DOI: 10.63550/ICEIP.2025.36.61.077

Integration of Heat Pump Units with Modern Refrigerants in Residential District Heating and Cooling Systems

A.L. Petrosyan[a] and K.A.Movsisyan[b]
National University of Architecture and Construction of Armenia, Yerevan, RA
artashespetrosyan@mail.ru, karen.movsisyan1999@gmail.com

Key words: heat pump, R32 freon, residential areas, heating, cooling.

Abstract: The decline in natural resources of organic fuels, the gradual deterioration of the living environment and the ecological situation of people are forcing specialists in the field to think about using more energy-efficient and environmentally friendly technologies. Heat pump installations (HPI) can be one of them. These, in thermodynamic and technological processes, use environmentally safe electrical energy obtained at a nuclear power plant, thermal power plant or combined heat and power plant, located at a safe distance from residential areas, use the energy of low-temperature thermal sources (LTS), and under normal operating conditions do not pose a danger to the population. However, there is a danger condition for RHCs: the type of refrigerant used in them and the formation of hazardous substances in the event of natural leakage and repairs - in the surrounding environment, in the biosphere, in the ozone layer. Refrigerants can emit greenhouse gases and, to a lesser extent, toxic substances. Their division into natural substances and hydrocarbons, which include one or another hazardous substances - fluorine, chlorine, etc., limits the areas of application of various refrigerants, although many of them have sufficient or high thermodynamic and energy properties.

1 INTRODUCTION

HPI are one of the safest sources of heat and artificial cold from a thermodynamic and technological perspective. Using electrical energy as a source of mechanical energy, its operation requires the energy of low-temperature heat sources (LTHS): groundwater, solar and ground energy, thermal potential of external and building exhaust air, and secondary energy waste. It can operate uninterruptedly during the heating season at outdoor air temperatures of up to -8…-10ºC without an additional heat source, with significantly high energy efficiency. At temperatures of -20ºC and lower, HPI's can also operate, but under certain technological and thermodynamic transformation conditions and with lower energy efficiency. In addition to the constant presence of outside air, the HPI's have limitations in the availability and application of the LTHS: in the winter season, the number of days of solar radiation and the intensity of the flow are few, the thermal potential of the deep layers of the soil is low, and deep waters are at great depths or are absent. Electricity may also be in short supply in some regions. The type of refrigerant used in the HPI is also important. These have been or continue to be used: R-22, R-134a, R-407A, R-410a, R-32 and other refrigerants. R-22 has good thermodynamic and energy properties, although it can release the toxic substance phosgene in the event of an open flame and has the ability to release greenhouse gases. The same goes for R-134a. R-407A is used mainly in refrigeration equipment. R-410a, R-32 are distinguished by high condensation and evaporation pressures. A problem of safe operation arises, the diameters of the freon pipes have a large thickness compared to other refrigerants. R-410a, in the case of limited installation volume - in household and automotive air conditioners, etc., this factor is not significant.

[a] https://orcid.org/0000-0003-4256-1036
[b] https://orcid.org/0009-0004-4232-1803

DOI: 10.63550/ICEIP.2025.36.61.077

2 MATERIALS AND METHODS

R-32 currently has limited, but will have significant future applications in low and medium, even 1 MW and larger, HVAC and refrigeration applications, despite its high energy costs. R-32 (Difluoromethane, Methane difluoro (CH_2F_2)) also has similar performance to R-410a, but has gained practical application in recent years.

Although it is not as safe, it is 65% less harmful than R-410a, so it can be used in various industries. It has a low density and viscosity, which will ensure low refrigerant consumption, but will not affect the required capacity. Low viscosity reduces pressure loss in devices, thus increasing the energy efficiency of the heat pump, for example, in household air conditioners, by 5%. R-32 has a 5…7% higher thermal conductivity and cooling capacity compared to R-410a. This will lead to a reduction in the size of heat exchangers and installations, as well as in electricity consumption. The installation has a simple structure, the refrigerant does not change the structural proportions of the equipment, there is no need to remove the old refrigerant and charge it with a new one, or change the oil. As in the case of R-410a, similar oils and equipment can be used. The minimum evaporation temperature is, as in the case of R-410a, -51.7oC. R-32 is a synthetic material. Unlike R-22 ($CHClF_2$), which contains chlorine in addition to fluorine, it can degrade the biosphere, but R-32 does not contain such molecules.

The above are the reasons why, within the framework of this article, the prospective option of using R-32 was studied, when the operation of the heating and cooling supply systems (HCS) of the residential district of “Tsarav Aghbyur” in Yerevan was observed, when the heat and cold sources for it are R-32-operated HVAC systems. As an experimental design option, it is planned to place the HPI on the roof of the building (taking into account the strength and resistance of the supporting structure). The operation of a central heating and cooling system was considered as a comparable option, when a central heat and cold source with greater heat and cold efficiency was located in the heating and cooling center (it can be located in the upper right part of the district, in a separate building, in the heating and cooling center). For the latter, the heating and cooling loads of the 14th and 13th floor buildings of the “Tsarav Aghbyur” district and their change patterns according to individual months of the seasons were determined, then the total load of the HCS, taking into account the seasonal heat and cold losses in the external heating network. The neighborhood consists of 10 14-story and 3 13-story buildings, which have similar exterior cladding structures. The total population of the district is 2,630 people. During the experimental design of multi-apartment buildings and district HCS, energy and economic indicators were determined when local-central and district central HCS operating with R-32 refrigerant are used. For comparative analysis, R-22, R-134a, and R-410a refrigerants were also considered. The plan and external heating network of the mentioned district are shown in Fig. 1.

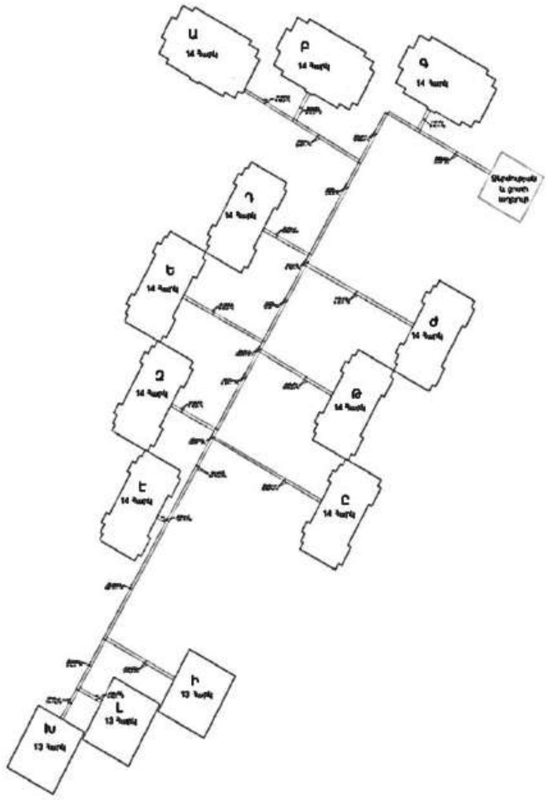


Figure 1: Master plan of a section of the "Tsarav Aghbyur" district.

Based on the building plans and external construction structures, thermal engineering calculations were performed. Accordingly, by applying the concept of conventional temperature, which includes both the calculated and current average monthly temperatures of the outside air, and the magnitudes of the solar radiation flux, heat losses from buildings were determined, taking into account internal heat losses caused by people, household and lighting devices. In the case of cooling, heat losses through enclosing structures and internal heat losses were calculated using a similar method. In this case, the solar radiation flux increases the heat losses, and

DOI: 10.63550/ICEIP.2025.36.61.077

therefore the cooling load. The external cladding of the buildings in the residential district is block-structured, with a heat transfer coefficient for the wall of: Uvalue = =0.85 W/m²°C.

For the district, according to the change in the climatic conditions of the outside air for different months, the heat losses of the building were determined according to the calculated temperature, which for the district was 2.9 MW, the mass flow of the heat carrier was 35.5 kg/s. The cooling load is 2.8 MW, and the refrigerant is 137.7 kg/s. The calculations were performed for the heating and cooling seasons, taking into account seasonal periods or the duration of individual months. According to, the duration of the heating season for Yerevan is set at 142 days (3408 hours), and the duration of the cooling season is set at 143 days (3432 hours). As a result of the analysis of the Tsarav Aghbyur district's heat loss network, it was found that during the heating season, heat losses from the network differ significantly in the temperature regimes of 80/60°C, 60/40°C and 45/25°C. In particular, compared to the heat load, the average heat losses during the season are 12% in the 80/60°C temperature regime, 8% in the 60/40°C regime, and 6% in the 45/25°C regime, when the total length of the external heat network is 540 m. According to the thermophysical properties of the heat source in the mentioned regimes, hydraulic calculations were carried out in the main pipelines, the results of which are as follows: 80/60°C - 10, 60/40°C - 9.8 and 45/25°C - 9.6 m H_2O. It follows from these results that reducing temperature regimes leads to a decrease in these losses, as a result of an increase in kinematic viscosity and density. As a result, the rated power of the electric motor of the circulation pump will decrease according to the modes, and will be 5.5, 5.3, 5.1 kW, respectively. As a result, electricity consumption will decrease by 1% due to the reduction in modes. By choosing an inverter type circulation pump, you can achieve additional savings.

As mentioned above, the feasibility of the measure, as a result of the use of R-32 refrigerant, will be determined by various factors: heating and cooling loads, the temperature regime of the heat pump was considered under the conditions of the same evaporation temperature: t^0=-20°C, different condensation temperatures: t^k=70,60,50°C. Such temperature-scale options were considered for further analysis.

It is accepted that in the winter months, the ambient air serves as a low-temperature heat source for the HCI, as a universal option, when we have the condition: to≤t"outs.des.ign air ". This will mean that the thermodynamic cycles of R-32 will be observed with the parameters tk=70,60,50oC and to=-20oC, which are given in Fig. 2. It follows from the cycles that depending on the change in , under the same conditions of to, the quantities qk, qo, lk also change, but by different percentages, which is due to the thermodynamic properties of the given refrigerant. When tk=70oC, the HPI conversion coefficient will be: qk/lk=μk=2.41 ,60oC-2.88, 50oC-3.35. As a result, the ratio of the values of the conversion factor to the HPI changes: 19% when we have 70/60 oC and 16% when we have 60/50oC. From the obtained result, it follows that the ratio of the conversion coefficients increases proportionally to tk. The increase in the conversion coefficient at 50/70oC will be 28%.

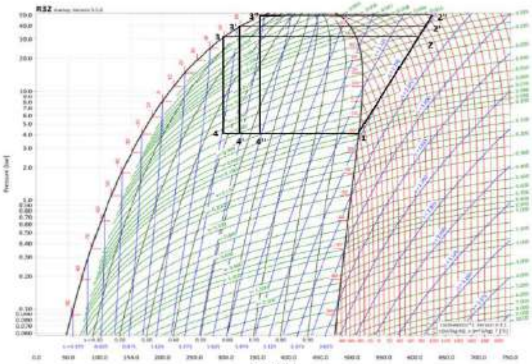


Figure 2: Thermodynamic cycles for different t^k and t^o=-20° C.

The same values for R-410a will be: t^k=60, μk=1.94, tk=50, μk=2.39. The ratio of the conversion coefficients will be 19%.

From the comparison of R-32 and R-410a, it can be seen that the use of R-410a for the RHP is not advisable (see Fig. 3), since at t^k=60°C the ratio of the conversion coefficients is 1.48 or the HPI energy efficiency is 48% lower, which is significant. At the same time, it follows from Fig. 3 that it is impossible to operate R-410a in high temperature regimes, even at tk=70oC. This would mean that the use of R-410a, according to its thermodynamic properties, would be considered inappropriate in HPI systems. The above conclusions were made based on the results of thermodynamic analysis. More solid conclusions can be drawn from the economic analysis of the system.

In addition to the thermodynamic analysis of the HPI, it is also necessary to perform a feasibility analysis, since high efficiency indicators alone are not sufficient for a complete assessment of the system in technical terms.

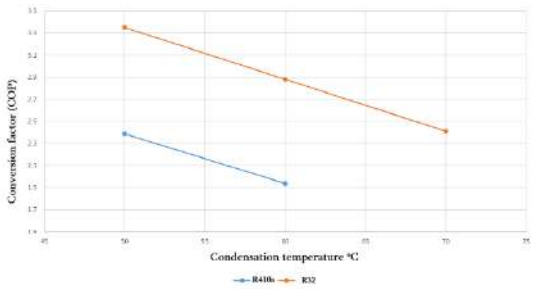


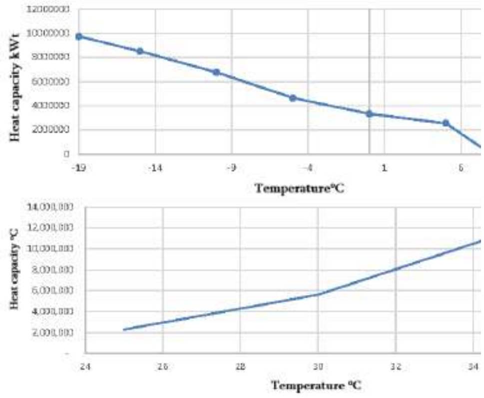
Figure 3: The regularity of the change in the conversion coefficients of R-32 and R-410a: the values of the conversion coefficient in the temperature regimes t^k=70,60,50°C and t^o=-20°C.

Within the framework of the feasibility analysis, it is necessary to take into account the costs of investment, operation and maintenance of the facility, energy consumption volumes, the payback period of investment costs, market competitiveness and environmental impacts. These approaches will allow not only to optimize the operation of the HPI, but also to ensure its economic feasibility and long-term profitability. The main investments are the costs of purchasing equipment, installation, and earthworks. Two options were considered: when the HCS is carried out from a central heating center, located in the upper right part of the plan, and local-central, where the HCS of each building is carried out from a heating and cooling center located on the roof. The comparison of the two options was made in terms of capital investments and operating costs, that is, according to the costs incurred. The costs of installing a central HVAC system are 4525437.10 USD, and in 1220568.64USD (for 13 level), 1393519.77(for big 14 level), 3518107.07 (for small 14 level) for a local-central HVAC system, separately for each type of building. These costs are determined by a number of factors: the climatic conditions of the location, construction features, as well as the quality of the equipment. The values of the latter were calculated based on average quality and price brands.

It turns out that the central HPI is more efficient than the local-central HPI in terms of capital investments. In particular, the capital investments of the central HPI amount to 4517047 USD, while in the case of the local-central HPI option, it is 6120826 USD. In other words, it is about 26% more affordable for the central JCMF, which is a serious financial burden in the case of such a large-scale project. In addition to capital investments, operating costs were also compared in two cases. Their analysis allows us to assess the profitability of the system throughout its entire life cycle. Electricity costs were considered as the main factor.

3 RESULTS AND DISCUSSION

To establish economically advantageous operating modes of thermal equipment, select appropriate heat carrier parameters, and conduct feasibility studies, it is necessary to take into account the heat loads during the year at the specified temperature regimes. For this purpose, it is necessary to construct a graph of annual heat consumption for heating (Rosander graph). It is created based on the duration of external temperatures and climatic data for a given location. For the central JCMF, it is presented in Fig. 4a, and for the local-central JCMF variant, in Fig. 4b.



a

b

Figure 4: a., b. For the central HCS, it is given in Fig. 4 a, and for the local-central HCS version.

Rossander schedules have also been constructed for the cooling season.

According to these schedules, electricity and gas costs are calculated (heating load at temperatures below -10°C, when provided by gas boilers and HPI). The electricity cost for the heating and cooling seasons is 971969.11 USD, and the gas cost is 15865 USD. The total gas and electricity cost for the year will be 987834 USD. Dividing it by the number of months in the year – 12, and the number of apartments - 895, we will get the average monthly cost of operating heating/cooling systems for 1 apartment: 987834/12/895 = 91,9 USD.

Such a calculation is performed in a local-central version, individual for each building, for which Rossander graphs are constructed for each building and, accordingly, the electricity and gas costs for 14- and 13-story buildings are determined on an annual basis. The annual electricity cost for a small 14-story building is 101971 USD, and gas is 1766.95 USD. The total annual operating costs will be 103737.97 USD. Again dividing by the number of months in the year, 12, and the number of apartments, 70, we will get the average monthly operating costs of heating/cooling systems for 1 apartment:

DOI: 10.63550/ICEIP.2025.36.61.077

103737.97/12/70 = 123.5 USD. The same will be done for the 14-story building. The annual electricity cost will be 105629.23 USD, and gas cost will be 1893.16 USD. The total operating cost for the year will be 107522.39 USD. Dividing it by the number of months in the year, 12, and the number of apartments, 70, we will get the average monthly operating cost of heating/cooling systems for 1 apartment: 107522.39/12/70 = 128 USD.

We will perform a similar calculation for a 13-story building. The annual electricity cost will be 54780.83 USD, and the gas cost will be 1325.21 USD. According to the above, the total operating cost for the year will be 81206.93 USD. The average monthly operating cost of heating/cooling systems for 1 apartment is 81206.93/12/65= 104.11 USD.

For three buildings, the total average cost will be 118.54 USD. It turns out that the operating costs are about 29% higher in the case of the local-central system.

The same calculations were also performed in the case of R134a, R410a freons. The condensation temperature of R134a freon is high - 101.1oC, and the evaporation temperature is low - -26.1 oC, that is, theoretically it can be observed that in winter the CHP can also work without an additional heat source, in which case we will have 101.73 USD/month in the case of a central system, and in the case of a local central system the average is 124.92 USD/month. The results obtained with R134a freon are about 15% higher than with R32. The reason is simple: the EGR of the refrigerant drops sharply when operating at negative temperatures, the conversion coefficient is 1.2. The thermodynamic parameters of R410A are very similar to R32, meaning we cannot avoid a secondary heat source. However, the conversion coefficient of R410A is 5.6% lower than that of R32, meaning operating costs should be higher. In the central version, we have 96.55 USD/month, and in the case of the local center, the average is 122.62USD/month. It turned out to be about 5% smaller than in the case of R134a, but about 5% larger than in the case of R32. Along with all this, let's also take into account that R134a, R410A freons have negative effects on ecology, we can definitely consider R32 the best freon.

4 CONCLUSION

1. Research has shown that when using modern freons, which have high specific efficiency, fan coils and underfloor heating systems can serve as indoor heating/cooling devices due to their low condensation temperatures.

2. Theoretical studies show that in district heat pump application options, the operating costs of centralized heating/cooling systems are 30% lower than those of semi-centralized systems (on the roof of each individual building).

3. A comparative analysis of R134a, R32, R410a refrigerants (freons) in heating and cooling systems shows that the selection of refrigerants should be made taking into account the operating temperature regimes, equipment compatibility and environmental impacts.

4. Of the above, it is preferable to use such refrigerants that will provide the maximum technical, economic and ecological indicators. As shown by theoretical and experimental studies, the use of R32 is economically feasible and technically more efficient.

REFERENCES

Avetisyan, A. G., 2018. Economy of Heat and Gas Supply and Ventilation Systems and Methodology for Improving Energy Efficiency: Educational-Methodical Manual. *National University of Architecture and Construction of Armenia*. Yerevan, 64 pages.

Becker, R., 1974. *Theory of Heat*. Moscow: Energiya, 504 pages.

Bogdanov, S. N., Ivanov, O. P., Kupriyanova, 1985. *Refrigeration Technology. Properties of Substances: Handbook*. Moscow: Agropromizdat, 208 pages.

Bogoslovsky, V. N., 1985. Air Conditioning and Cold Supply. Moscow: Stroyizdat, 367 pages.

Bogoslovsky, V. N., 1980. *Heating and Ventilation*. Moscow: Stroyizdat, 295 pages.

Care for the Climate (Guide to the UN Framework Convention on Climate Change and the Kyoto Protocol). Ministry of Nature Protection of the Republic of Armenia, UN Development Programme. Yerevan, 2004. 50 pages.

https://www.bitzer.de/cz/en/tools-archive/software/software/

https://www.ipu.dk/products/coolpack/

Jha, A.R., 2006. Cryogenic Technology and Applications/ USA-Oxford , 288p.

Langevin, J., Harris, C.B., Reyna, J.L., 2019. Assessing the Potential to Reduce U.S. Building CO2 Emissions 80% by 2050 Joule. 3:2403-2424

Martynovsky, V. N., 1990. Thermodynamic Cycles and Principles of Operation of Thermotransformers. Moscow: Vysshaya Shkola, p. 376.

Mitsubishi Electric. ecodan renewable heating technology data book, 2024

DOI: 10.63550/ICEIP.2025.36.61.077

Oluseyi, P. O., Okoro, O.I., 2006 Prospects of renewable energy in the third world, Energy Education, Pedagogical University, Havana, Cuba, Nov.

Petrosyan, A. L., 2006. "Improvement of the Energy and Environmental Characteristics of Heating Boilers through the Use of a Heat Pump." *Scientific Proceedings of the National University of Architecture and Construction of Yerevan*, no. 2: 130–132.

RA SNIP 22-01-2024**.** *Construction Climatology: Construction Norms of the Republic of Armenia*. 259 pages.

Xuan, W., Yonglong, Lu., 2024. Total-factor energy efficiency of ten major global energy-consuming countries, *Journal of Environmental Sciences,* Vol 137, p. 41-52

Zhou, Z., 2018. Heating energy saving potential from building envelope design and operation optimization in residential buildings: a case study in northern China J. Clean. Prod.