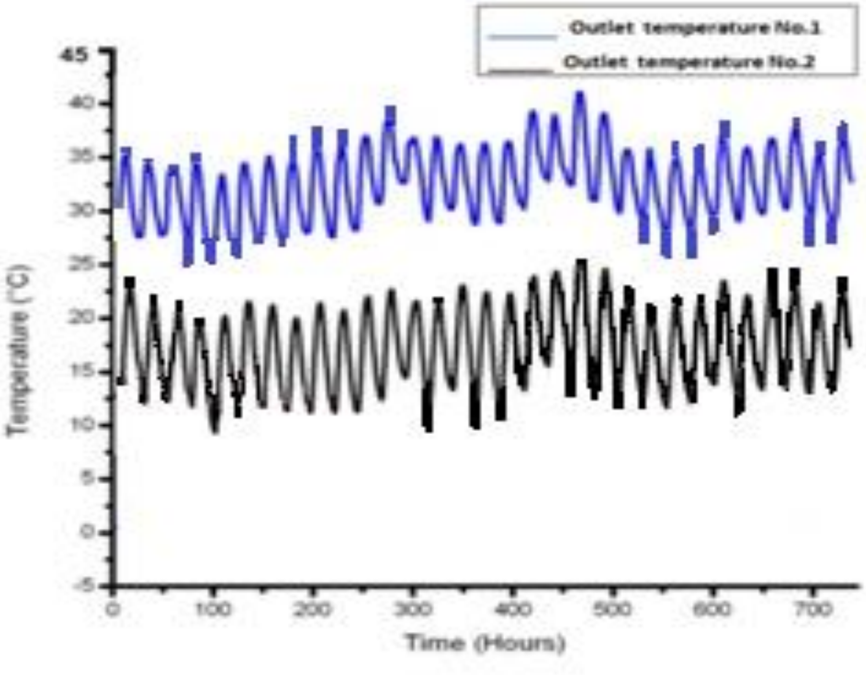

Figure 7. Simulated air temperature of the two test models, July 2019

5. Exchanger evaluation (EAHE) effective improvement

To improve EAHE, we studied in that paper impact we studied in that paper impact for several parameters on air temperature at air outlet for studied period air outlet for studied period. Calculated parameters are tube diameter, pipe length and burial depth. Table 3 shows various values increase of these parameters 20%. Simulations let us study the several parameters in seeing of exchange optimization (EAHE) we hold as a case study.

Table 3. Average ambient air temperatures for different indicators of depth, length and diameter

Month	Ambient air tempe (°C) (20% Depth)			Ambient air tempe (°C) (20% Length)			Ambient air tempe (°C) (20% Diameter)		
	T.min	T.max	Thermal Gradient	T.min	T.max	Thermal Gradient	T.min	T.max	Thermal Gradient
January	10.2	21.7	11.5	1.0	25.8	24.8	0.9	30.5	29.6
February	11.6	22.8	11.2	6.1	29.1	23	6.4	35.9	29.5
March	13.2	24.8	11.6	8.8	32.6	23.8	10.8	39	28.2
April	15	26.6	11.6	12.8	36.2	23.4	14.1	41	26.5
May	18.2	28.9	10.7	13.8	41.7	27.9	16,8	47.4	30.6
June	21.9	32.8	10.5	21.2	44.8	23.6	24.3	48.3	24.3
July	24.5	35.6	11.1	25.9	46.4	20.7	26.9	48.6	21.7
August	25.5	36.8	11.3	25.7	46.8	21.1	27	49.3	22.3
September	22.8	34	11.2	19.4	45.3	25.9	21.5	49.5	26
October	19	30.1	11	15	38	23	16.5	44.8	28.3
November	14.6	25.8	11.3	7.5	32.2	24.7	8.9	37	28
December	12.5	23.3	10.8	6.0	26.8	20.8	1.0	30.6	29.6

5.1. Effect of depth on exchanger (EAHE)

Table 3 shows average twist EAHE outlet according to the depth of the burial. The temperature drop can be seen as depth of pipe burial increases. Reads stability from depth of 2 m, where the temperature is about 18.70°C.

5.2. Pipe length effect

Length is a Factor that is no less Importance than the deepness of its burial in the ground. In fact, for heat exchange, the tube length provides a top surface area with exchange the earth and this decrease the temperature when the air exits. Table 3 shows average air temperature at_exit of EAHE exchange depending on its length. The temperature is observed decreases significantly to 19.7°C with an increase of 30% in length.

5.3. The effect from the internal diameter of the exchanger

The diameter is a parameter that is no less important than other parameters, the average air temperature at outlet of exchange is proportional to the tube's diameter. Note that this temperature decreases dramatically by increasing the diameter until it reaches 21.8°C a diameter within to 360 mm.

5.4. Comparison of thermal comfort limits and results

In summer of 2019, measuring average air temperature at the dry air temperature inside a room (1) of 28.3°C, about 23% RH. The air temperature in a wet thermometer is 17.2°C [17]. The air flow rate is about 1.5 m/s. Hence, the temperature is perceptible for a person in normal clothing (Clo1). Accordingly, in Fig. 8, it will be 22.1°C, and these fall Among the determinants of thermal comfort [18].

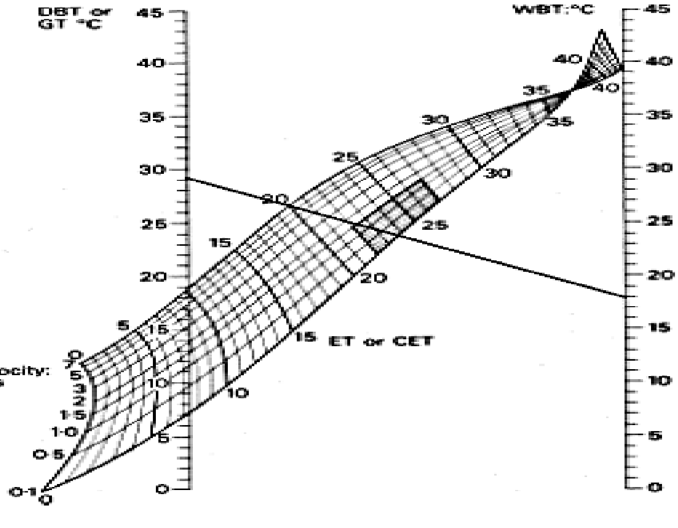

Figure 8. Temperature effective of thermal comfort limits to persons In normal clothes, relation between air speed and air temperature and humidity

6. Conclusions

The building ventilation system within the windcatcher geothermal heat exchange system contributes to reducing the summer temperatures in Baghdad. Experimental results received during the summer cooling need are remarkably distinct. The calculated mean temperature decreases of 9°C, with a 60.33% coverage ratio for refrigeration needs, after they're a perfect match between the results of the experiment and the simulation (Trnsys 16) results obtained.

The heat exchange activation has been studied within specific indicators, including burial depth, tube length, tube diameter with an increase of 20% from the original values, and the evaluation of increasing the exchange values between air tube and the neighboring earth. Use of buried underground pipes and moist air paths can represent a solution to cool the building, and this reduces the energy cost and thus contributes to reducing gas emissions and global warming and achieving a sustainable building.

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