Hydrocarbon heat and refrigeration supply systems for a mini-hotel with a shop and laundry

RANGE OF PROBLEMS

Fulfillment of obligations under the Montreal protocol on substances that deplete the ozone layer, 1987, will soon entail practically full phase out of production and use of chlorine synthetic refrigerants, hydrochlorofluorocarbons (HCFC), possessing ozone-depleting potential (ODP). Their ozone-safe substitutes, hydrofluorocarbons (HFC), cannot be considered as an adequate alternative for their significant global warming potential (GWP), so, in case of venting into the atmosphere, they provoke the global climate change. By now, many countries have already adopted laws restricting use of HFC. Thus, EC F-gas regulations provide for 5-time reduction of HFC use in Europe by 2030 and limits maximum refrigerant GWP for various uses.

In light of current trends, refrigerants used today are to be replaced with substances with similar physical and chemical profile but better energy efficiency, zero ODP and low GWP.

The existing alternatives may be divided in two groups:

- non-fluorine natural refrigerants with low or zero GWP: ammonia, hydrocarbons (propane, isobutane, etc.), and carbon dioxide;
- fluorine synthetic refrigerants with low or medium GWP: hydrofluoroolefins (HFO), hydrochlorofluoroolefins (HCFO), and some HFC (R32, etc.).

HFO and HCFO are at least as expensive as HFC. Besides, production of these refrigerants in Russia in the foreseeable future is not in the plan. So, taking into account the economic situation and following the state policy of import substitution, special attention should be given to natural refrigerants, particularly, propane (R290).

Demo-project “Hydrocarbon heat and refrigeration supply systems for a mini-hotel with a shop and laundry” is aimed at familiarization of federal executive bodies, business and society with results of implementation of conversion to ozone-safe and energy efficient natural refrigerant performed as part of UNIDO/GEF-MNRE Project “Phase out of HCFCs and Promotion of HFC-Free Energy Efficient Refrigeration and Air-conditioning Systems in the Russian Federation through Technology Transfer”.

SOLUTION: OSTROV TECHNOLOGY

OSTROV TECHNOLOGY is an innovative refrigeration supply system for commercial or industrial facilities developed by Ostrov company. OSTROV TECHNOLOGY system was designed as a future solution which takes into account the latest energy efficiency and sustainability requirements for refrigeration systems. The system excels the existing analogues in the following performance evaluation criteria:

- operating costs;
- environmental impact;
- flexibility in use.

Basically, OSTROV TECHNOLOGY modules are divided in separate compression-condensation unit and thermal transformers joined with a cooling water circuit into an integral system.

Through the integral system, the cooling water circuit ensures heat transport. The heat carrier is circulated mechanically, by means of circulation pumps.

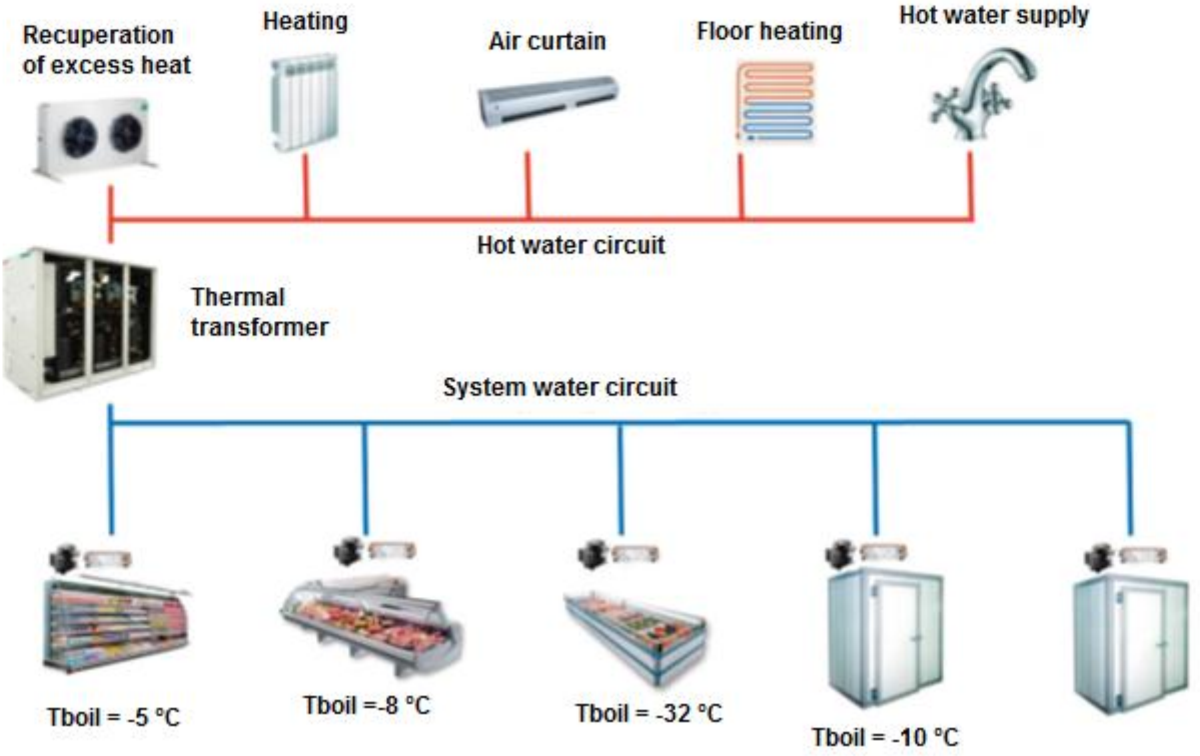

Figure 1. OSTROV TECHNOLOGY scheme

The design and installation of the cooling water circuit do not require considering many limitations of traditional halocarbon systems. The OSTROV TECHNOLOGY system does not need pipeline pitches or oil return loops to be foreseen or arranged, and the system efficiency is almost fully independent from the pipeline length.

Separate modules (compression-condensation units) are designated for each item of refrigerating equipment. The unit may be installed at the majority of existing commercial models, refrigerating chambers, air conditioners, and other devices.

To select a module only two criteria are applied: refrigerant boiling temperature and cooling capacity of an equipment item. The modules operate independently and do not interact. The quantitative and qualitative composition of the system does not influence operation of separate components thus significantly simplifying selection and design.

Each item of refrigerating equipment furnished with OSTROV TECHNOLOGY modules contains the minimum refrigerant charge. The refrigerant type is selected with account of the customer’s tasks and legislation of the region where the system operates. As compared to the central refrigeration supply system, the refrigerant charge is several times lower thus ensuring significant reduction of the environmental load even in case of using non-sustainable refrigerants.

The separate module can be installed directly on, or near the refrigerating equipment. Thanks to the small size, the module can be covered with decorative elements.

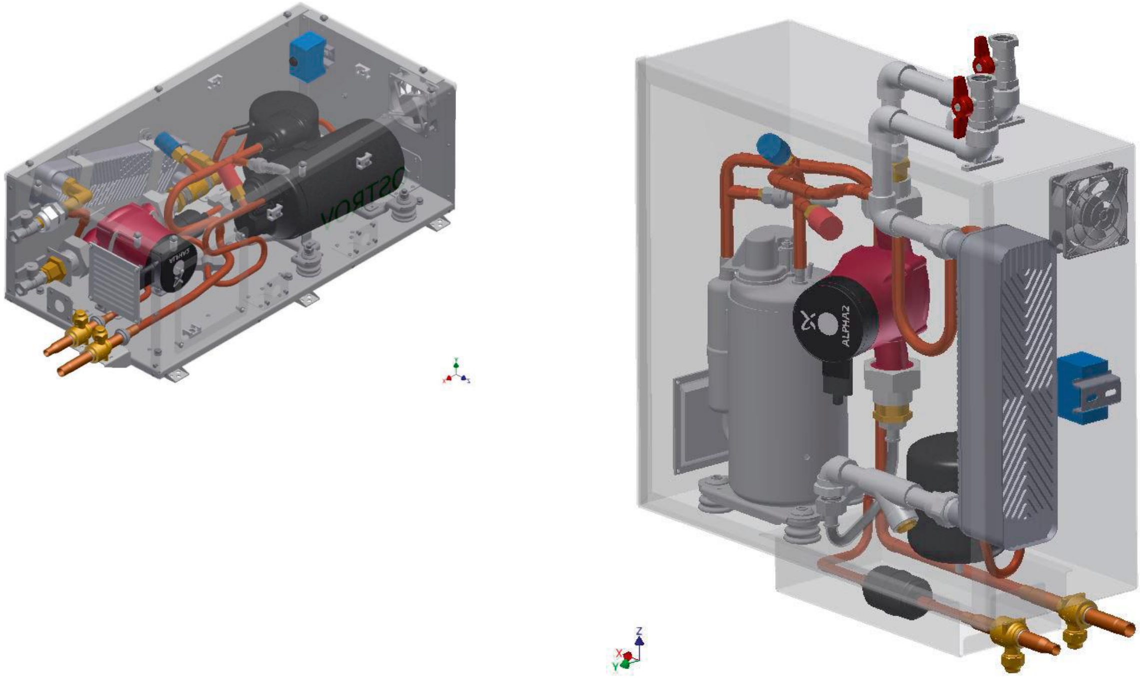

Figure 2. Horizontal (on the left) and vertical (on the right) units of the OSTROV TECHNOLOGY system

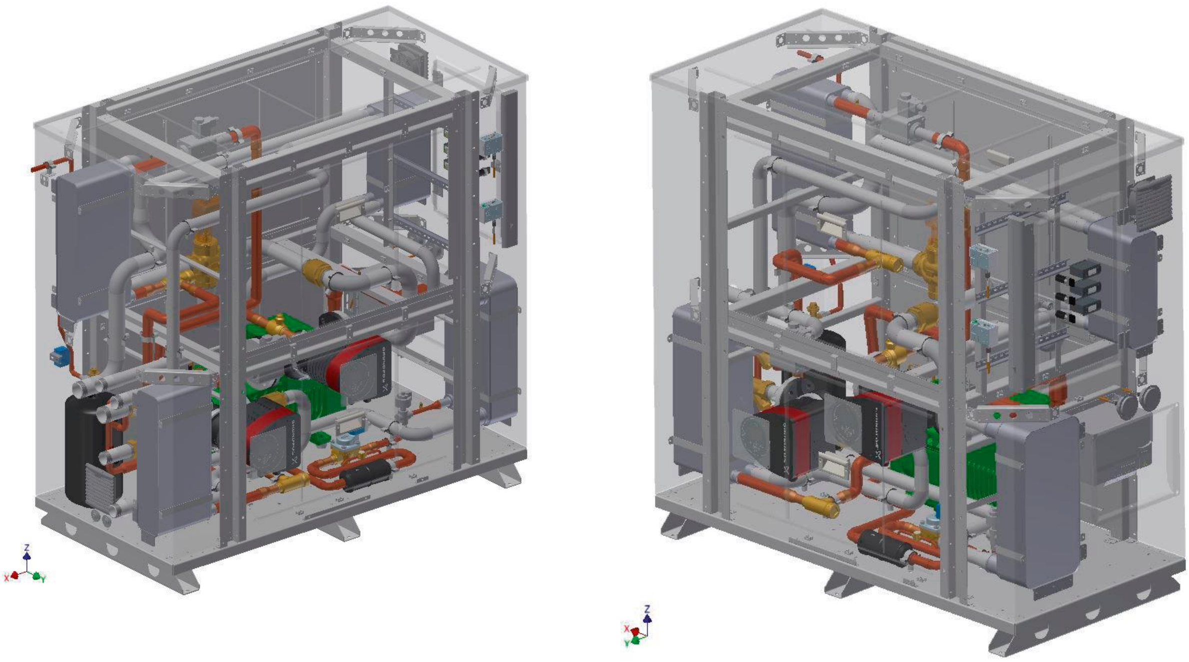

Figure 3. Thermal transformer

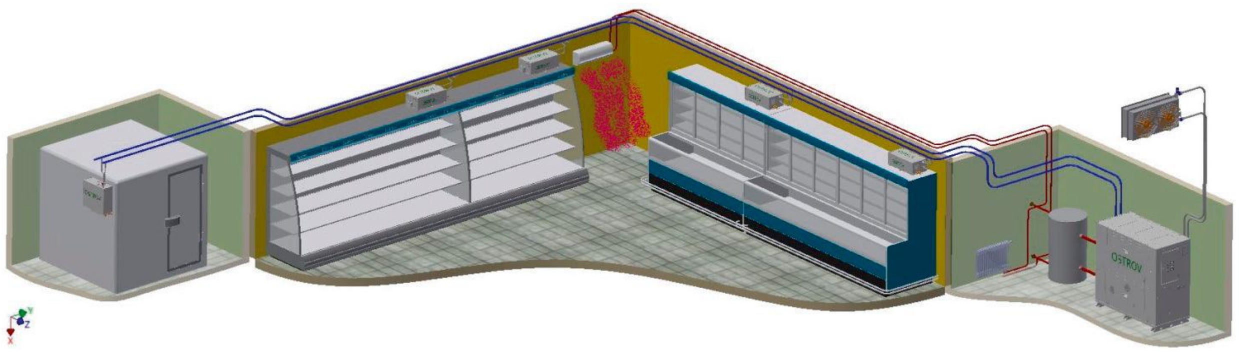

Figure 4. Example of installation of the OSTROV TECHNOLOGY system

The thermal transformer is a core of the OSTROV TECHNOLOGY system. It removes heat of condensers of separate units under constant temperature of the cooling water.
At the same time, the thermal transformer generates high potential heat for various economic needs: heating, hot water, air curtains, floor heating, etc.

Excess heat, if available, are released into the environment through a radiator (dry-cooler) or an air condenser depending on the selected options and place of the thermal transformer. The system modules are joined into an integrated circuit by means of standard water pipes of any type. Temperature and pressure in circuits are usually even low than those in hot water supply and heating systems.

When designing the cooling water circuit, factors important for halocarbon refrigerant circuits are not taken into account. The system may operate with any pipeline pitch, even at several floors.

To lay the circuit of the system of 10–20 modules, two to three days are usually necessary from completion of installation of the commercial equipment till the system startup.

Configuration

The demo stand presenting a working model of a refrigerating and heating system for a typical mini-hotel with a shop and laundry consists of:

- 30 m^2 shopping space with installed commercial refrigerating equipment, chamber, and units;
- technical space cooled with an A/C system with thermal transformer located inside the premises. The heating and A/C system maintain 20–25 °C thus simulating a hotel room;
- handwashers simulating hot water consumption;
- key parameter monitoring system of the OSTROV TECHNOLOGY stand.

Refrigerating equipment and units

Units of the shopping space are charged with R290 (propane). These units are small and placed directly on the commercial refrigerating equipment (counter, cooling chest, multi-deck cabinet, case, chamber). The OSTROV TECHNOLOGY system contains 15 times less refrigerant than a standard system with external heat exchangers. As a rule, a unit contains no more than 300 ml of refrigerant which corresponds to 150 g of R290.

The thermal transformer is located in the technical space and charged with natural refrigerant R290. The space is also equipped with double-flow air cooler Ostrov OH221–135S1A-C55 simulating air-conditioner load in a hotel room. The chamber of the demo stand is equipped with a cubic air cooler Ostrov OH201–135S1A-C70.

In summer, rejection of excessive heat into atmosphere through a dry-cooler (air-cooled radiator) is foreseen.

Figure 5. Horizontal separate OSTROV TECHNOLOGY unit appearance

Figure 6. Arrangement of the horizontal separate OSTROV TECHNOLOGY unit

Figure 7. Double-flow air-cooler Ostrov OH221

Figure 8. Cubic air-cooler Ostrov OH221

Furniture for the stand

After analysis of commercial refrigerating equipment, Ostrov specialists selected Brandford and Polair products.

Table 1. Specification for refrigerating equipment (furniture)

Name	Model
1. Wall-adjacent multi-deck cabinet	TESEY250
2. Cooling chest	Krios 250
3. Case	AURORA SQ 250
4. Chamber	KXH-11,02

ENVIRONMENTAL ADVANTAGES OF THE SOLUTION

Small charge

First and main advantage of the OSTROV TECHNOLOGY system over traditional refrigerating systems is small refrigerant charge. The total charge used in separate modules and thermal transformer is 80% less on the average.

The separate modules installed on the commercial equipment contain small amounts of refrigerant. Most often the refrigerant charge does not exceed 300 ml which corresponds to 150 g of propane (R290).

The thermal transformer located in the technical space or outside may be charged with various refrigerants: R134a (HFC-134a), R744 (carbon dioxide), and R290 (propane).

Low energy consumption

General energy consumption of the OSTROV TECHNOLOGY system is lower than of other popular refrigeration supply systems. This is ensured by optimization of operation modes of refrigerating machines.

In the refrigerating system with external compressor unit operating with several loads, refrigerant boiling temperature and respective pressure in the compressor suction line depend on the load with the lowest evaporation temperature. So, the efficiency of the whole system depends on the least efficient load.

Suction line loss in a system with external compressor unit, even in case of the best installation work and short pipeline, do not exceed 2 K.

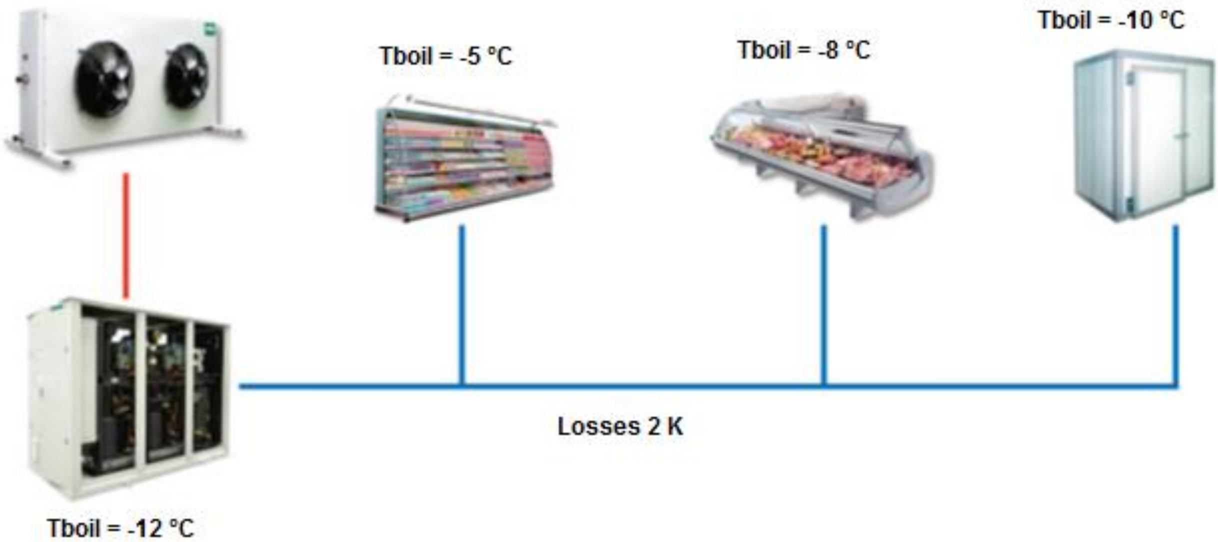

Figure 9. Scheme of the refrigeration supply system with external compressor unit

OSTROV TECHNOLOGY compressor units of each load are independent, which allows joining medium temperature loads with various boiling temperatures and join low, medium temperature units and air conditioners in the single system with the same efficiency. All system modules operate independently, and the operation mode of a certain module does not influence others.

Minimization of refrigerant leakage

Since circuits of the OSTROV TECHNOLOGY system charged with refrigerant are independent, leakage in one of them does not cause emission of the whole charge into the atmosphere. So, the potential leakage volume decreases many times. This feature directly affects the total system GWP.

Possibility to use natural refrigerants

Natural refrigerants used today have a number of significant engineering constraints. For example, there are difficulties (or even ban) related to the use of ammonia, a toxic substance, in occupied spaces. Hydrocarbons are usually flammable and maximum charge is limited by law. Transcritical CO2 systems, in the first place, operate under high pressure, and, in the second, are expensive.

The OSTROV TECHNOLOGY system may operate with various refrigerants, so negative factors are minimum. Separate units of the OSTROV TECHNOLOGY system may be charged with any hydrocarbon refrigerants, as charge volumes of any separate element are very low. The thermal transformer of the OSTROV TECHNOLOGY system may use any refrigerant, including ammonia and carbon dioxide, and is located in a separate specially equipped space.

TECHNICAL ADVANTAGES OF THE SOLUTION

Simple installation

Installation of on-site OSTROV TECHNOLOGY units is simpler, faster and cheaper than that of traditional centralized refrigeration supply systems. The cooling water circuit joining units into the system is made of polypropylene tubes. The pipe junction technology is simpler than halocarbon pipes.

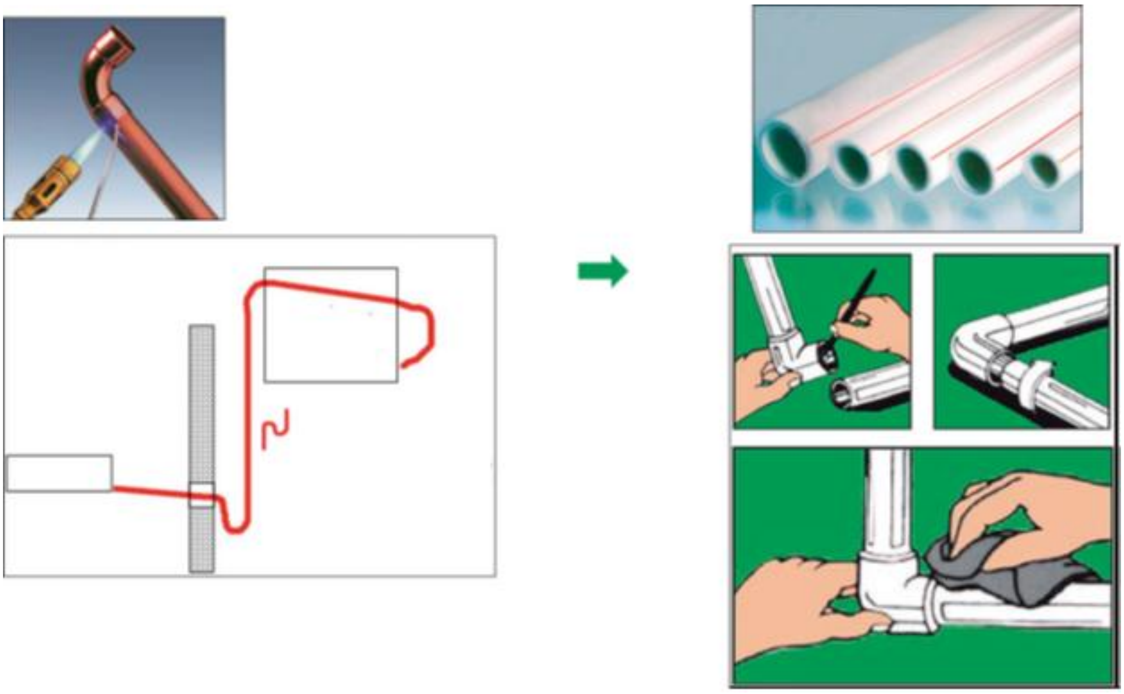

Figure 10. Difference of pipe junction technology for a traditional system with external heat exchanger and OSTROV TECHNOLOGY system

The OSTROV TECHNOLOGY system uses only common installation materials. All pipes, fittings, and shut-off valves are standard and generally used in construction.

Reliability

Due to modular nature and independent circuits, the OSTROV TECHNOLOGY system is stable. In case of failure of any module or damage of its circuit, the rest system continues operating as per normal.

A leakage does not cause the system shutdown. The coolant loss can be offset by running water, and leakages, stopped without special tools.

All the units of the OSTROV TECHNOLOGY system operate in optimal modes. The issue of frequent start-ups is totally eliminated by individual module selection and, in great measure, by extent of the control.

Simple operation

The OSTROV TECHNOLOGY system does not require regular maintenance of modules or circuits. Since all the key units are assembled and adjusted in-plant, maintenance teams do not need to check or adjust parameters during operation. So, critical faulty settings of the operation mode are practically excluded.

OSTROV TECHNOLOGY refrigeration supply systems may be equipped with various monitoring and control devices. In case of equipping all the modules and elements with control systems, no visual inspection of units is required: all operating parameters are directly transmitted to responsible companies thus preventing a human error.

ECONOMIC ADVANTAGES OF THE SOLUTION

Calculation procedure of overall cost of a traditional refrigerating system

Today owners of trade facilities pay more attention to cost and energy efficiency of refrigerating systems.

We will analyze the key factors affecting energy consumption of a refrigerating system, and see how they change in case of the OSTROV TECHNOLOGY system.

1. Compressor load factor. This value always depends on the environmental and operation conditions. The technical documentation usually contains data on energy consumption under 100% load and maximum condensing temperature. The average energy consumption by a commercial refrigerating machine is usually about 70% of the maximum.

Compressors of separate OSTROV TECHNOLOGY modules constantly operate under optimal load because the condensing temperature is stable no matter what season it is.

2. Quality of installation works. Any refrigerating system, except for built-in units with air-cooled condensers, must be installed in accordance with numerous rules and regulations. However, failure to comply with them does not always cause the system failure. Most often design and installation errors are set-off by reduced boiling pressure. Such errors often cause 40–50% excess of the real energy consumption rate of the system over the designed one.

Factory assembly of components of the OSTROV TECHNOLOGY system makes installation errors impossible. Quality of performance of the coolant circuits has minor effect on total energy efficiency and no effect on energy efficiency of refrigerating plants.

3. Winter heat abstraction is the most ambiguous parameter. Cooling capacity is a quantity of energy taken by loads from the premises. If the condenser is located outside, all the heat abstracted from the premises is thrown into the atmosphere. With account of current heat energy rates, the cost of compensation of heat abstraction may commeasure the cost of compressor energy consumption. In case of electrical heating, the cost of heat loss will be several times higher than the compressor energy cost.

Equipment with built-in units meet the reverse problem in summer. Heat emission in the premises requires increase of the A/C system power improvement and energy consumption growth.

The OSTROV TECHNOLOGY system does not abstract heat when the temperature in the premises does not exceed the set one. However, in case of heat excess in the premises, the system will automatically switch to the external cooler and does not heat the premises when unnecessary.

4. Service, reliability and leakages. In addition to energy costs, servicing and maintenance is another important expenditure for a refrigerating system. Minor breaks, refrigerant leakage and other problems caused by tear and wear or poor installation are difficult to predict and plan at a reasonable time. Only best practice of operation of similar equipment may be a key benchmark in this regard.

Use of the OSTROV TECHNOLOGY system reduces the refrigerant leakage possibility by several times. If the leakage does occur, loss of refrigerant will be minimum. Correspondingly, need in servicing and repair will arise more seldom and in smaller extent.

Thus, operating costs and, therefore, energy efficiency indicators of any refrigerating system must be considered as a whole but not individually. Popular and well known solutions offer low energy consumption by a compressor but result to be very expensive if all the expenditures will be taken into account.

FEASIBILITY STUDY OF A MINI-HOTEL

The hotel is simulated in a three-floor monolithic single-section building. The ground floor is commercial, the first and the second ones place 50 hotel rooms: 20 single, 20 double rooms and 10 deluxe suites with an air-conditioning system. The ground floor accommodates a built-in 120 m^2 shop and a 100 m^2 laundry.

Table 2. Object properties

№	**Parameters**	**Unit**	**Data**
1	Function	-	Hotel
2	Type of construction	-	Monolithic
3	Year of construction	-	2013
4	No. of floors	-	3
5	Heated volume	m3	4320
6	Total building area	m2	1620
7	Reliability rating of electrical receivers	-	Rate III

Table 3. Refrigerating equipment

Loads	**Qx, W**	**Tboil, °C**	**Refrigerant**
MT loads			
Multi-deck cabinet 216 × 3,75	4500	-8	R290
Multi-deck cabinet 216 × 2,5	3800	-10	R290
Multi-deck cabinet 216 × 1,25	2100	-8	R290
Case 150 × 2,5	4200	-8	R290
Cooling chest 150 × 2,5	1000	-8	R290
Chamber	3500	-8	R290
LT loads			
Cabinet	2200	-28	R290
Chamber	2600	-28	R290
Air-conditioners			
Air conditioner	1500	+7	R290
Air conditioner	1500	+7	R290
Air conditioner	1500	+7	R290
Air conditioner	1500	+7	R290
Air conditioner	1500	+7	R290
Air conditioner	1500	+7	R290
Air conditioner	1500	+7	R290
Air conditioner	1500	+7	R290
Air conditioner	1500	+7	R290
Air conditioner	1500	+7	R290
TOTAL	38900	-	-

Legend:

Qx is refrigeration consumption of commercial equipment.

Tboil is a refrigerant boiling temperature in the evaporator.

The thermal transformer is calculated for the maximum ambient temperature +32 °C.

Refrigerant is R744.

Table 4. Thermal transformer

Designation	Qx max/min, W	Ptt max/min, W
Thermal transformer	42900	13400-3851

Legend:

Qx is thermal transformer refrigerating capacity.

Ptt is thermal transformer power.

The total cost of equipment is EUR 32 729,91 (thirty two thousand seven hundred twenty nine Euro 91 euro cent) without VAT.

Heat supply of the hotel

The limit of the hotel heating system is located at the municipal heat network inlet with an individual heat supply station. The outside face of wall is the inventory responsibility limit between the heating network and operational responsibility between a heat supply company and consumer, i.e. the hotel. The primary heat transfer fluid of the heating, ventilation and hot water supply system is system water of 150–70 °C.

Performance and commissioning have been carried out. The heating system is in working condition.

The heat from the central heating system is used for heating the system water (preparation of water for ventilation and heating) and heaters of the hot water supply system.

The temperature of the feed and make-up water is 104 °C. Through water heaters the system water is heated from 70 °C to the necessary temperature. The end-user receives thermal energy in accordance with the approved temperature chart:

- heating 95/70 °C;
- hot water supply 65/50 °C.

Heating

To assure productive activity under specified temperature and humidity conditions, a heating system is provided in the hotel.

Table 5. Calculation data for thermal energy consumption by the heating system

№	**Building**	**Volume, V, m3**	**Specific building heating characteristic, go, kcal/m3·h, °C**	**Interior temperature, Tin, °C**	**Annual heat consumption, Q0, kW·h/year**	**Comments**
Own consumption						
1	Hotel	4320	0,46	24	449410,00	Numerator is flow at t°cp -3,1 °C, denominator is flow at tH -28 °C

Hot water supply

For the energy balance, hot water consumption for household and practical needs is calculated on the basis of the number of consumers and of days in a reference year.

The calculation results for annual consumption of hot water and heat energy for water preparation are in Table 6.

Table 6. Annual hot water supply

End-user	Period	Period heat consumption, kW·h	Period hot water consumption, m3	Annual heat consumption, kW·h	Annual hot water consumption, m3
Hotel	Summer	9407,74	32100	14939,55	54750
	Heating	5531,81	2260		
Laundry	Summer	1567,96	5353	2672,81	9880
	Heating	1104,85	4530		
Store	Summer	4076,69	13888,89	6473,81	23698,41
	Heating	2397,12	9809,52		
Total				24086,17	88328,41

Analysis of the data from Table 6 shows that rated annual hot water consumption is 88 328,41 m^3/year, and thermal energy for its preparation is 24 086,17 kW·h/year.

The total annual heat consumption for heating, supply ventilation and hot water supply is: 449 410,00 + 24 086,17 = 473 496,17 kW·h/year.

ROI analysis

The heating period in the Moscow region is 214 days. The annual heat recovery in the OSTROV TECHNOLOGY system is 215 869,99 kW·h/year. The heat may return to the premises during the whole heating period and is used for hot water preparation in summer.

With cost of thermal energy in the central heating system equal to RUB 1,73 per 1 kW·h:

- thermal energy for heating is 473 496,17 kW·h;
- annual cost of thermal energy for heating (central heating) is RUB 819 148,37/
- recovered thermal energy for heating is 215,869.99 kW·h;
- savings through recovery amount RUB 373 455,08.

Payback time

The discounted payback period equals to time necessary to recover discounted capital investments out of profits from operation of the facility.

Determination of the payback period is one of the simplest and wide used and does not involves scheduled cash proceeds. The determination is based on the sum of net profit by account period year till this amount will come up with the investment amount. The minimum value of the number of the year when the positive difference of the discounted net profit and discounted investments is obtained is payback time.

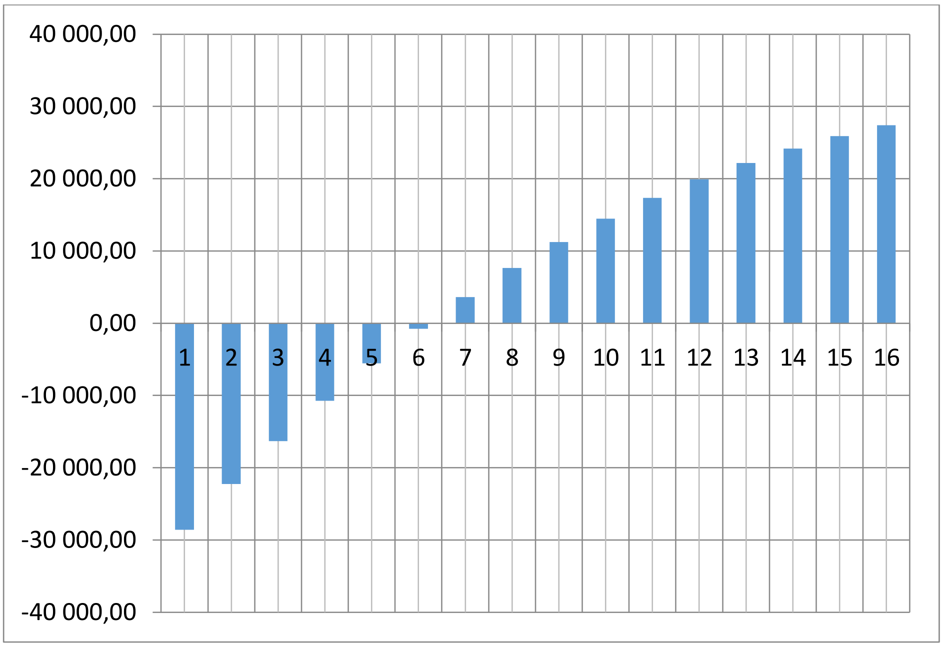

Figure 11. Cash flow calculation by years starting from installation of the OSTROV TECHNOLOGY system

The rate of gas price increase under the energy sector development scenario by 2030 (APBE, Ministry of Energy) are presented in table 8.

Table 8. Rate of gas price increase

Year	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Rate of price increase	110,5	110,2	110,0	109,0	108,5	180,2	107,7

In view of given scenario conditions, with account of cost of 1 Gcal, 2010,10 RUB in 2015, and initial price of the OSTROV TECHNOLOGY system EUR 32 729,91, the payback time will amount 6 years.

Table 7. Calculation of the payback time for the OSTROV TECHNOLOGY system

Capital investments: OSTROV TECHNOLOGY system															
Full investments, EUR															32729,91
Heat supply calculation															
Heat supply, kW*h															215869,99
Receipt of funds, EUR															
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Thermal energy, kW*h, EUR															
0,030	0,033	0,037	0,040	0,044	0,048	0,052	0,056	0,059	0,063	0,067	0,072	0,076	0,081	0,086	0,092
Earnings from heat recovery, EUR															
6476,10	7181,99	7914,56	8706,01	9489,56	10296,17	11140,45	11998,27	12778,16	13608,74	14493,30	15435,37	16438,67	17507,18	18645,15	19857,08
Savings from reduced refrigerant leakage, EUR															
131,51	142,03	153,39	165,66	178,91	193,23	208,68	225,38	243,41	262,88	283,91	306,63	331,16	357,65	386,26	417,16
Total receipt of funds, EUR															
6607,61	7324,02	8067,95	8871,67	9668,47	10489,39	11349,14	12223,65	13021,57	13871,62	14777,22	15741,99	16769,82	17864,83	19031,41	20274,24
Outflow, EUR															
Service and maintenance, EUR															
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1002,74	1082,96	1169,60	1263,16	1364,22	1473,35	1591,22	1718,52	1856,00	2004,48	2164,84	2338,03	2525,07	2727,08	2945,24	3180,86
OSTROV TECHNOLOGY energy consumption, EUR															
1126,89	1293,67	1469,60	1656,24	1851,68	2053,51	2277,35	2514,19	2740,47	2987,11	3255,95	3548,99	3868,39	4216,55	4596,04	5009,68
Other costs															
212,96	237,66	263,92	291,94	321,59	352,69	386,86	423,27	459,65	499,16	542,08	588,70	639,35	694,36	754,13	819,05
Total															
2342,59	2614,29	2903,12	3211,35	3537,49	3879,55	4255,43	4655,98	5056,12	5490,75	5962,87	6475,71	7032,81	7637,99	8295,41	9009,60
Revenue, EUR															
4133,51	4567,71	5011,44	5494,67	5952,07	6416,61	6885,03	7342,29	7722,04	8117,98	8530,43	8959,65	9405,86	9869,19	10349,74	10847,48
Accrued revenue, EUR															
4133,51	8701,22	13712,66	19207,32	25159,39	31576,00	38461,03	45803,31	53525,35	61643,34	70173,77	79133,42	88539,28	98408,47	108758,21	119605,69
Cash flow, EUR (NPV)															
-28596,40	-22248,79	-16304,23	-10734,67	-5564,56	-785,33	3611,58	7628,21	11235,13	14463,91	17343,75	19901,67	22162,67	24149,87	25884,67	27386,87

CONCLUDING REMARKS

This demo project will allow studying operation of systems and units based on natural refrigerants and make sure that transition from traditional refrigerants (CFC, HCFC, HFC) may not only improve the environmental indicators of a system but also increase its energy efficiency.

This solution may be used as a typical project for air-conditioning, refrigeration, heat and hot water supply of mini-hotels, hotel facilities, commercial facilities (supermarkets, hypermarkets, corner stores), and cold storage facilities.

It is planned to use the demonstration stand for regular training of target groups which may include specialists of the construction sector, representatives of the Customer, federal executive bodies and other parties concerned.