Energetic and Exergetic Analysis of the Low-temperature Heating System in a model library

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Abstract

Objectives: Energetic and exergetic analysis of the low-temperature heating system in a model library are conducted numerically in this research. **Methods:** The method of numerical investigation and simulation are employed to compute the energetic and exergetic analysis of the low-temperature heating system in a model library. The use of C++ programming and Hourly Analysis Program software were done the simulation and optimization. The results of this investigation are presented in this article. **Findings:** Simulation presents that the most of energy which is required for heating is capable to be declined using low-temperature heating system in a model library. It is shown that gas consumption decreases when low-temperature radiators are applied and the value which is obtained is about 61,458,480 m^3/yr. This means that the performance of the low-temperature radiation is better than high-temperature radiator and it is about 57,150,000 m^3/yr. The use of low-temperature radiators and high-temperature radiators are compared in this article. The radiator quality factor of the low-temperature radiators and high-temperature radiators are obtained 0.13 and 0.22, respectively. By using the low-temperature method, radiator quality factor is able to be declined 7% of the energy efficiency. Based on these cases, using the low-temperature system can be used in some regions in Iran. The economic investigation shows that the IRR is evaluated based on discount 30%, and interest rate 22% in 20 years. **Application and improvement**: The declination of energy consumption in building is significant. Therefore, a method which can use to reduce energy consumption is low-temperature heating in winter.

Keywords: Low Temperature Heating, Low Temperature Radiator, Heating, Economic evaluation.

1. Introduction

Forty percent of total energy is consumed in household, commercial, and public. As a result, these are important sector which is used final energy such as CNG, Diesel, and electricity. The increment of the energy consumption growth in the building sector is approximately 10%, and it is likely to lead Iran to leave from the Organization of the Petroleum Exporting Countries (OPEC) in a few years later as long as the amount of energy consumption in different sector will remain in the future. Based on Iranian's energy balance, there are 15 million buildings in Iran and average as consumption rate is 30 m^3 per square meter of the building in Iran. Whereas, the average gas consumption rate is 5.5 m^3 per square meter of the building in European countries which are colder than Iran. According to this report of Iranian's energy balance, domestic and commercial buildings use 30% of total fossil fuel and 70% of this use for heating. As a result, energy which is consumed for heating is 20% of total energy consumption in Iran. In addition, this point should be mentioned that building which are in cold climate regions of Iran use often heating energy, as a consequence, it is possible to diminish the amount of the energy consumption if low energy buildings is built in cold climate region. However, there is much kind of method in the world. While, one kind of building which can be used in cold climate regions. These can thermal comfort and good quality. At first, the district heating (DH) system is used in some buildings which have constructed in Northern European Countries like Sweden. This method applied by many researchers in northern European countries and other regions in the world. These studies are presented as follows:

DH networks use hot water as heat transfer fluid [1]. The temperature range of the low-heating system was considered between 90 °C and 120 °C [1]. Different kind of building use low energy and the capability to reduce demand for primary energy in European buildings [2]. The result of this study shows that 20% of the energy consumption in European countries can reduce if energy performance of the building is modified or use low-energy building [2]. Low-temperature hot water in a heating system and heat pump is pumped to reduce the amount of energy used in building [3]. In addition, the result of this study was compared by the high-temperature heating system. According this comparison, it was observed that enhancing the coefficient of performance (COP) is almost 2% [3]. A numerical study on the optimization of a ventilation radiator by several the distribution of vertical longitudinal convection fins is performed [4]. Combination of ventilation air supply and heat emission of to the rooms was used in the system. They also applied higher driving force of air in between the radiator panels compared to traditional radiators.

The result shows that thermal efficiency improves by the low-temperature heating system [4]. A theoretical investigation on energy consumption in five new built semi-detached dwellings in Stockholm, Sweden is conducted [5]. They employed low-temperature heating system combining under-floor heating and ventilation radiators [5]. Exhaust ventilation heat pumps have been gained to preheat supply water for the low-temperature heating system. In addition, IDA indoor Climate and Energy (ICE) were applied to simulate buildings [5]. New building with low-temperature heating system in term of energy consumption and thermal comfort and to pay some attention to energy saving and indoor air quality are evaluated [5]. The result showed that 23% of the energy

was saved in this simulation [6]. A model of emission loss and heat loss of the low temperature heating system and radiators is obtained in European countries which are in the north and central [5]. This research allows creating the building energy simulation model [5]. This model showed that convectional heating losses greater than 50% of the heating energy were computed in the flats. Based on this model and PI type thermostats and limited heating period distribution and emission losses could reduce energy losses in the building [5].

A new method of the low-energy DH is introduced [6]. The energy demand declined by using low-energy buildings in this research [6]. As a result, 14.3% of the energy use decreased by these methods [6]. The low-temperature heating method is employed to reduce energy consumption in the buildings [7]. They used the computational fluid dynamic (CFD) and presented the analytical rates of the typical outdoor temperature with the increasing the airflow inside the baseboard heater [7]. A numerical modelling and an experimental measurement for a low-temperature DH are carried out [8]. Using this method, the performance of the building enhances [8]. The result shown it had an important positive effect on writing time for DHW, heat loss, and overall cost [8]. Ventilation and heat emission unit is applied to determine potential for increasing energy efficiency in exhaust-ventilated buildings with warm water heating [9]. They used CFD simulations to confirm an experimental investigation [9]. The error of this experimental study shown that the energy efficiency of ventilation radiators is improved and it is approximately 20% [9].

The low-temperature heating system is used in typical Danish single-family from 1970s [10]. In this study applied the IDA-ICE software to simulate energy consumption in the house. The result of simulation was compared with the experimental result which achieved, as a consequence, it was determined that temperature reduced in low temperature to reach 60 °C while it was 68 °C to 78 °C in family house [10]. The low exergy system applied and they propose that the low-temperature heating system should be used for buildings [11–12]. This method can help us to use the low valued energy sources. In addition, this system provides comfortable temperature and most of them is clean [13–14].

The low-temperature method is applied to decline heating load in the building [15]. They presented that the simulation results for the combined low-temperature water heating system is compared with those for three convectional radiator and floor heating system [14]. The result illustrated that the performance of the combined low temperature water heating system was good and it was capability to maintain the zone temperature levels [14]. Furthermore, the thermal comfort analysis indicated that the heating system can provide heating energy which is based on Ashrae Standard [14]. The convection and radiation contributions for two temperature levels are calculated [15]. Heat transfer rate is enhanced by using a force convection air velocity component along the radiator surface [15]. Building energy performance with the low energy buildings in Sweden has been evaluated by Building Energy Simulation [16]. A research is done on the controlled by a radiator system which was connected to DH network since the lowest possible DH return temperature which can provide heating energy is optimized [17]. They modified the control curve for radiator circuit enabling it consistently to provide an optimal cooling of the DH water [18]. A numerical simulation on the low energy buildings in Sweden is

carried out [17]. They could reduce 39% of the energy use originates from the building sectors [19]. They used ESP-r software and CFD-model is applied to simulate airflow [17]. The capabilities in using DH for lower energy houses are studied [20]. They design new model of DH network. The result showed that energy consumption has decreased in the building [19]. Experience's on low-temperature DH in Lystrup – Denmark was done [20]. A new method of a low-energy DH system is designed [22]. This method measured based on substation type and network layouts [21].

This work will be assumed that the majority of the heating energy demand in a model library can be provided by using a low-temperature method. In the beginning, energy need for heating and ventilation system will be computed by hourly analysis program 4.5vs (Carrier Corporation 2012) and non-linear programming. After that, the efficiency of energetic and exergetic will be calculated. The result may be applied in enhancing efficiency of buildings and in decreasing air pollution from domestic, commercial, and public building.

2. Theory

Heating load of the radiator is calculated based on fluid temperature. As is flow:

$$Q_{\text{th}} = 1 - T_0 / T \ (\text{W}) \tag{1}$$

where Q is thermal load of producing from radiators in 60 °C, Q_n is heating load which can be produced by each radiator in 60 °C, ΔT is the differential supply temperature and return temperature. M is the specific coefficient for each radiator which is presented based on the manufacture's catalogue.

Exergy is calculated, as in:

$$\partial E_{\text{inlet}} - \partial E_{\text{outlet}} = dE_{\text{system}} \tag{2}$$

where $\partial E_{\text{inlet}}$ is energy which is entered system, $\partial E_{\text{outlet}}$ is energy which is outlet energy, dE_{system} is exergy, which is calculated, in the system.

If the energy which pass from the bound of systems, exergy equation is calculated as follows:

$$ds = \partial Q / T \tag{3}$$

where ds is exergy, Q is differential heating load, T is temperature.

Heating efficiency is achieved as is follow:

$$\eta_{\text{th}} = 1 - T_{\text{o}} / T \tag{4}$$

where η_{th} is exergy efficiency, T_{o} is outlet temperature, T is inlet temperature.

$$\delta Q = \delta w - T_0 ds \tag{5}$$

$$=\text{-d}U - P_\text{o}\text{d}V + T_0\text{d}S \qquad (6)$$

Using integral, equation obtains as is follow:

$$W = (u - u_0) + P_0(v - v_0) + T_0(s - s_0) \qquad (7)$$

where u is internal energy, P is pressure, v is volume, T is primary temperature, s is entropy

Equation (7) shows that internal exergy of a closed system is more than zero or it is no longer a minor.

The overall heat transfer is calculated by equation (8):

$$Q_\text{h} = (Q_\text{T} + Q_\text{v}) - (Q_\text{s} + Q_0 + Q_\text{e} + Q_\text{L}) \qquad (8)$$

where Q_h is heating load of the building, Q_T is heat loss of transmission, Q_v is heat loss of ventilation, Q_s is heat loss of solar heat gain, Q_0 is heating load which is calculated from occupants and equipment, Q_e is heating load which computed from equipment, Q_L is heating load which is used from lighting.

Radiator surface temperature is calculated from logarithmic temperature. Temperature is computed by the equation (9):

$$T_\text{heat} = (T_\text{in} - T_\text{ret} / 2\ln((T_\text{in} - T_\text{i}) - (T_\text{ret} - T_\text{i})) + T_\text{i} \qquad (9)$$

where T_heat is logarithmic temperature, T_in is internal temperature, T_ret is water or fluid return.

Radiator factor which is called quality of surface temperature radiator is computed as is follow:

$$F = 1 - (T_\text{ref} / T_\text{heat}) \qquad (10)$$

According to equations (8) and (9), exergy is obtained as is follow:

$$E_{x_\text{heating}} = F \times \dot{Q}_\text{h} \qquad (11)$$

3. Case Study Description

It is mentioned that this work investigates the central library of Islamic Azad University. At first, detail of building needs to simulate the heating and cooling load of the building. As a result, this detail was received from the constructor and then heating and cooling load was calculated. This library was built in a field, which had 6650 m². In addition, this building constructed on 5 floors and different part of the building which use for various spaces include books, catalogue, offices, Amphitheatre, Website and etc. Furthermore, there have been two under the floor in a model library which used for heating, ventilation and air conditioning and electrical room and main part of the second basement gained for storage

and workshop. Total area of the building was 35,000 m² and 25,000 of this area has been ventilated.

The height of floors and ceiling were about 4.6 m and 3.5, respectively. Moreover, florescent is used for lighting system in a model library. The characteristic of house includes area, area of windows in Table 1. The characteristic of material building, which is used to construct the building, is presented in Table 2.

The library is located in Tehran with average daily temperature of 17.7 °C. The weather in Tehran is given by the Iran meteorological organization and the weather report of airport organization. Based on these references, the coldest temperature was −10 °C on 21 January and the warmest temperature was 36.4 °C on 22 July 2013.

4. Method of Design the Low Temperature Building

The performance of the library and heating ventilation air conditioning system is evaluated by gaining hourly analysis program and non-linear program. The hourly analysis program

TABLE 1. The characteristic of library

Items	Value
Building area (m²)	25,000
Area of windows (m²)	6615
Area of external walls (m²)	10,127

TABLE 2. The characteristic of building material

The part of building	Building material	Thickness (mm)	Heat transfer coefficient (W m^{-2} K^{-1})	Heat resistance (m² w^{-1} K^{-1})
Wall	Plasterboard	16	7.48	0.13798
	Air space	50	6.24	0.16026
	Common brick	203	3.57	0.27954
	Air space	50	6.24	0.16026
	Gage steel deck	0.853	–	0.00002
	Gypsum board	15.875	10.14	0.09863
	Air space	600	6.24	0.16026
	Lightweight concrete block	250	2.28	0.43772
Roof	Light weight concrete	30	5.67	0.17680
	Asphalt roll	1.588	37.06	0.02698
	Board insulation	25.4	0.82	1.22299
	Slate	12.7	113.5	0.00881

can dynamic simulation with weather dates which is based on the Ashrae standard, simultaneous airflow, and heat transfer rate of wall and windows. This program can be applied to assess the simultaneous performance of all items which require designing the building such as shape, glazing, partition, lighting system, controlling indoor air quality and fresh air, comfort temperature, energy consumption, HVAC system and operating and investing cost and etc. Furthermore, non-linear program is used to develop the model and it also has been employed to calculate all of the cases mentioned before. Moreover, in this research has been applied the energetic and the energetic method because the effect of using low-temperature heating in a model library is achieved. After which the result of the energy calculated for high temperature system compared with the result of low-temperature system. Thermal comfort is important to provide satisfaction of people since this point is definitely different for everyone, who have various old and sex so that the providing thermal comfort in a different space in the library has been employed standard of Ashrae [22].

5. Results and Discussion

It is mentioned that energy consumption in the library is computed by two methods. The result is illustrated in Figure 1. According to Figure 1, it can be observed that gas consumption reduces when low-temperature radiator has been used and it is about 61,458,480 m³/yr. This means that the performance of the low-temperature radiation is better than high-temperature radiator and it is about 57,150,000 m³/yr.

Moreover, comfort temperature is calculated by using non-linear programming and exergetic and energetic concept. In high-temperature system, the comfort temperature was 24.2 °C and the low-temperature system, the comfort temperature was 24.7 °C. Furthermore, it should be mentioned that the efficiency of the energetic and exergetic are investigated in this research. By using the thermal performance achieves based on overall heat transfer internal energy and external into buildings. Furthermore, the quality factor
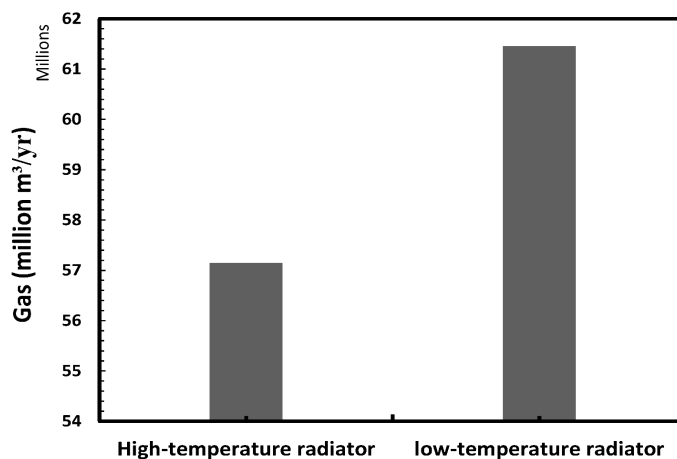

FIGURE 1.   Comparison of the gas stimulation before and after simulation.

of the high-temperature radiators and low-temperature radiators are computed by non-linear programming. The result is shown in Figure 2.

According to the figure, it can be observed that the radiator quality factor of the low-temperature radiators and high-temperature radiators are 0.13 and 0.22, respectively. By using the low-temperature method, it can be reduced 7% of the energy efficiency. Based on these cases, using the low-temperature system can be used in some regions in Iran.

Based on investing data, economic assessment has been conducted in this study. Investing cost of the low-temperature radiator is \$ 14511.2 and simple payback time of the using low-temperature radiator has been computed. Whereas, operating cost can reduce and it is about \$ 2400. In addition, IRR is evaluated based on discount 30%, and interest rate 22%. IRR obtains 0.04 and therefore payback period is 31 years.

5. Conclusion

In this research, the effect of using low-temperature radiators in a model library were investigated by using energtic and exergetic. The results may be summarized as follows:

1. The thermal performance of the heating system is definitely enhanced when the heating system works with the low-temperature because the exergy performance of the low-temperature radiator is lower than high-temperature radiators as a consequence of the energy efficiency should definitely improve or it is led to be saving energy.
2. By using the low-temperature radiator, 4,302,000 m³/yr of energy decreases.
3. The quality factor of the low-temperature radiators is lower than the high-temperature radiator and the energy efficiency reduces up to 7%.
4. Exergy performance IRR and payback time are 0.03 and 20.8 year, respectively.

According to the result, using the low-temperature system has been reduced the proportion of the demand for building energy. In fact, the decreases 7% of total heating
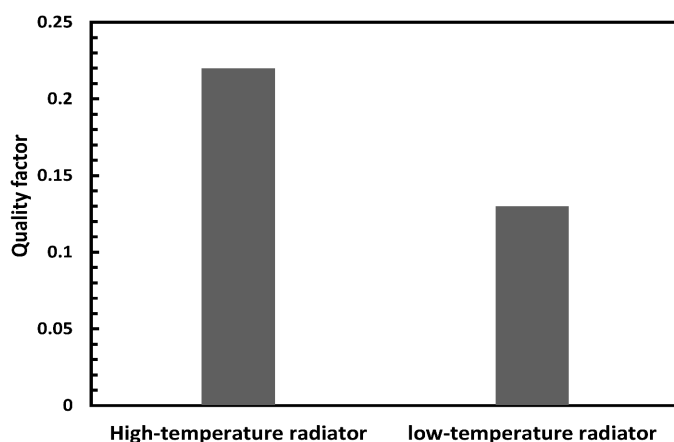

FIGURE 2. Comparison between quality factor of the low-temperature radiators and high-temperature radiators.

load. In addition, these have the minimum investment return and the result of payback period obtaining these systems.

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