

Fossil Fuels Non-Consuming Heating, Ventilation and Domestic Hot Water Supplying Integrated System

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To cite this article:

Zohrab Melikyan, Siranush Egnatosyan. Fossil Fuels Non-Consuming Heating, Ventilation and Domestic Hot Water Supplying Integrated System. *International Journal of Systems Engineering*. Vol. 2, No. 1, 2018, pp. 29-35. doi: 10.11648/j.ijse.20180201.17

Received: June 26, 2018; Accepted: July 25, 2018; Published: August 16, 2018

Abstract: Large use of different kinds of fossil fuels in gas, liquid, solid and other forms for heating, ventilating and domestic hot water supplying of houses and heat generation for industrial purposes, in contemporary conditions creates ecological and economical serious problems, contributes to global climate change and requires big efforts and means, as well as long periods, for implementation of expensive conventional heat supply systems. Mentioned problems become even greater because of systematical rise in prices of fossil fuels. The solving of the problem gets harder because of absence of appropriate technology for accomplishing heat generation and its supply without consuming of fossil fuel. The mentioned disadvantages force to develop new generation of heat production and consumption technologies that operate without usage of fossil fuel and simultaneously accomplishes ventilation and domestic hot water supply of houses. For this reason, the authors of this study have decided to develop a new type of heating, ventilation and domestic hot water supplying integrated system, which does not consume at all fossil fuels. The integrated system realized on example of a residential house with 432 m³ of volume. The study proves energy high efficiency and cost effectiveness of suggested system, as it allows to save 2660 m³ of fossil fuel per season. Comparison of data shows that specific cost of seasonal heating, referred to 1m² of the building is 2.06 times less than for ordinary system.

Keywords: Heating System, Fossil Fuel, Refrigerant Gas, Energy Consumption, Energy Saving

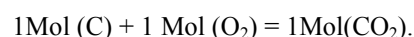
1. Introduction

The problem of fossil fuels usage elimination from practice aiming at amelioration of environmental conditions [1] and living standards have been one of main goals of human beings as a mean for growth in prosperity. The main barrier against denial of fossil fuels has been the problem, arising in case of their burning, which is accompanying by two following controversial effects:

- 1) The positive effect is the generation of useful heat for various heating purposes,
- 2) The negative effect is the pollution of environment and production of combustion toxic products, causing various health problems.

According to [2], in process of combustion of fossil fuels are produced chemical elements in form of oxides by atomic weights of which can be composed material balance of chemical reactions of combustion. For instance, in case of the

complete combustion of carbon the following chemical reaction takes place:



As 1Mol(C)=12kg of carbon and 1 Mol (O₂) = 32 kg of oxygen (O₂), then 12kgC+32kgO₂ = 44 kg CO₂. Because of same kind of oxidation reaction, from burning of, for Instance, 1Mol of sulfur (S), 64 kg very toxic SO₂ gas is rejected.

The listed above toxic and harmful rejections became permanent reasons of environmental hard problems that provoke the main consequences of global climate change. However, until now, the problem has not found serious solution, and, at present, it requires cardinal new approaches to change the environmental situation especially in the field of heating and heat supply technologies.

In research works of last three –four years serious attention

was concentrated on problems of simultaneous use of various heat and cold generating systems, acting in the framework of one integrated system. As show investigations of authors [13], [14], such approach to energy generation and consumption provides significant energy and means economy.

To solve the problem new types of heat supplying systems have to be developed and used. The authors of this article made efforts to develop new type of heat supplying system, which is named fossil fuels non-consuming heating, ventilating and domestic hot water providing integrated system.

2. Structure and Operation of Fossil Fuels Non-consuming Heating, Ventilation and Hot Water Providing System

Developed integrated heat supplying and ventilating system has rather simple structure as shows the Figure 1. The system consists of three main sections, which provide all-kinds of energy demands of a residential house like heating; ventilation; domestic hot water preparation and distribution.

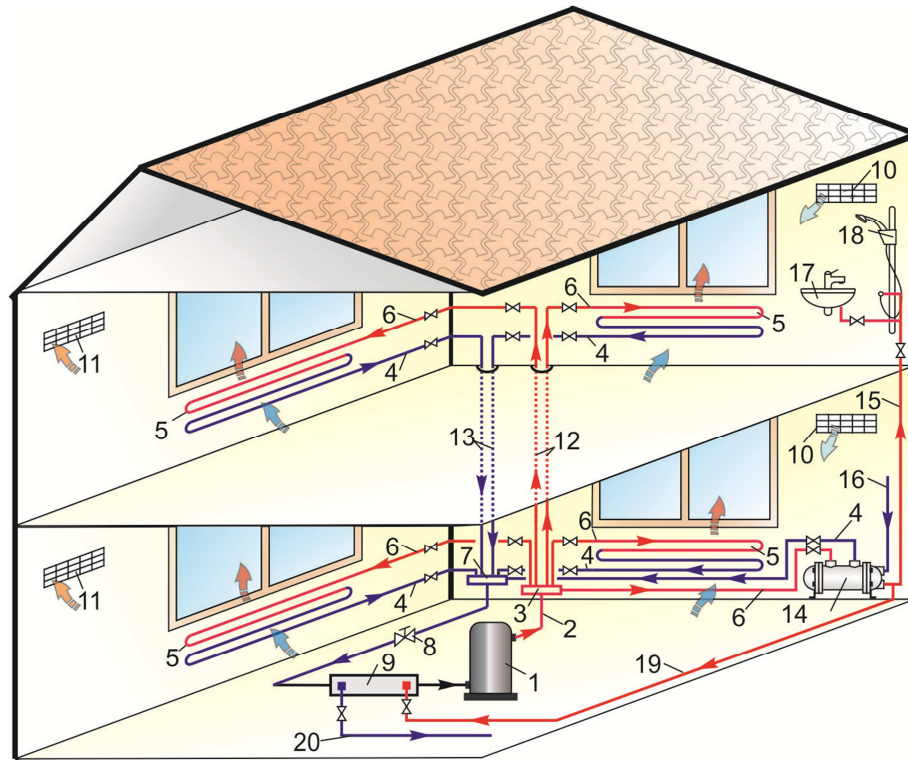


Figure 1. Fossil fuels non-consuming heating, ventilation and domestic hot water supplying system of a family house.

1-R-22 refrigerant compressor; 2-compressed hot gas supplying pipeline 3-R-22 hot gas-supplying collector; 4-R-22 condensed gas return pipeline, 5-pipe type air heater; 6-liquid R-22 return pipeline(branch) to the liquid's collector, 7-liquid R-22 return collector, 8-throttling valve; 9-hot water to liquid R-22 heat exchanger, 10-ventilation air inlet scapular valve; 11-ventilation air outlet scapular valve; 12-R-22 hot gas supplying stands; 13-return stands of R-22 liquid refrigerant; 14-domestic hot water preparation heat exchanger, 15-domestic hot water supplying pipeline, 16-tap water pipe, 17-hand-wash stand, 18-shower, 19-hot water pipe to heat exchanger (9), 20-cooled water return pipeline.

Preliminary investigation proves that most suitable and efficient heat carrier for suggested system can serve refrigerant Freon R-22. The compressor (1) is installed in the basement of the house. Freon gas supplying pipelines (2) and distributing collectors (3) are connected to pipe type air heaters (4), which hangs on walls or stand on floors of the rooms.

The suggested heat supplying integrated system operates in

the following way: the compressor (1) is installed in the basement of the house and serves for compression of Freon R-22 gas. Because of compression, the R-22 gas is heated and through the hot R-22 supplying stands (2) of heating system is forced into the hot gas supplying collector (3). From the hot gas-supplying collector (3) the compressed hot gas is distributed among the pipe type air heaters (5), which are hanged on inside walls, on ceiling or stand on the floors of rooms. Because of heat transfer from hot gas of R-22 to inside air of the house, Freon gas condenses and by liquids' stands (6) returns into the liquid's collector (7). Afterwards the liquid R-22 passes through throttling (expanding) valve (8) where it decreases its pressure and temperature. Then the cooled liquid passes through the "hot water - liquid R-22" heat exchanger (9) where from hot water absorbs heat. As a result, the liquid refrigerant is evaporated and the compressor (1) sucks the vapor of R-22 for repeating above described processes

For providing $t_{ins}=18^{\circ}\text{C}$ [3] inside comfort temperature in winter period, the outside fresh air through air filter and plenum ventilation grills (10) enters into the inside area of the

house where contacts the external hot surface of the pipe type air heaters (6). Through tubes of pipe type air heater flows compressed in the compressor (1) hot refrigerant gas. As a result, of heat exchange, the hot refrigerant gas transfers heat to the inside air, which contacts external hot surface of air heater tubes (6). The heated air is extended in the room and heats the inside space. Because of heat exchange with inside air, the compressed refrigerant gas is condensed in pipe type air heater tubes and sequentially passes through throttling valve (8) and then heat exchanger (9), where, by absorbing heat from hot water, the liquid refrigerant is evaporated and the compressor (1) sucks the vapor of R-22 for repeating above described processes.

The domestic hot water is prepared in heat exchanger (14) which is installed in the basement of the house, and is connected with tap water (16) and domestic hot water (15) supplying pipelines.

3. Main Equipment's Characteristics of Heat Supplying Integrated System

The most important feature of suggested system is the absence of the heating boiler, which is replaced by a refrigeration compressor. Consequently, the main equipment of heat supplying integrated system are the followings: 1- R-22 gas compressor (1); 2- pipe type air heaters (5); 3- hot water preparing heat exchanger (14); 4-hot water to liquid R-22 heat exchanger (9).

Based on results of calculations accomplished by the method, published in [4, 5] wintertime heating demands' diagrams of considered family house were composed, which is represented in the Figure 2.

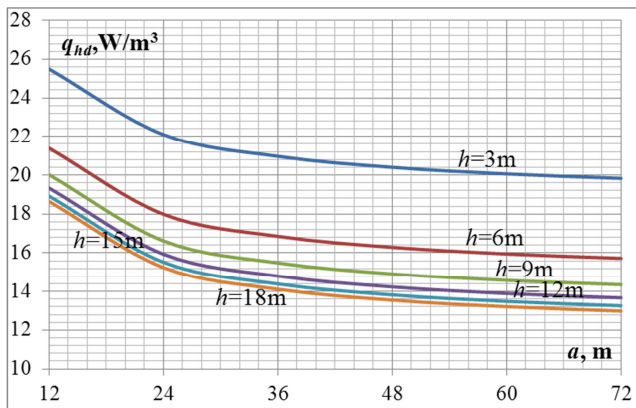


Figure 2. Values of specific heating demands q_{hd} , W/m^3 of the house at outside design temperature $t_{out,dsg} = -19^\circ C$, and required inside temperature $t_{in} = 18^\circ C$, depending on sizes of buildings (lengths $a = 12m$ to $72m$, heights $h = 3$ to $18m$ and widths $b = 12m$).

Above diagrams (figure 2) show that the specific heating demands, q_{hd} , W/m^3 of the considered house with sizes $a = 12m$, $b = 12m$ and $h = 3m$ (volume is $432m^3$) makes $25,6 W/m^3$.

For finding the absolute value of heating demand, Q_{hd} , W , the specific value q_{hd} , W/m^3 is multiplied by the volume V_b , of the building:

$$Q_{hd} = q_{hd} V_b = 25.6 \cdot 432 = 11059 W \text{ or } 11kW. \quad (1)$$

4. Determination of Required Total Length of Pipe Type Air Heater Tubes

For providing inside comfort temperature in the house, the pipe type air heater tubes (6) should have appropriate total L_{tot} length. To reveal the required value of total length of air heater tubes, the following equation of heat transfer [6, 7] is applied:

$$Q_{hd} = \pi d_{ext} L_{tot} \alpha_{ext} (t_{liq.R22} - t_{ins.}), \quad (2)$$

where:

Q_{hd} - heating demand of the house, which conditions the total heat productivity of pipe type air heater tubes;

$d_{ext} = 0.01 m$ - external diameters of air heater tubes;

L_{tot} - total length of air heater tubes,

$\alpha_{ext} = 100 W/(m^2 \cdot ^\circ C)$ [8] - convective heat transfer coefficient on external surfaces of air heater tubes,

$t_{liq.R22} = 45^\circ C$ - temperature of condensed R-22 refrigerant gas, in air heater tubes,

$t_{ins} = 18^\circ C$ - design temperature of inside air of the house.

For finding the total length of air heater tubes, the equation (2) is converted into the following fraction:

$$L_{total} = \frac{Q_{hd}}{\pi d_{ext} \alpha_{ext} (t_{liq.R22} - t_{ins.})}. \quad (3)$$

Substitute of given above characteristic values in (3) and making calculations will derive the following required total length of air heater tubes to cover 11000 W of heating demand of the house:

$$L_{total} = 11000 / (3.14 \cdot 0.01 \cdot 100 \cdot (45 - 18)) \approx 130 m \quad (4)$$

From 130m long copper tub with diameter $d_{ext} = 0,01m$ can be made coiled radiators for using them as heating appliances of rooms. The Figure 3 shows developed "Pipe type" heating appliance of the building.

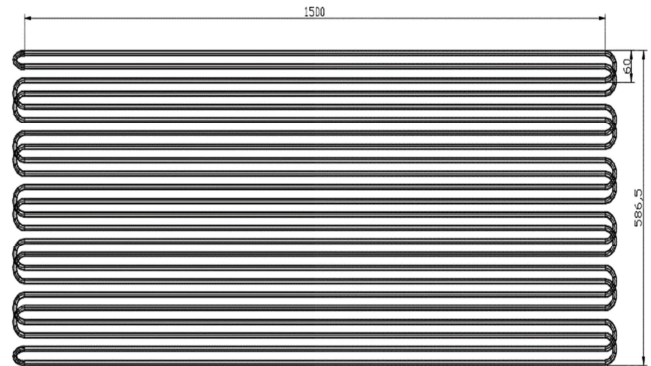


Figure 3. "Pipe type air heater" heating appliance of the building.

For heating purposes, high temperature heat carrier should circulate through air heater tubes. In the considered system, the hot liquid of Freon R22 can serve as heat carrier. Hot liquid

Freon's preparation processes are represented on enthalpy – pressure (*i-logP*) diagram of R-22 refrigerant [9, 10].

5. Determination of Energy Consumption by the Heat Supplying Integrated System

The consumers of energy in the suggested heating,

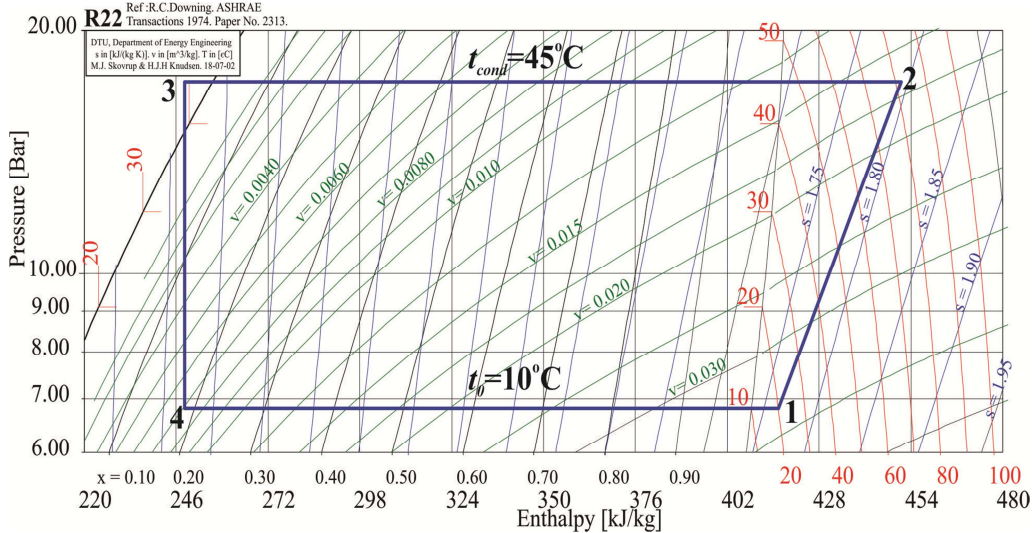


Figure 4. R- 22 refrigerant's gas compression and other related processes plotted on (*i-logP*) diagram.

In the Table 1 the values of enthalpies, pressures and temperatures of characteristic points of R-22 gas compression cycle are represented.

Table 1. Refrigerant's characteristic parameters.

characteristic parameters	Point 1	Point 2	Point 3	Point 4
Pressure, bar	6.8	17.3	17.3	6.8
Temperature, °C	20	83	39	10
Enthalpy, kJ/kg	417	451	248	248

Refrigerant's flow rate G_{ag} , in the system is:

$$G_{ag} = Q_{hd} / (i_2 - i_3) = 11 \text{ kW} / (451 - 248) = 0.054 \text{ kg/s}.$$

Power, consumptions by processes, represented on Figure 4 are the followings:

process «1-2»-compression of the gas refrigerant in the compressor- $N_{1-2} = G_{ag}(i_2 - i_1) = 0.054(451 - 417) = 1.85 \text{ kW}$;
 process «2-3» R-22 refrigerant's condensation in air heating tubs and rejection of condensation heat into the inside space of the house- $Q_{2-3} = G_{ag}(i_2 - i_3) = 0.054(451 - 248) = 11 \text{ kW}$
 process «4-1»-R-22 liquid refrigerant's evaporation of liquid R-22 “in hot water to liquid R-22” heat exchanger: $Q_{4-1} = G_{ag}(i_1 - i_4) = 0.054(417 - 248) = 9.1 \text{ kW}$

From the last expression is clear that for evaporation of liquid refrigerant in the heat exchanger (9) $Q = 9.1 \text{ kW}$ of heat should be transferred from hot water to liquid R-22.

ventilating and domestic hot water providing integrated system are the compressor (1), domestic hot water providing system, hot water preparing heat exchanger (14) and hot water to liquid R-22 heat exchanger (9). To define compressor's energy consumption, on the diagram (*i-logP*) of R-22 gas compression and other related processes are plotted. The Figure 4 represents (*i-logP*) diagram of R-22 with related processes taking place during operation of suggested integrated system.

$$G_w = \frac{Q_{4-1}}{c_w (t_{w.in} - t_{w.fin})}, \quad (5)$$

where:

$c_w = 4.18 \text{ kJ/(kg°C)}$ specific heat of water,

$(t_{w.in} - t_{w.fin}) = 20^\circ\text{C}$ –water temperature drop in “hot water-liquid R-22” heat exchanger.

Substituting in (5) given above values and making calculations will receive $G_w = 0.11 \text{ kg/s}$ of hot water to be supplied into “hot water-liquid R-22” heat exchanger (9).

6. Energy Efficiency and Cost Effectiveness of Integrated System

To reveal energy efficiency and cost effectiveness of the developed “integrated” system, it is necessary to compose its optimization mathematical model. The mathematical model represents a set of totality of all equations forming the methods for determination of design, constructive, energy and economic parameters of the system, which are included into the economical functional of the system. The economical functional is the criteria of energy efficiency and cost effectiveness of the system. For determining the value of economical functional T_s , $\$/\text{m}^2 \text{ year}$, the following ratio is used [4]:

$$T_s = T / S \quad (6)$$

where:

T – seasonal total expenditures made for assembling and operating of “integrated” system, \$/year,

$S=144\text{m}^2$ – surface of floor of considered house, m^2 .

The required seasonal total expenditures T , \$/year needed for running of “integrated” system is determined by the following formula:

$$T = \Sigma K / Y + \Sigma U \quad (7)$$

where:

ΣK – total capital cost of the system, \$,

ΣU – total seasonal operational cost of the system, \$/year,

Y – capital investments payback period, which is selected to be equal to the life cycle duration of the system or any other period in case of which the cost of heat supply T_s , \$/(\$/\text{m}^2\text{year}) becomes affordable for consumers and acceptable for investors.

The total capital cost is a function of constructive and energy characteristics of main equipment. For the “integrated” system total capital cost ΣK is determined by the following sum:

$$\Sigma K = (K_{comp} + K_{P.T.A.H} + K_{HEX.d.h.w} + K_{evap}) \cdot 1.4 \quad (8)$$

where:

K_{comp} – cost of compressor, \$,

$K_{HEX.d.h.w}$ – cost of domestic hot water preparing heat exchanger, \$,

$K_{P.T.A.H}$ – cost of pipe type air heater, \$,

K_{evap} – cost of “hot water-liquid R-22” heat exchanger, \$,

1.4 – system’s assembling, testing and extra expenditures factor.

The costs of listed equipment are determined below

Cost of compressor depends on its cooling capacity and is defined by the following production:

$$K_{comp} = C_{comp} Q_{comp} \quad (9)$$

where:

C_{comp} – specific cost of compressor, \$/kW,

Q_{comp} – cooling capacity of compressor, kW.

To determine the specific cost of the compressor special investigation has been accomplished on the example of Danfoss company production [11], aiming at establishing the mathematical function $C_{comp}=f(Q_{comp})$ on the base of price list of different power consuming compressor’s. The results of mentioned investigations are represented in form of diagrams, given in the Figure 5.

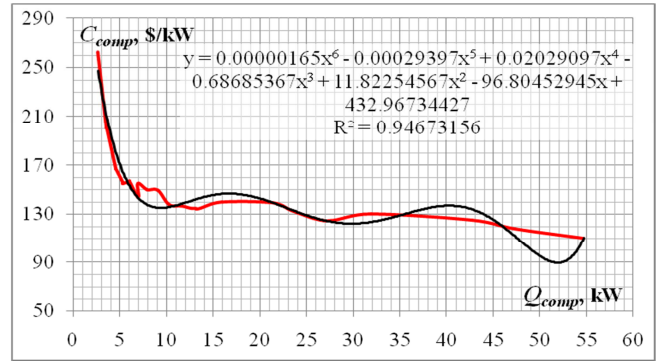


Figure 5. Specific costs of refrigeration compressor C_{comp} , \$/kW of various cooling capacity Q_{comp} , kW for MTZ type compressors of “Danfoss” company production.

From the diagram Figure 5 can be seen that the specific cost for a compressor of 9.1 kW cooling capacity makes 135 \$/kW. According to this value, the capital cost of compressor makes:

$$K_{comp} = 135 \cdot 9.1 = \$1228$$

Cost of domestic hot water preparing heat exchanger is determined by the following production:

$$K_{HEX.d.h.w} = C_{HEX} F_{HEX.d.h.w} = 20 \cdot 0.25 = \$5 \quad (10)$$

where:

$C_{HEX} = 20\$/\text{m}^2$ – the specific cost of “R-22 liquid-water” heat exchanger,

$F_{HEX.d.h.w}$ – “R-22 liquid-water” type heat exchange surface, which is determined by the following ratio:

$$F_{HEX.d.h.w} = \frac{Q_{h.w}}{k_{HEX} \Delta t} = \frac{1000}{350 \cdot 11.5} = 0.25 \text{ m}^2 \quad (11)$$

where:

$Q_{hw} = 1 \text{ kW}$ – quantity of heat for heating of domestic hot water for 6 person,

$k_{HE} = 350 \text{ W/m}^2 \text{ } ^\circ\text{C}$ – heat transfer coefficient of “R-22 liquid to water” type heat exchanger,

Δt – mean logarithmic temperature difference in counter flow heat exchanger, which is determined by the following equation:

$$\Delta t = \frac{(t_{cond} - t_{w1}) - (t_{cond} - t_{w2})}{\ln \frac{t_{cond} - t_{w1}}{t_{cond} - t_{w2}}} = \frac{(45 - 10) - (45 - 43)}{\ln \frac{45 - 10}{45 - 43}} = 11.5 \text{ } ^\circ\text{C}$$

where:

$t_{cond}=45^\circ\text{C}$ – condensation temperature of refrigerant gas in pipe type air heater,

$t_{w1}=10^\circ\text{C}$ – tap water initial temperature,

$t_{w2}=43^\circ\text{C}$ domestic hot water required final temperature.

Cost of “hot water-liquid R-22” heat exchanger is determined by the following production:

$$K_{evap} = C_{HEX} F_{evap} = 20 \cdot 1.24 = \$25 \quad (12)$$

where:

F_{evap} - “hot water-liquid R-22” type heat exchange surface, which is determined by the following ratio:

$$F_{evap} = \frac{Q_{4-1}}{k_{HEX} \Delta t} = \frac{9100}{350 \cdot 21} = 1.24 \text{ m}^2 \quad (13)$$

where:

Q_{evap} = 9.1 kW - quantity of heat for evaporation of R-22 liquid refrigerant,

Δt - mean logarithmic temperature difference in counter flow “hot water-liquid R-22” heat exchanger, which is determined by the following equation:

$$\Delta t = \frac{(t_{w.in} - t_0) - (t_{w.fin} - t_0)}{\ln \frac{(t_{w.in} - t_0)}{(t_{w.fin} - t_0)}} = \frac{(43 - 10) - (23 - 10)}{\ln \frac{(43 - 10)}{(23 - 10)}} = 21 \text{ } ^\circ \text{C}$$

Cost of pipe type air heater

$$K_{P.T.A.H} = C_{copper} L_{total} = 5 \cdot 130 = \$650 \quad (14)$$

where:

C_{copper} = 5 \$/m- specific cost of 1m copper tube with diameter d_{ext} = 10mm [12],

L_{total} - total length of pipe type copper tube air heater, m.

So, the approximate total capital cost ΣK , \$ for the “integrated” system makes:

$$\Sigma K = (1228 + 5 + 25 + 650) \cdot 1.4 \approx \$2672$$

Total seasonal operational cost of the “integrated” system is formed from following sum:

$$\Sigma U = U_{comp} + U_{rep} \quad (15)$$

where:

U_{comp} - cost of seasonal consumption of electricity by compressor, \$/seas.,

U_{rep} - seasonal cost of current repair of the system, \$/year,
Seasonal cost of electricity, consumed by the compressor

$$U_{comp} = C_{el} N_{comp} Z_{seas} m \quad (16)$$

where: C_{el} = 0.08 \$/kWh tariff of electricity in Armenia,

N_{comp} = 1.8 kW power capacity of compressor,

Z_{seas} = 3500h - durations of heating season in Yerevan,

m - weather averaging factor for winter heating season

Cost of seasonal consumption of electricity by the compressor makes:

$$U_{comp} = 0.08 \cdot 1.8 \cdot 3500 \cdot 0.5 = \$252$$

Seasonal cost of current repair of integrated system is determined by the following expression [4]:

$$U_{rep} = 0.04 \Sigma K = 0.04 \cdot 2672 = 107 \text{ $/year} \quad (17)$$

Summing obtained data, will find the following seasonal operational cost of the considered integrating system:

$$\Sigma U = \$252 + \$107 = \$359$$

Seasonal expenditures for running the “integrated” system makes:

$$T = \frac{2672}{25} + 359 = 465 \text{ $/year}.$$

Respectively, the cost of seasonal heating, referred to 1m² of building makes $T_s = 465/144 = 3.2 \text{ $/m}^2 \text{ year}$.

For evaluating efficiency of integrated system it is compared with another kind of effective heating system that uses fossil fuel in form of natural gas. The cost of seasonal quantity of gas, consumed by gas fired boiler of considered heating system is determined by the following equation:

$$U_{boil} = C_{fuel} B_{gas} Z_{seas} m \quad (18)$$

where:

C_{fuel} - cost of unit of fuel (tariff), \$/m³,

B_{gas} - seasonal consumption of fuel by gas boiler,

The value of B_{gas} is determined by the help of following fraction:

$$B_{gas} = \frac{Q_{boil}}{\eta_{boil} Q_{gas}} = \frac{12}{0.85 \cdot 9.3} = 1.52 \text{ m}^3/\text{h} \quad (19)$$

where:

η_b = 0.85 energy efficiency (COP) of boiler.

Q_{gas} - fuel combustion heat capacity 9.3 kWh/m³

Substitute of above values in the formula (19) and making calculation will obtain the value of gas consumption which makes B_{gas} = 1.52 m³/h. Then according to formula (18) the seasonal gas consumption for ordinary system makes U_{boil} = 0.3 · 1.52 · 3500 · 0.5 = 798 \$/seas.

The integrated system allows saving 2660 m³ fossil fuel during heating season. In Table 2 are shown comparative energy and economic indices of both systems. Comparison of data of Table 2 shows that specific cost of seasonal heating T_s referred to 1m² of the building is 6.6/3.2 = 2.06 times less than for ordinary system.

Table 2. Comparative energy and economic indices of fossil fuel non-consuming integrated system and heating cooling ordinary systems.

Characteristics	“integrated” system	Ordinary system
Total capital cost, ΣK x 1,4, \$	2672	2012
Total seasonal operational cost of system ΣU , \$/year	359	877
Seasonal expenditures for running the system, T,	465	957
Specific cost of seasonal heating referred to 1m ² of building, T_s ,	3.2	6.6

7. Conclusion

1. Detailed studies of well-known heating system's structures, operation principles, kinds of consumed fuels', energy and cost effectiveness and other constructive and operational features it is concluded that developed fossil fuels non - consuming heating, ventilation and domestic hot water providing integrated system is publically issued and discussed first time.

2. The critical advantage of developed heat supply integrated system is the prevention of surrounding environment from pollution, because it does not use at all natural fossil fuel.

3. Hot liquid refrigerant preparation proposed system works as refrigeration open loop high efficiency invers device, as instead of useless waste of condenser's produced heat it is used for air heating useful purpose.

4. Use of a refrigerator as a heating boiler provides all necessary requirements for realization of the idea of creation fossil fuel non-consuming heat generation and supply system.

5. Analyses prove the higher energy efficiency and cost effectiveness of developed fossil fuel non-consuming heat supply integrated system compared to well-known traditional types of heat generation and supply systems.

6. Experimental implementation of developed fossil fuel non-consuming integrated heat supply system and its farther studies will spur new system's wide use, will create plentiful of new job places, and will develop economy of the country.

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