Solar Heating System to Reduce Friaje in High Andean Homes

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Abstract- This research is the applied technological kind and has an applied level it's within the Solar Energy Research line, the purpose is to define the configuration of the solar heating system that has an efficient influence to reduce the cold temperature in high Andean homes. To that aim a solar heating systems was designed, built and installed in the districts located between 3600 m.a.s.l. and 4000 m.a.s.l. in the provinces of Chupaca and Concepcion in Junin, Peru. We used the Systemic method and the cause comparative design, to measure temperature variation within the chamber and the room we made sure the isolation of the room was the best possible state. To test the hypothesis, we used the linear regression and the F statistic test of Fisher to determine the significant coefficients of the model. The outcome of the research states that configuration of the solar heating system should have a smaller volume of the chamber with a bigger area of the collector-accumulator, which will increase the temperature in Andean homes.

Keywords solar energy, heating, Friaje, energy efficiency.

1. Introduction

A total of 409 people died in Peru for pneumonia and diseases related to the cold temperature from January to July in 2010. The "Friaje" caused deaths for pneumonia in children under five years old not only in the Andean region but also in the rainforest region, such as the Loreto region with 23 toddler deceased and six in San Martin and five in Ucayali.[1]

The Friaje is a natural phenomenon that occurs in Peru in the months of June, July and August ranging ambient temperature from 10 ° C to 20 ° C and accompanied by dry air. It has a great impact to Andean settler in poverty.

In recent years, the applications of renewable energy to heating, cooling and drying systems have received a strong boost. [2]

To solve this problematic situation the research question was: What is the configuration of the solar heating system that influences efficiently to reduce the Friaje in high Andean homes? to determine the configuration of solar heating system that can influence efficiently to reduce the Friaje in high Andean homes.

This research contributes to determine a model sizing solar heating system for homes located in high Andean areas, that is to say, housing located between 3600 MASL and 4000 MASL of the Andes, in the districts of Junin region of Peru. These districts, during the months of May, June and July are affected by the Friaje, causing respiratory diseases usually in children and elderly. The importance of this work is that will determine the optimal size of the configuration that allows to store heat during the day to use during the cold night efficiently.

2. Literature Review

Domancic Herrera [3] proposes a solar system of flat collector for air of 60 m2 to be installed on the north roof of the building and a collector type Trombe Wall of 14.5 m2 located on the north side, which also receives an additional contribution of a conventional heating system, which contributes 10% of the energy equivalent to 24 kW.

Chávez Oblitas [4] proposes a similar system to a solar one, made up by a flat plate absorber and heat box system. The absorber plate is the receiving unit of the solar radiation which heats the oil through pipelines in parallel, a heat storage tank in oil and a heat exchanger that heats the air in the room through a serpentine.

SENCICO [5] was the organization that installed 17714 Trombe Walls, in houses located about 3,500 meters above the sea level in the Ayacucho, Apurímac, Arequipa, Pasco, Cusco, Huancavelica, Huánuco, Junín, Moquegua, Puno and Tacna Regions in Peru, where the angles of flat path of the sun varies between 54° and 101° relative to the ground.

Torres [6] concludes that thermal comfort greatly influences physical and mental health of people, because it provides a better predisposition to perform everyday tasks.

Olivares Clavel & Torres Flores [7] propose a dehydrated system what consists of a solar collector of 60 m2, insulated pipelines to transporting hot air, heat storage system in a rock chamber and dehydrating chamber.

Nacif Hartley [8] concludes that “the studied accumulator presents a high degree of stratification, low heat loss, high storage capacity per unit volume, can be implemented with a solar air collector, it has a relatively low economic cost and easy construction and implementation.

The support group for the rural sector at the “Pontificia Universidad Católica Del Perú”, in its “America Renewable” magazine proposes the installation of the Hot Wall Project for the Friaje alleviation in high Andean housing in Cusco, Puno and Huancavelica, this technology uses the principle of Trombe Wall [9]

Sarachitti and others [10] conclude that the solar collector of concrete can raise the temperature of an enclosure in 2.6 °C compared to other conventional.

Arkar y Medved [11] They state that the analysis of the storage performance system of thermal energy of latent heat at different levels of daily solar irradiation has shown that 54% to 67% of the heat produced by the heating system of solar air during the day can be delivered during the night for the heating of the building.

Truong y Gustavsson [12] asseverate that the willingness of integration of solar heating helps it to reduce the use of other primary energy sources such as biomass, but the use of renewable energy in urban setting heating is not profitable yet.

Dabaieh y Elbably [13] affirm that many researchers believe that the successful use of Trombe wall system, passive solar, is to design properly the appropriate size, position and orientation of the components based on the elevation angle of the sun.

Andersen and others [14] conclude that it is possible to lower the cost of energy each year about 25% through the use of solar heating system and a control strategy simple.

Skaarup y Svendsen [15] discuss that the low temperature heating provides an efficient way to heat buildings and to obtain high efficiency, they must be operated with low supply and heat recovery.

Flynn y Sirén [16] conclude that there is great potential for urban heating systems high solar fraction worldwide, as well as for new and existing buildings, as long as there is some adaptation of the original designs to applicable sites.

Seralea, Fabriziob y Perino [17] state that a solar heating system of low temperature based on material suspension of phase-changing is promising, since the collector operated at low temperatures, still provides a stream of satisfactory enthalpy with reasonable mass flow rates, making possible the use of solar energy at lower values of irradiance.

Schwarz [18] has determined the environmental conditions of San José de Quero, the weather is mild and warm, in winter, there is less rainfall than in the summer, and the average annual temperature is 6.9 °C. The hottest month of the year is January with an average of 7.7 °C, and the coldest month of the year is July with an average of 5.3 °C.

3. Methods and Materials

3.1. Type and level of research

The research is of the technological type because the purpose is to apply knowledge about solar energy, heat storage and heating homes. According to Espinoza [19, p. 90] the aims of the technological research is to apply scientific knowledge to solve the various problems that benefit society.

The level of research conducted is applied research because the purpose is to apply technological knowledge to design and build solar heating systems to improve the environmental conditions of the high Andean homes. The aims of the applied research is to apply the results of experimental research to design technologies for immediate application in solving the problems of society. [19, p. 90]

3.2. Method and research design

The method of research used is the systemic one with cause comparative design [19], we related the Solar Heating System variable with the reduction of Friaje in high Andean homes; to avoid external factors by external variable it was controlled the isolation of the room. The scheme used is as follows:

Table 1: Research scheme design

Homes	Measurements	Control variables
H_1	M_1	x, y, z
H_2	M_2	x, y, z
H_3	M_3	x, y, z
H_4	M_4	x, y, z
H_5	M_5	x, y, z
H_6	M_6	x, y, z

Where: H_1, H_2, H_3, H_4, H_5 y H_6 are the homes, which have installed solar heating systems. M_1, M_2, M_3, M_4, M_5 y M_6 are measurements of the temperature variations of the chamber and the room. The houses were controlled according to the isolation of the room (x), the chamber insulation (y) and height above sea level of housing (z).

The heating system is made-up of a hot air storage chamber, an accumulator collector and the room.

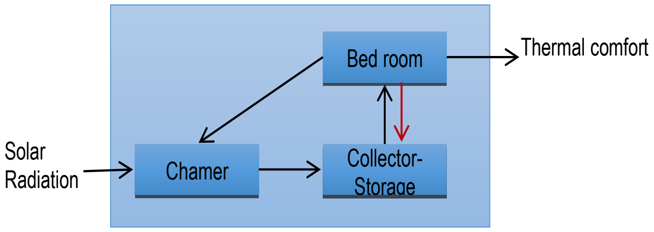

Fig 1: Solar heating system

Each of the elements of the heating system is contributing to their particular functions to generate a comfortable temperature in the room.

Table 2: Function elements of the solar heating system

Element	Function
Chamber	Stores the hot air and insulates the collector-storage environment.
Collector-Accumulator	Solar radiation absorbed by a black body for storage in a storage heat
Bedroom	Transfers the energy captured by the accumulator to the room.
Orientation	It allows for a number of hours of sunshine.

The construction of the heating systems was performed taking into account the dimensions of existing homes, trying to maximize the size of the collector-accumulator. The measurements allowed determining the model that maximizes the heating of the room.

Figure 2 shows the profile of a solar heating system installed against the wall of the housing, which faces north. The cold air of the room enters through the bottom warming from the hot stones and hot air enters the room at the top.

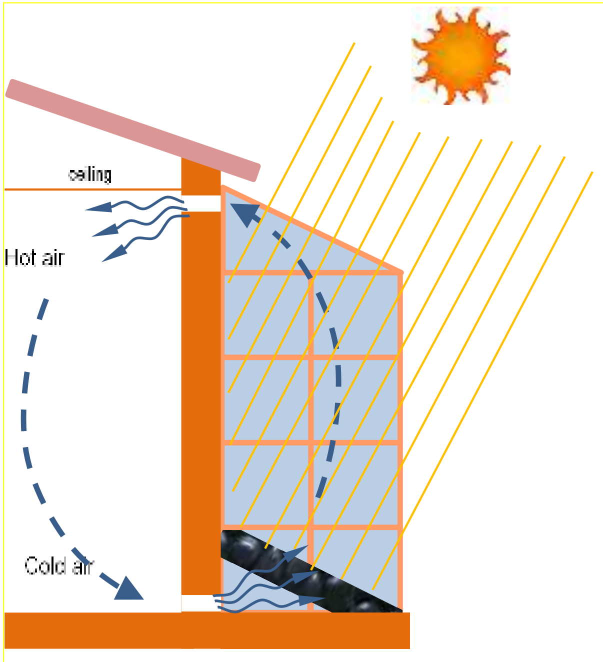

Fig 2: Operation of the solar heating system

3.3. Population and sample

The sample for the study was selected according to the following control variables:

X: Isolation room.

Y: Chamber isolation.

Z: Height above sea level.

Households with solar heating system selected were six, three in the district of San Jose de Quero and three in the district of Yanacancha. They all have a properly insulated room, the camera is insulated properly, and they are located between 3600 m.a.s.l and 4000 m.a.s.l (table 3).

Table 3: Places with Solar Heating System

Homes	Places	X	Y	Z
H_1	Huayllacancha	Good	Good	3834
H_2	Huayllacancha	Good	Good	3900
H_3	Centro	Good	Good	3803
H_4	Quishuar	Good	Good	3652
H_5	Quishuar	Good	Good	3714
H_6	Usibamba	Good	Good	3624

3.4. Techniques and instruments for data collection

In order to obtain the design model has been evaluated six heating systems that meet the control variables.

Fig 3: Solar Heating System

The technique used is empirical, from direct observation. An instrument that measures the temperature and relative humidity were used. The instrument used is the thermometer, hygrometer and anemometer Kestrel® 4200 Pocket Air Flow® Tracker 25.

3.5. Data processing techniques

The descriptive statistics for each variable is: number of valid cases, average and typical deviation.

The statistical for hypothesis testing is linear regression, with which the coefficients of the linear equation is estimated, with the dimensions of the independent variable that predict best the value of the dependent variable.

Two models were tested with temperature variation of the chamber dimension, with the stepwise method of SPSS. With this software, every step is introduced in that dimension of the independent variable that is no longer in the equation and that is likely the smallest F, if that probability is small enough. The dimensions already introduced in the regression equation are removed of it if their probability of F becomes sufficiently large. It ends when there are no more dimensions to be included.

4. Results

4.1. Description of the location of Solar Heating Systems

The six houses selected for measurement are in the districts of Yanacancha and San Jose de Quero, located between 3600 m.a.s.l. and 4000 m.a.s.l. The hours of sunshine received by the collector varies according to the orientation of the house already built is used with the existing orientation. The maximum number of hours of sunshine ranges from 6 to 8 hours and depends on the orientation of the house.

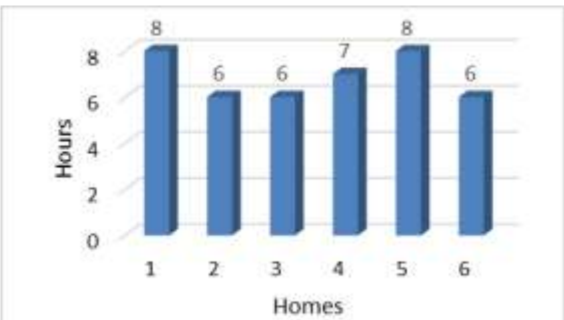

Fig 4: Sample of the longest hours of sunshine

There are three houses in the district of Yanacancha with solar heating system, but the orientation in each house is different, so we selected the wall where there is more hours of sunshine.

There are three houses with solar heating systems in the district of San José de Quero, too, but the orientation in each house is different, so we selected the wall where there is more hours of sunshine.

According to measurements made in the Mantaro Valley we found out the sun's rays have the smallest angle (54°) on June 21 and reach the largest angle (101°) on December 21 (fig 5). It was found out that only since March 21 it can be used effectively the solar radiation due to the shadow cast ceilings.

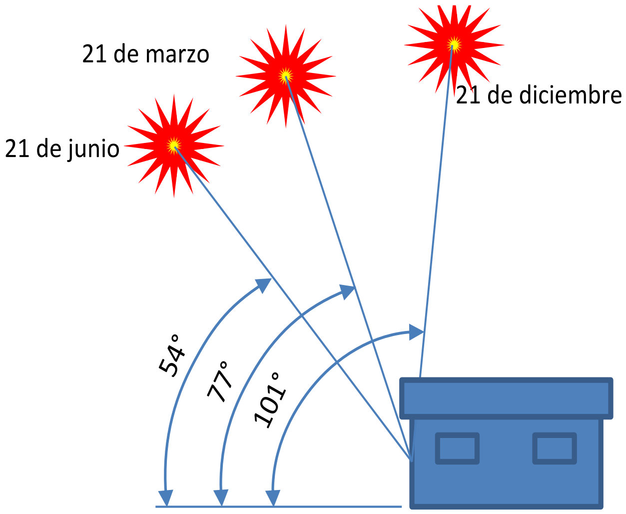

Fig 5: Angles planes path of the sun in Peru

In order to determine the angle of inclination of the collector, according to the months of radiation, in table 4 calculations were recorded when the collector needed to function from March to September or from April to August. It should be kept in mind that from May to August the lowest temperatures are recorded. If we want better use of solar radiation during the month of lower ambient temperature, the collector must have an inclination angle of 36 °.

Table 4: Angle of elevation and azimuth of the sun to San Jose de Quero

months	elevation	7 months	5 months
March	77°	13°	--
April	66°	24°	24°
May	57°	33°	33°
June	54°	36°	**36°**
July	57°	33°	33°
August	66°	24°	24°
September	77°	13°	--
Average		**25°**	**30°**

4.2. Description of results

The variable for solar heating system is represented by data of Chamber Volume (m3) Collector-collector area (m2), room volume (m3) and the orientation represented by the maximum number of hours of sunshine can receive the system in June (table 5).

Table 5: Data Solar Heating System

Homes	Dimensions IV			
	Volume of the chamber	Collector area	Volume of the room	Hours of sun
H_1	6.14	3.84	19.2	8.0
H_2	5.76	3.6	18.0	6.0
H_3	8.64	5.4	27.0	6.0
H_4	6.91	6.84	18.0	7.0
H_5	11.52	7.2	27.0	8.0
H_6	4.37	3.36	22.0	6.0

The dependent variable is represented by raising the chamber temperature relative to ambient temperature and raising the temperature of the room also about room temperature. The measuring chamber temperatures, room and environment were conducted between 11:00 h and 13:00 h, measured at intervals of 15 minutes. While we conducted the measuring the air ducts were open. The average of these temperatures and the variation from the room temperature were recorded in Table 6.

Table 6: Temperature Variation Data

Homes	Temperature °C			Temperature variation	
	Chamber	Room	Ambient	Chamber	Room
H_1	18.0	15.0	11.0	7.0	4.0
H_2	16.8	14.5	10.0	6.8	4.5
H_3	15.8	12.8	10.0	5.8	2.8
H_4	17.8	16.0	9.8	8.0	6.2
H_5	14.2	11.2	8.2	6.0	3.0
H_6	17.2	15.0	11.0	6.2	4.0

In Fig 6, the variation of the temperatures in the chamber and in the room is presented. The minimal increase in chamber temperature, compared to room temperature reached 5.8 °C, number recorded in house 3, and the maximum temperature rise is 8 °C and occurred in house 4. The minimum increase in the room temperature, compared to environment temperature reached 2.8, also registered in the home number 3; and the maximum temperature increase occurred in house No. 4.

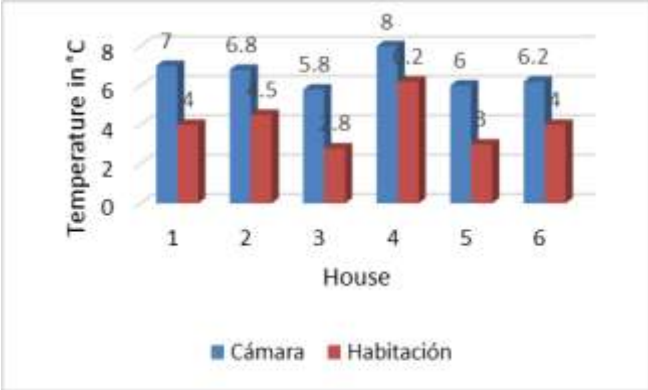

Fig 6: Variation of the chamber temperature and the room

With the data in tables 5 and 6 the data matrix was formulated, which served for statistical procedures and hypothesis testing (table 7)

Table 7: Data matrix

Homes	Dimensions IV				Temperature variation	
	Volume of the chamber	Collector area	Volume of the room	Horas so Hours of sun l	Chamber	Room
H_1	6.14	3.84	19.2	8.0	7.0	4.0
H_2	5.76	3.6	18.0	6.0	6.8	4.5
H_3	8.64	5.4	27.0	6.0	5.8	2.8
H_4	6.91	6.84	18.0	7.0	8.0	6.2
H_5	11.52	7.2	27.0	8.0	6.0	3.0
H_6	4.37	3.36	22.0	6.0	6.2	4.0

4.3. Hypothesis testing

The hypothesis that guided the investigation was:

Setting Solar heating system with a lower volume of the chamber, with a greater area of the collector-accumulator, a smaller volume of the room and with an orientation to the north that predisposes to 9 hours of sunshine influences efficiently to reduce Friaje in high Andean homes.

To formulate statistical hypotheses the model used was $y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4$ where:

Y: Temperature variation in the chamber (Friaje)

X_1: Chamber

X_2: Collector-accumulator

X_3: Room

X_4: Orientation

b_i: coefficients

Definition of the null hypothesis and alternative for the research hypothesis:

H_0: the variables as chamber, collector-accumulator, room and orientation do not influence on the rise of the temperature of the chamber, i.e, all constants are 0 except b_0.

$$H_0: b_1 = b_2 = b_3 = 0$$

H_1: at least one of the variable as chamber, collector-accumulator, room or orientation influence in the temperature elevation of the camera, that is, there is at least a constant which is different from 0, except b_0.

$$H_1: \exists b_i \neq 0$$

Data Analysis with SPSS

The result of data analysis using SPSS presents two models (table 8)

Table 8: Model Summary

Model	R	R-squared	R squared corrected	Standard error of estimate
1	0,841[a]	0,707	0,633	0,49306
2	0,980[b]	0,961	0,935	0,20696

a. predictors: (Constant), VHab

b. predictors: (Constant), VHab, ACol

The statistic of contrast ANOVA is the statistical F (Model 1 and Model 2 = 9,629 = 37.178), the same that is associated with an empirical significance of 0.036 for Model 1 and 0.008 for model 2.

Table 9: ANOVA

Model		sum of squares	DF	quadratic mean	F	Sig.
1	Regression	2,341	1	2,341	9,629	0,036[b]
	Residual	0,972	4	0,243		
	Total	3,313	5			
2	Regression	3,185	2	1,592	37,178	0,008[c]
	Residual	0,128	3	0,043		
	Total	3,313	5			

a. dependent: VTCam

b. predictors: (Constant), VHab

c. predictors: (Constant), VHab, ACol

The p value obtained in both models, is less than the theoretical significance (= 0.05), so Ho is rejected, then accepting the proposed model (table 10).

In table 8 the results of the lineal regression performed with data of the independent variables and as the dependent variable the variation of the temperature of the collector-accumulator are presented.

Table 10: Model coefficients

Model		Coefficients not standardized		standardized coefficients	t	Sig.
		B	Typ Error	Beta		
1	(Constant)	10,165	1,156		8,795	0,001
	VHab	-0,162	0,052	-0,841	-3,103	0,036
2	(Constante)	9,767	0,493		19,797	0,000
	VHab	-0,204	0,024	-1,064	-8,556	0,003
	ACol	0,265	0,060	0,552	4,439	0,021

a. Variable dependiente: VTCol

Considering the coefficients of the models of the table 10, these have the following expression:

Model 1: $Y = 10{,}165 - 0{,}162X_3$

Model 2: $Y = 9{,}767 + 0{,}265X_2 - 0{,}204X_3$

Where, X_2 is the area of the collector-accumulator and X_3 s the volume of the room.

Then, the null hypothesis is rejected and the alternative hypothesis is accepted considering that the factor that positively influences reducing the Friaje is the area of the collector-accumulator and the factor that negatively influences is the volume of the room.

Variables that are excluded in this analysis are the collector-accumulator area in model 1 and volume of the camera and hours of sunshine in model 2.

These dimensions or factors are excluded because their level of significance is greater than 0.05 or have a very high partial correlation. The collector-accumulator area has a significance level of 0.021 but a partial correlation of 0.932.

Table 11: Excluded variables

Model		Beta in	T	Sig.	partial correlation	Collinearity statistics
						Tolerance
1	VCam	0,511[b]	1,489	0,233	0,652	0,479
	ACol	0,552[b]	4,439	0,021	0,932	0,837
	HSol	0,252[b]	0,908	0,431	0,464	0,997
2	VCam	-0,276[c]	-0,937	0,448	-0,552	0,155
	HSol	0,021[c]	0,134	0,906	0,094	0,781

a. Variable dependent: VTCol

b. Variables predictors in model: (Constant), VHab

c. Variables predictors in model: (Constant), VHab, ACol

Finally, we can say that the design of a solar heating system, according to the predictor variables Volume of the room (VHAB) and collector-accumulator area (ACOL) are most influential in the system efficiency, becoming essential elements.

According to model 2, the largest increase in temperature (ΔTmax) in the solar heating system will be achieved by the following equation:

$$\Delta Tmax = 9{,}767 + 0{,}265\ ACol - 0{,}204\ VHab$$

The volume of the room (VHAB) negatively influences in the system, ie, the larger the volume of the room, the system efficiency will be lower, therefore the variation of the temperature in the chamber will be lower.

The collector-accumulator area (ACOL) positively influences the system, ie when the collector-accumulator area is higher, the efficiency of the system is higher too, and thus the variation of the temperature in the chamber will be greater.

The secondary elements such as the chamber and the orientation also have an important influence, but statistically determined not to be significant.

5. Discussion

When comparing the results with the research hypothesis, we agree with the influence of collector-storage area and volume of the room; and the volume of the chamber and the orientation of the system are excluded.

The area of the collector-accumulator influences in a positive way and the volume of the room influences in a negative way (table 8). This influence is because the collector-accumulator will capture greater radiation when the collector area is large and when the room is larger volume will require more heat to raise the temperature thereof.

The collected data provide no evidence of accumulation of energy. Since the accumulation of energy do not depend of the collector-accumulator area, but the volume of the accumulator material. The exclusion of the volume of the chamber and the orientation of the system is that the measurements made between 11 h and 13 h have not been sufficient to evaluate the effect of chamber volume and the hours of sunshine.

Then, to design the collector- accumulator area must be maximized the area of it for a determine room. I.e. install the collector-accumulator on the wall with the longest length, as long as this is perpendicular to north or north-west.

Comparing the results with the background, the heating system is active type because it's necessary that the air flow through the collector-accumulator area to the positively influence in the variation of the temperature of the room. This is attributed to the active type accumulator has high storage capacity where the air flows between the collector and the room [8]

The collector-accumulator, which is part of the solar heating system, is flat type. The use of Trombe wall is rejected because sun lights in the districts of Yanacancha and San Jose de Quero, an elevation is reached in June 54° and in December is 101° both are measured at noon (12:15 h). Instead Domancic Herrera [3] proposes a system for air flat plate collector to be installed on the roof of the building and a Trombe Wall collector located in the front, both headed to the north. This proposal is because sunlight in Santiago de Chile the highest elevation angle is reached at 11:45 h and is 33° in June and 80° in December.

Trombe Walls do not reduce the Friaje in Peru, the evidence is in SENCICO [5] who installed 17714 Trombe Walls in houses located about 3,500 meters above sea level in the departments of Ayacucho, Apurímac, Arequipa, Pasco, Cusco, Huancavelica, Huanuco, Junin , Moquegua, Puno and Tacna, the results are invalid and are not being used.

Then, the solar heating system must have a collector-accumulator with angle of 30-36 ° in order to make better use of solar radiation and stones should be boulder, also it should allow air circulation through the stones (black body) which acts as a collector and accumulator.

The chamber volume and orientation are excluded from the model.

The chamber volume has a negative influences in the system, but statistically is excluded from the model (table 9), because it has not been measured the influence of air temperature of the chamber in the temperature of collector-accumulator Then, hot air ducts should be located at the top, at the level of the roof, and cold air ducts must be located on the bottom, at the level of the floor of the room. Due to the phenomenon of thermosiphon hot air rises and cold air stays down [21, p. 17].

Regarding the orientation, it is determined that this dimension has a positive influences in the system, but statistically is excluded of the model (table 9), because it is not performed the measuring of the variation of the chamber temperature for 24 hours. There will be more hours of sunshine irradiates the collector-accumulator surface when the orientation is toward the north.

6. Conclusions

The sizing of solar heating system is carried out with the equation: $\Delta Tmax = 9{,}767 + 0{,}265\ ACol - 0{,}204\ VHab$. It must be installed in the wall that has the longest length, as long as this is perpendicular to north or north-west. The inclination of the collector should be 30º to 36° in order to make better use of solar radiation in the months of Friaje and the stones should be boulder to capture radiation at different times and separated to allow air circulation through stones (black body) which acts as a collector and accumulator.

The ceiling should be located at the lower height possible in order to prevent hot air accumulated at the top where it is not used. The chamber should also have the smallest possible volume, its height should be equal to the height of the room.

The hot air ducts should be located at the top of the wall where the camera is installed at ceiling level, and cold air ducts must be located at the bottom, level with the floor of the room; so that airflow by the thermosiphon principle can be achieved.

Finally, the solar heating system suitable, should be designed with a collector-accumulator system with largest possible area according to the room at annexing, the room should have the least possible height to help reduce the volume there of and camera, it must have air circulation ducts from the ground and feed hot air from the ceiling, and should be oriented to the north.

References

[1] Agencia EFE, «Un total de 409 personas han muerto en Perú por neumonías y frío este año,» 20 julio 2010.

[2] S. Chamoli, R. Chauhan, N. Thakur y J. Saini, «A review of the performance of double pass solar air heater,» Renewable and Sustainable Energy Reviews, vol. 16, nº 1, p. 481–492, January 1012.

[3] P. Domancic Herrera, «Diseño de un sistema de calefacción solar para un edificio público,» Universidad de Chile, Santiago de Chile, 2008.

[4] G. Chávez Oblitas, «Almacenamiento de energía solar térmica para diferentes aplicaciones (calefaccion de vivienda rural),,» Arequipa, 2009.

[5] SENCICO, «Calefactores solares SENCICO,» Suplementos Especiales de Construccion&Vivienda, vol. III, nº 31, pp. 3-7, 15 agosto 2009.

[6] J. Torres, «Climatización considerando el ahorro de energía y el confort térmico de las personas en ambientes dedicados a tareas de oficina,» Editorial de la Universidad Tecnológica Nacional, Santa Fe, 2010.

[7] A. Olivares Clavel y G. Torres Flores, «Caracterización de un sistema de calentamiento de aire por medio de energía solar con almacenamiento energético,» Universidad Centroamericana José Simeón Cañas, El Salvador, 2010.

[8] J. Nacif Hartley, Acumulación térmica para un sistema solar de calefacción activo, Santiago de Chile: Universidad de Chile, 2011.

[9] GRUPO PUCP, «Casa caliente limpia: K'oñichuyawasi,» America Renovable, vol. 5, nº 14, pp. 60-62, noviembre 2011.

[10] R. Sarachitti, C. Chotetanorm, C. Lertsatitthanakorn y M. Rungsiyopas, «Thermal performance analysis and economic evaluation of roof-integrated solar concrete collector,» Energy and Buildings, vol. 45, nº 6, pp. 1403-1408, June 2011.

[11] C. Arkar y S. Medved, «Optimization of latent heat storage in solar air heating system with vacuum tube air solar collector,» Solar Energy, vol. 111, pp. 10-20, January 2015.

[12] N. Truong y L. Gustavsson, «Solar heating systems in renewable-based district heating,» Energy Procedia, vol. 61, p. 1460–1463, 2014.

[13] M. Dabaieh y A. Elbably, «Ventilated Trombe wall as a passive solar heating and cooling retrofitting approach; a low-tech design for off-grid settlements in semi-arid climates,» Solar Energy, vol. 122, p. 820–833, 2015.

[14] E. Andersen, Z. Chen, J. Fan, S. Furbo y B. Perers, «Investigations of intelligent solar heating systems for single family house,» Energy Procedia, vol. 48, pp. 1-8, 2014.

[15] D. Skaarup Østergaard y S. Svendsen, «Case study of low-temperature heating in an existing single-family house—A test of methods for simulation of heating system temperatures,» Energy and Buildings, vol. 126, pp. 535-544, August 2016.

[16] C. Flynn y K. Sirén, «Influence of location and design on the performance of a solar district heating system equipped with borehole seasonal storage,» Renewable Energy, vol. 81, pp. 377-388, 2015.

[17] G. Serale, E. Fabrizio y M. Perino, «Design of a low-temperature solar heating system based on a slurryPhase Change Material (PCS),» Energy and Buildings, vol. 106, pp. 44-58, 2015.

[18] C. Espinoza Montes, Metodología de investigación tecnológica. Pensando en sistemas, Segunda ed., Huancayo, Perú: Soluciones Gráficas SAC, 2014.

[19] H. Sánchez Carlessi y C. Reyes Meza, Metodología y diseños en la investigación científica, Segunda ed., Lima, Perú: Gráfica Los Jazmines, 1996.

[20] M. Fernández Barrera, Energía Solar. Sistemas térmicos para acs, Barcelona: Liber Factory, 2010.

[21] T. Schwarz, «Climate-Data,» 12 05 2013. [En línea]. Available: http://es.climate-data.org/location/771599/.