O'ZBEKISTON RESPUBLIKASI
EKOLOGIYA VA ATROF - MUHITNI
MUHOFAZA QILISH DAVLAT QO'MITASI

POTENTIAL FOR IMPROVING ENERGY EFFICIENCY IN THE REFRIGERATION AND AIR CONDITIONING SECTOR IN UZBEKISTAN

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Abbreviations and acronyms

UNECE	United Nations Economic Commission for Europe
UNDP	United Nations Development Programme
GEF	Global Environment Facility
RAC	Refrigeration, air conditioning
EE	Energy efficiency
RRCEM	Republican Research Centre of Emergency Medicine
TSTU	Tashkent State Technical University
CFC	Chlorofluorocarbon
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HPU	Heat pump units
ODP	Ozone depletion potential
GWP	Global warming potential

Units of measure

kWh	Kilowatt hour
gWh	Gigawatt-hours
TWh	Terawatt hour
м2	Square meter
kWh/year	Kilowatt hour per year
MW	Megawatt
kW*h/m2	Kilowatt hour per square meter
Btu/hour	British thermal unit per hour
GJ/t.f.e.	Gigajoule per ton of fuel equivalent
t.o.e.	Tons of oil equivalent

Executive summary

The effective design and implementation of public policy is key to improving energy efficiency. Due to the significant differences between technologies that are available on the market and the ones used, it becomes apparent that, not just technical progress, but also the effective management and use of legal and financial instruments are the basis for improving energy efficiency.

The best available refrigeration and air conditioning (RAC) technology is at least twice as efficient as conventional equipment. Based on current expert estimates, their energy efficiency is 50 to 60 percent of the theoretical maximum, but there is potential to increase this indicator to 70 to 80 percent through technological innovation. The replacement of refrigerants proposed by the Kigali Amendment to the Montreal Protocol to phase down HFCs, offers a key opportunity to maximize the potential benefits of energy efficiency.

Currently there are energy efficiency indicators which can be expressed in absolute or specific form. The standardized labelling of household appliances when divided into energy consumption classes was established in Uzbekistan by Directive 92/75/EEC dated 22 September 1992. The Decree of the Cabinet of Ministers of Uzbekistan No. 86 'On Measures for Implementation of the System of Mandatory Energy Efficient Labelling and Certification of Household Electrical Appliances, Newly Constructed Buildings and Constructions' dated 9 April 2015, established a requirement for mandatory content in the technical documentation and information about the corresponding energy efficiency class. The Decree applies to household electrical appliances imported and sold in the territory of the Republic of Uzbekistan. Effective promotion and information campaigns play an important role in encouraging consumers to purchase household appliances with a high energy efficiency class.

The Republic of Uzbekistan is implementing comprehensive measures to strengthen structural reforms, modernize and diversify the main sectors of the economy, within a balanced, socio-economic framework. According to experts from the Center for the Efficient Use of Energy, the energy intensity of the national economy is 2-2.5 times higher than in developed countries.[1] Large losses of energy resources occur in the housing sector. The facts cited by the information service of the Ministry of Energy indicate that, while the world average energy consumption in the residential sector is 23 percent, for Uzbekistan this figure reaches 40 percent.[2] Each household in Uzbekistan (on average 7 million households connected to electricity) has an opportunity to save up to 400 kWh of electricity per year.[2] The national average is 2.8 billion kWh. If energy efficiency is not enhanced in the economy, particularly in regards to social facilities and households, then a significant amount of energy resources will continue to be wasted.

This report analyses both annual (2020) and 5-year (2016-2020) electricity consumption for the production of refrigeration and air conditioning equipment in the

[1] http://www.cenef.ru/file/FINAL_EE_report_rus.pdf
[2] https://nuz.uz/ekonomika-i-finansy/1209242-energorastochitelnyj-uzbekistan.html

Republic of Uzbekistan. In recent years, the products of domestic manufacturers are becoming more present in foreign markets, and show a positive trend in the growth of export indicators for all their main products. According to this analysis, there are significant sources indicating dynamic changes in the energy intensity of raw material processing and production over time. In addition, there have been significant changes in the raw materials used for refrigerators and air conditioners due to changes in construction, design and services offered.

The second chapter of this report presents some joint developments co-funded by the United Nations Development Programme (UNDP) and stakeholders in the field of refrigeration and air conditioning. To determine efficiency, parameters of work were determined, and the effectiveness of developments were analysed. The results of the research were given in the form of specific and absolute values of energy efficiency parameters.

Institutional strengthening and scientific capacity building activities have traditionally included training of technicians in the service sector, trainings of regional networks and public awareness campaigns to help consumers choose energy-efficient and environmentally-friendly products. Such activity in the field of energy efficiency complements other programmes and activities. In Uzbekistan there is a systematic provision of training, retraining and advanced trainings of technical specialists in the field of refrigeration and climate technology, with special attention being given to training women in the RAC field. Standard curricula for RAC courses and programmes should focus on energy efficiency and modernization of RAC systems.

Introduction

Increasing the level of rational use of energy resources is one of today's more important issues. This is due to not only growth in demand for energy resources and the increasing costs of their extraction and production, but also by the fact that humankind is approaching the maximum allowable threshold in terms of volume of energy resource usage and its associated impact on nature.

In Uzbekistan, total final energy consumption in 2018 was 29.5 million t.o.e. The housing sector is the largest national energy consumer, with a share of over 40 percent. Previously the building sector, including housing, public and commercial buildings, accounted for 55 percent of the nation's final energy consumption. Buildings accounted for 75 percent of final heat consumption, 26 percent of final electricity consumption, and 64 percent of final natural gas consumption.[3] In this regard, energy saving in this area gives a more tangible effect. First of all, it is necessary to apply methods and means of saving energy, so that the highest energy saving and beneficial environmental impact is achieved at minimal additional costs.

The energy supply sector (electricity, heat and other forms of energy) is the largest source of global greenhouse gas emissions, accounting for about 35 percent of total emissions. Households consume 29 percent of the world's energy, and are responsible for 21 percent of the corresponding CO_2 emissions.[4] Most of the energy in households is used for heating and cooling. The demand for energy for cooling is the fastest growing characteristic in buildings, with ten air conditioners projected to be sold every second over the next 30 years. Currently, about 80 percent of the world's energy and 66 percent of its electricity is generated from fossil fuels.[4]

As a result, more efficient consumption of energy is the main strategy for achieving sustainability in the future. At its core, energy efficiency (EE) means the provision of services, such as lighting, household comfort, conservation of food and medicine, and mobility, with less energy consumption.

Energy efficiency in refrigeration and air conditioning (RAC) systems cannot be achieved by a single action, such as choosing an efficient refrigerant, but rather it depends upon an integrated solution that combines all available opportunities. The efficiency of refrigeration and air conditioning depends on the thermodynamic properties of the refrigerant, the loss of any liquids, the efficiency of heat exchange, and the design, materials and control of mechanical equipment.

According to research undertaken by the United Nations Environment Programme (UNEP) United for Efficiency (U4E)[5], the application of energy efficiency measures in the sector of household refrigerators and air conditioners in Uzbekistan can reduce electricity

[3] https://unece.org/sed/documents/2021/03/working-documents/gap-analysis-framework-guidelines-ee-standards-buildings
[4] https://www.un.org/ru/actnow/facts-and-figures
[5] United Nations Environment Programme (UNEP) United for Efficiency (U4E) Model Regulation Guidelines 2020

consumption by more than 1.8 TWh by 2030. The study describes the results of the implementation of minimum energy efficiency standards at two levels, being minimum and high. The implementation of the minimum level makes it possible to reduce energy consumption by 1,800 GWh by 2030, and at a high level this figure can reach up to 2,660 GWh. At the same time, these measures will reduce CO_2 emissions by more than 1.1 million tons.

During the initial phase-out of chlorofluorocarbons (CFCs), many manufacturers took the opportunity to redesign their systems to improve energy efficiency in new CFC-free installations. New CFC-free chillers sold worldwide were 50 percent more energy efficient than the equipment they replaced.[6]

Phasing down the consumption and production of hydrofluorocarbons (HFCs) can similarly contribute to significant improvements in the energy efficiency of air conditioning and refrigeration systems. New generation technologies have almost always resulted in lower electricity consumption, both for their producers and consumers.

Economic analysis has shown that countries that integrate energy efficiency into their HCFC phase-out and HFC phase-down programmes can create savings for consumers and reduce carbon and air pollution emissions by reducing energy consumption, allowing manufacturers to rationally plan their investments in re-engineering and refurbishment.

The promotion and implementation of modern, non-traditional, and in particular absorption refrigeration units at enterprises with thermal emissions, is of great relevance. An analysis of work performed earlier showed that, under certain conditions, absorption heat converters of various schemes can be used to create energy-saving systems.

[6] Energy efficiency guide for refrigeration, air conditioners and heat pumps, Bishkek, B.: 2018 -43 p.

CHAPTER 1. ENERGY EFFICIENCY ANALYSIS IN THE REFRIGERATION AND AIR CONDITIONING SECTOR

1.1 Methodology for assessing the energy efficiency of refrigeration and climate-control equipment

Energy supply is the largest source of global greenhouse gas emissions, accounting for about 35 percent of total emissions. Households consume 29 percent of the world's energy and are responsible for 21 percent of the corresponding carbon dioxide emissions.[4] Most of the energy in households is used for heating and cooling. The demand for energy for cooling is the fastest growing end use in buildings, with ten air conditioners projected to be sold every second over the next 30 years. With about 80 percent of the world's energy and 66 percent of its electricity currently generated from fossil fuels, efficient and sustainable energy consumption is the main strategy for achieving a sustainable future for all.[4]

Energy efficiency in the RAC sector involves the provision of services such as comfort and food preservation with less energy consumption. An indicator of energy efficiency is the ratio of refrigeration (thermal) power to consumed power. The improved energy efficiency of equipment involves the improvement of the technology or design of a product, appliance or component, resulting in less energy being consumed for the same performance (cooling/heating capacity).

The share of emissions from fossil fuels in the production of energy for refrigeration, air conditioning and heat pumps is more than 80 percent.[6] Based on expert estimates, the best available RAC and HP technologies are at least twice as efficient as conventional equipment - currently their energy efficiency is 50 to 60 percent of the theoretical maximum, but there is potential to increase this figure up to 70 to 80 percent through technological innovation.[6] The replacement of refrigerants proposed by the Kigali Amendment offers a key opportunity to achieve the maximum possible benefits from energy efficiency.

Energy efficiency indicators can be expressed in absolute or relative ratios. The absolute ratio characterizes the consumption of fuel and energy resources in regulated conditions (modes) of operation. The relative ratio characterizes the ratio of the consumption of fuel and energy resources to the generated or consumed energy, manufactured products, or performed work in regulated conditions (modes) of operation.

In terms of indicators of energy efficiency, there is a preference for using relative indicators such as the amount of energy or fuel consumed by a machine or by a mechanism for the production of a unit of output or work.

To compare equipment energy efficiency, the test protocols and operating parameters utilized must be the same or at least comparable. Table 1 shows performance and energy efficiency figures for air conditioners, heat pumps and refrigeration systems.

Table 1. Performance and energy efficiency indicators

#	Term	Definition
1.	Unit cooling capacity, $\boldsymbol{Q_x}$	Unit of performance of the refrigeration system. This is expressed numerically as the amount of heat removed from the cooled object per unit of time. It is measured in watts, kilowatts, megawatts, and British thermal units per hour (W, kW, MW, Btu/h).
2.	Heating capacity of the unit, $\boldsymbol{Q_T}$	Unit of performance of a heat pump system. This is expressed numerically as the amount of heat supplied to the heated object per unit of time. It is measured in watts, kilowatts, megawatts, and British thermal units per hour (W, kW, MW, Btu/h).
3.	Electric power of the unit, $\boldsymbol{N_{cons}}$	A physical quantity that characterizes the rate of transmission or conversion of electrical energy. The units of measurement are: W, kW, horsepower (hp).
4.	Momentary energy efficiency indicator of the air conditioner in cooling mode, EER	Equal to the ratio of cooling capacity to total power input under designed operating conditions. EER is measured in W/W or Btu/W.
5.	Momentary indicator of energy efficiency of the air conditioner in heating mode, COP	The ratio between the produced thermal energy, and the energy consumed in order to generate it. Measured in W/W or Btu/W.
6.	Seasonal indicators of energy efficiency SEER (Season Energy Efficiency Ratio) and SCOP (Season Coefficient of Performance)	SEER and SCOP are designed to consider local climate, building types and human behaviours, and therefore there are differences in the calculation of indicators used in different countries and regions. Measured in W/W or Btu/W.
7.	kWh of energy consumption per day, or kWh per year for a certain volume	Specific electricity consumption per day, per unit volume of the refrigerating chamber (kW*h/day; kW*h/y).
8.	Energy Efficiency Index	This is equal to the ratio of the actual electricity consumed to the standard annual consumption.

For air conditioners and heat pumps, the EER (Energy efficiency ratio) and COP (Coefficient of performance) indicators have the following features:

- EER and COP are indicators tied to certain conditions, meaning they are momentary indicators.
- Usually, the EER and COP are given for nominal duty (100 percent load at standard conditions). This can be useful for quickly evaluating the efficiency of equipment, but then only one mode of operation will be considered.

- Often in catalogues, the calculation of EER and COP is made taking into account only compressor power (excluding fans and other parts of the air conditioner) which does not represent an accurate evaluation of energy efficiency.
- EER and COP are internationally recognized indicators, understood by specialists from all countries and continents.
- According to EER and COP, air conditioners are divided into classes of energy efficient ranging from 'A' to 'G' (Table 2 and Table 3).

Table 2. Division of air conditioners into energy efficiency classes by cooling capacity

Cooling air conditioner energy efficiency class	A	B	C	D	E	F	G
EER	>3.2	3.0-3.2	2.8-3.0	2.6-2.8	2.4-2.6	2.2-2.4	<2.2

Table 3. Division of air conditioners into energy efficiency classes by heating capacity

Heat efficiency class of air conditioner	A	B	C	D	E	F	G
COP	>3.6	3.4-3.6	3.2-3.4	2.8-3.2	2.6-2.8	2.4-2.6	<2.4

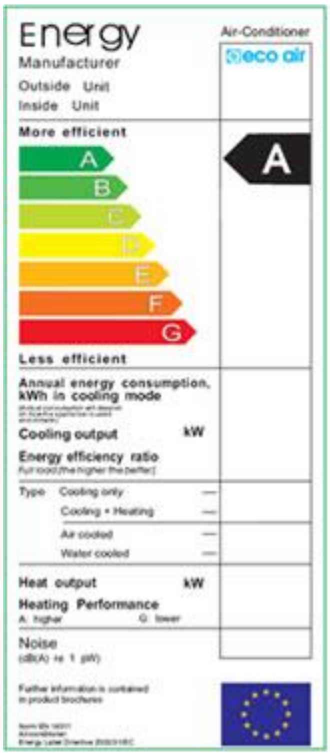
The standardized labelling of household appliances, when divided into energy consumption classes, was established by Directive 92/75 / EEC, dated 22 September 1992. The Decree of the Cabinet of Ministers of Uzbekistan No. 86 'On Measures for Implementation of the System of Mandatory Energy Efficient Labelling and Certification of Household Electrical Appliances, Newly Constructed Buildings and Constructions' dated 9 April 2015, established a requirement for mandatory content in the technical documentation and labelling of information concerning the corresponding energy efficiency class. The Decree applies to household electrical appliances imported and sold in the territory of the Republic of Uzbekistan.

There must be symbols of energy efficiency of classes 'A', 'B', 'C', 'D', 'E', 'F' or 'G', in the documentation and on the labels of household electrical appliances, including air conditioners. The label of class 'A' is intended for household electrical appliances with the highest energy efficiency, while class 'G' signifies electrical appliances with the lowest energy efficiency.

Starting from 1 January 2016, it was prohibited to import household electrical appliances that do not have information on the corresponding energy efficiency class in technical documents, markings and labels. This excluded the sale of household electrical appliances already imported.

The Decree provided for the phased introduction of energy efficiency requirements. For example, the import and sale of class 'G' household electrical appliances was banned on 1

January 2017, while the sale of class ‘F’ appliances was banned from 1 January 2018, and the sale of class ‘E’ appliances was banned from 1 January 2019. The required energy efficiency of air conditioners and refrigeration machines was increased by 18 percent. Thus, the efficiency class ‘D’ became the minimum for such equipment in Uzbekistan.



Unit efficiency class in cooling mode:		Unit efficiency class in heating mode:	
A	$ERR > 3{,}20$	A	$COP > 3{,}60$
B	$3{,}20 \geq ERR > 3{,}00$	B	$3{,}60 \geq COP > 3{,}40$
C	$3{,}00 \geq ERR > 2{,}80$	C	$3{,}40 \geq COP > 3{,}20$
D	$2{,}80 \geq ERR > 2{,}60$	D	$3{,}20 \geq COP > 2{,}80$
E	$2{,}60 \geq ERR > 2{,}40$	E	$2{,}80 \geq COP > 2{,}60$
F	$2{,}40 \geq ERR > 2{,}20$	F	$2{,}60 \geq COP > 2{,}40$
G	$2{,}20 \geq ERR$	G	$2{,}40 \geq COP$

Figure 1. Sticker (label) indicating the energy efficiency class of air conditioners

From 2013 the methods of assessing the energy efficiency coefficients of air conditioners have changed. Seasonal energy efficiency ratios were introduced, including Season Energy Efficiency Ratio (SEER), Seasonal Refrigeration Coefficient (SFC), Season Coefficient of Performance (SCOP), and Seasonal Heat Performance Coefficient (SHPC). The main reason for the introduction of seasonal indicators was the need to evaluate the efficiency of refrigeration equipment under conditions close to reality. That is, throughout the season at different loads and ambient temperatures.

The developers of the methodology believed that such calculations more accurately reflected the energy efficiency of the air conditioning system. By diversifying calculations and expanding measurements, experts developed a new classification of air conditioners. Classes ‘E’, ‘F’ and ‘G’ were excluded from it, while classes ‘A+’, ‘A++’ and ‘A+++’ were added.

SEER Value (Cooling mode)

A+++	> 8,5
A++	> 6,1
A+	> 5,6
A	> 8,5
B	> 4,6
C	> 4,1
D	> 3,6

SCOP Value (Heating mode)

A+++	> 5,1
A++	> 4,6
A+	> 4,0
A	> 3,4
B	> 3,1
C	> 2,8
D	> 2,5

Figure 2. Classification of air conditioners depending on SEER and SCOP

The generalized ratings consider unloaded modes of operation, which is why they are sometimes referred to as energy efficiency ratios in partial load. Experimental data show that the load on the air conditioning system during the year varies in the range from 10 to 100 percent (see Figure 3).

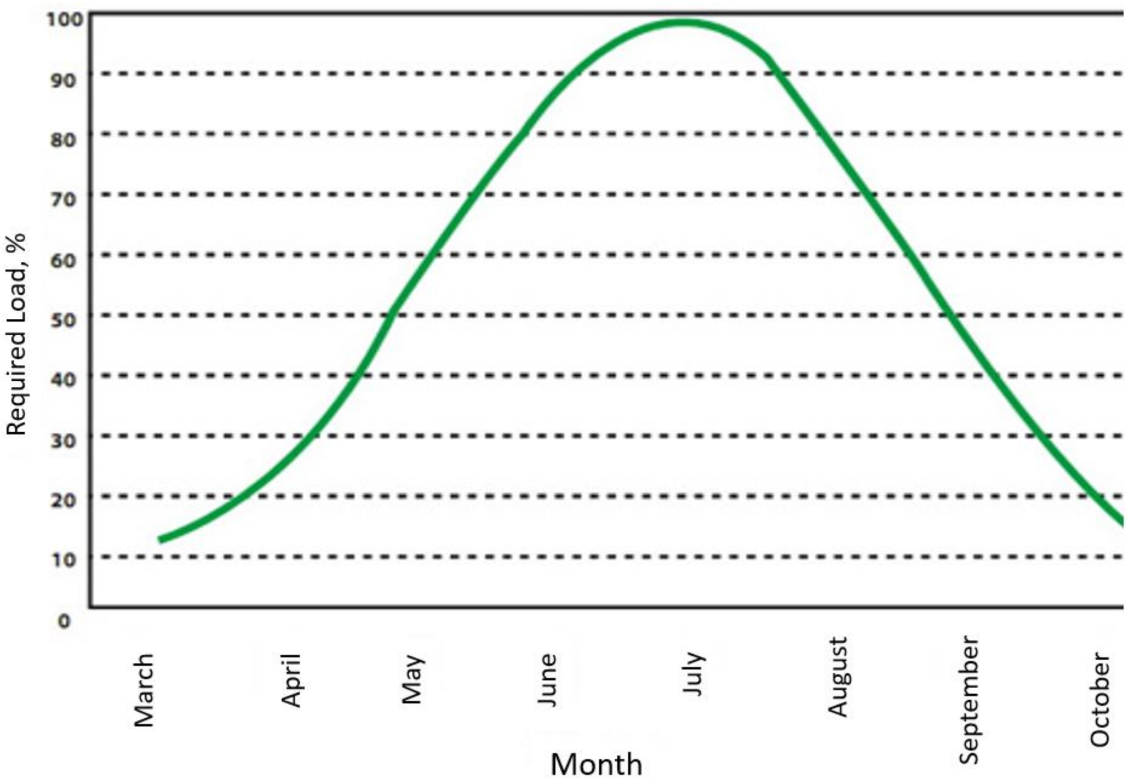


Figure 3. Change in the load on the air conditioning system during the year

This curve can vary significantly depending on the climate of a particular area. In order to simplify the calculations of energy efficiency coefficients, and to expand the range of their application, such a curve requires averaging. When applying the practice of using a heat pump as a heating/cooling unit, the combined cycle EE factor is used.

The energy efficiency indicator of the simultaneous generation of heat and cold on the same equipment represents the ratio of usefully-used amounts of heat and cold to electrical energy consumed by compressors, water pumps and air fans.

Calculations and studies show that in the optimal mode of operation of the refrigerating machine-heat pump unit, the EE index (COP) reaches a value of 5.5, more than two-times higher than the lower limit of the expedient use of HPI.

For household refrigerators, energy efficiency is calculated using several parameters:

- The volume of the refrigerating and freezing chambers;
- Minimum possible temperature in all chambers;
- The presence of additional functions, for example, No Frost, display, Wi-Fi and others.

Efficiency is measured as energy consumed in kWh per day or per year, and can be applied per cooling volume. For household compression refrigerators (freezers), this indicator is the specific electricity consumption per day or per 1 litre of volume under regulated conditions. Units of measurement include kWh / day, or kWh / dm3.

For industrial refrigerators, they are calculated as a kilowatt hour per day under regulated conditions (kWh/day), or specific electricity consumption for cold production (kWh/Gcal).

The energy efficiency indicator of a household refrigerator directly depends on the Energy Efficiency Index (EEI), with the index itself depending on the annual electricity consumption of the device.[7] The index shows the timeframe that the freezer or refrigerator requires from the network, in order to maintain the set temperature.

To characterize the energy efficiency of refrigerators, a range of classes has been established from 'A+++' at the most efficient level to the 'G' at the least-efficient level, reflecting the energy efficiency index.

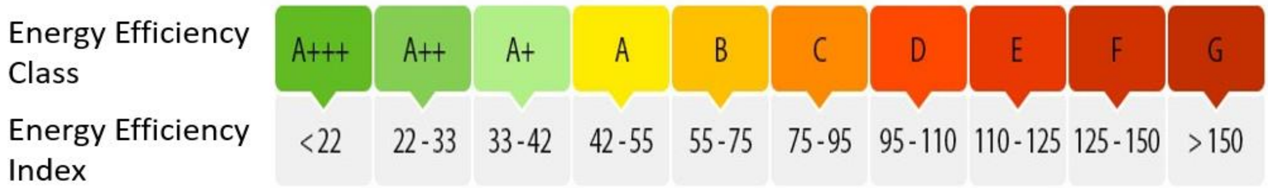


Figure 4. Classification of refrigerators in accordance with the energy efficiency index

1.2 Energy consumption in the refrigeration and air conditioning sector by various sectors of the economy

In 2019, Uzbekistan produced 61.6 TWh of electricity, mainly from natural gas (85 percent).[8] The Republic is one of the world's larger producers of natural gas, annually producing about 60 billion cubic meters, of which 35-40 billion cubic meters are supplied

[7] https://make-a-choice.ru/chto-takoe-klass-energopotrebleniya-holodilnika
[8] https://stat.uz/ru/ofitsialnaya-statistika/industry

by the JSC 'Uzbekneftegaz'. In 2019, natural gas production amounted to 60.4 billion cubic meters.[9]

Uzbekistan is implementing comprehensive measures to expand structural reforms, modernize and diversify the main sectors of its economy, and balance socio-economic development in its territories.

The Decree of the President of the Republic of Uzbekistan No. PP-4477, dated 4 October 2019, approved a strategy for transitioning the Republic of Uzbekistan to a green economy for the period 2019 of 2030. The strategy has many goals across several priority areas.[10]

The Ministry of Energy, being responsible for the energy sector, was established by the Decree of the President of the Republic of Uzbekistan No. UP-5646, dated 1 February 2019 'On measures to radically improve the management system of the fuel and energy industry of the Republic of Uzbekistan'. Table 4 presents data on electricity consumption by regions of the republic in the period of 2016-2020.

Table 4. Electricity consumption (provided to users, million kWh)[8]

	2016	2017	2018	2019	2020
For the Republic of Uzbekistan	45,058.8	46,746.3	60,744.8	54,174.8	53,839.8
Republic of Karakalpakstan	1,041.9	1,088.7	1,578.3	1,690.1	1,372.9
Regions					
Andijan	2,406.3	2,639.5	3,975.4	2,627.3	3,479.5
Bukhara	2,580.3	2,678.2	3,338.8	2,437.0	3,112.9
Jizzakh	1,518.8	1,581.4	2,177.8	1,924.4	1,768.6
Kashkadarya	4,857.6	5,116.1	5,561.3	5,594.6	5,169.2
Navoi	6,895.0	7,002.6	7,431.4	8,775.3	7,920.8
Namangan	2,612.9	2,789.6	3,898.9	3,099.1	3,597.3
Samarkand	2,947.5	3,247.8	4,425.8	2,769.7	4,130.1
Surkhandarya	2,148.1	2,230.9	56,530	2,364.3	2,633.5
Syrdarya	1,177.3	1,159.4	1,455.1	1,748.9	1,283.2
Tashkent	6,981.3	7,235.1	8,868.5	9,253.6	7,358.5
Fergana	3,829.4	3,534.0	4,965.3	4,591.8	4,787.7
Khorezm	1,090.6	1,118.1	1,799.3	1,765.7	1,558.5
Tashkent city	4,971.7	5,325.0	5,615.8	5,532.9	5,667.2

Most electricity is consumed by industry, population and agriculture (table 5 and table 6).

[9] https://minenergy.uz/ru/news/view/1063
[10] https://lex.uz/docs/4539506

Table 5. Electricity consumption in Uzbekistan by sector, 2019[8]

Industries	Electricity consumption
Industry	40%
Households	23%
Agriculture	20%
Public utilities	13%
Transport	3%
Construction	1%

Table 6. Net electricity consumption by type of activity (million kWh)[8]

Name	2016	2017	2018	2019	2020
Total (gross consumption)	57,605.2	60,180.8	62,502.8	64,844.0	69,021.1
By type of activity:					
Industry	21,035.8	22,298.4	15,007.1	16,967.3	18,284.3
Construction	360.7	325.0	414.8	414.8	1,448.0
Agriculture	9,502.3	9,683.9	18,053.9	15058,0	9,202.4
Transport	1,165.9	1,222.2	1,474.6	2,115.0	1,058.0
Commercial enterprises and government agencies	5,242.3	4,040.6	4,970.9	4,970.9	5,238.9
Households	11,195.7	12,779.8	13,593.8	13,478.8	15,549.5
Other sectors not specified	-	-	-	1,170.0	1,170.0

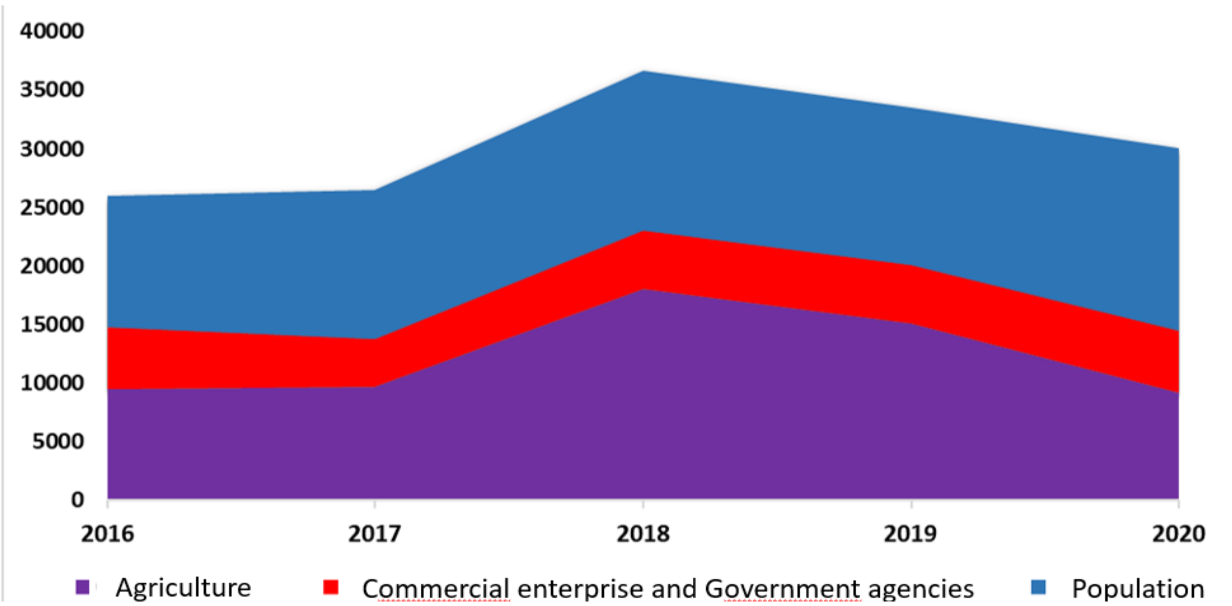


Figure 5. Net electricity consumption by activity (Million kWh)

Uzbekistan has been a party to the United Nations Framework Convention on Climate Change since 1993, has signed the Kyoto Protocol in 1998 and ratified it in 1999, and ratified the Paris Agreement in 2018.

1.3 Analysis of energy consumption in the refrigeration and air conditioning sector

The press centre of the Ministry of Energy has cited the facts of energy-wasting activities in the housing sector of the republic.

According to experts, the energy intensity of the national economy is 2-2.5 times higher than that of developed countries. Large losses of energy resources fall on the housing sector. While the world average primary energy consumption for the residential sector is 23 percent, in Uzbekistan this figure reaches 40 percent. Thus, if in Europe energy consumption per square meter is 120-150 kilowatt-hours per year, then in Uzbekistan this figure exceeds 390 kilowatt-hours.[9]

According to a study conducted by energy efficiency experts, currently each household in Uzbekistan (on average 7 million households connected to electricity) has the opportunity to save up to 400 kWh of electricity per year. On average, this is 2.8 billion kWh, being a significant amount of energy that is not wasted.[2]

For the purpose of undertaking a substantive study of such reserves, the energy efficiency of social facilities on the ground is being studied by specialists from a specially created unit of the Ministry of Energy. Through the analysis, it is revealed that at many social facilities energy savings and efficiencies do not meet necessary parameters.

Thus, such buildings and structures will waste a significant amount of the energy, which will affect the available supply of energy resources for consumers. Therefore, it is necessary to constantly work to increase energy efficiency in the economy.

It is important to analyse the annual (2020) and 5-year (2016-2020) electricity consumption required for the production of refrigeration and air conditioning equipment in the Republic of Uzbekistan.

In February 2017, the Presidential Decree No. PP-2772 'On measures to further improve management, accelerate the development and diversification of the electrical industry in 2017-2021' was adopted. This decree approved a programme of measures for the further development and diversification of the electrical industry, including forecast production indicators for electrical products with high added value for 2017-2021.

According to analysis, the total energy consumption to produce refrigerators varied from about 180 MJ (50 kWh) for the 1974 model, and decreased to 50 MJ (13.8 kWh) for models after 2008.

For example, there are significant sources indicating dynamic changes in the energy usage of raw material processing and production over time. In addition, there have been important changes in the raw materials used for refrigerators, due to changes in construction, design and services offered.

Energy analysis shows that consumption of energy (including thermal and electric energy) for processing 1 kg of raw materials ranges from 1.595 MJ (0.44 kWh) to 2.538 MJ (0.7 kWh). As a result, the total processing and production energy of 1 kg of raw materials ranges from 2.164 MJ (0.6 kWh) to 3.107 MJ (0.86 kWh) for a 2.1 kW single-phase AC (cooling capacity 7,000 BTU/h). The 2.1 kW room air conditioner is one of the smaller models of room air conditioners, with the size of room air conditioners varying from 2.1 kW (weight 29 kg) to 12.5 kW (179 kg).[11]

The annual energy consumption for refrigerators could increase by an average of 1.0-1.6 percent per year. Around 8-10 percent of the total of 15 to 20-year-old refrigerators, have component failures (such as hardened or defective door seals) that cause them to run continuously, significantly increasing energy consumption (in one study, such cases were 58 percent). Component failures that can be repaired simply account for nearly half of performance degradations. As newer refrigerator designs include better insulation, more efficient seals and improved compressors, they can be more tolerant of performance degradation. In most cases, it is easy to improve efficiency by introducing new technologies, for example, replacing an incandescent refrigerator bulb with an LED bulb that has the double benefit of using less electricity for lighting and generating less heat to be removed, which extends the life of the compressor.

Currently, Uzbekistan's electrical engineering industry continues to develop dynamically. More than 450 enterprises operate in the industry, producing a range of about 2,000 electrical items. The majority of electrical products (about 90 percent) are produced by the enterprises of the 'Uzeltexsanoat' association (table 7, diagramme, figures 6 and 7).

In recent years, the products of Uzbekistan's domestic manufacturers are increasingly making their way into foreign markets, and a positive trend in the growth of export indicators for all major types of products is evident. In 2019, the export of electrical products amounted to US$250 million, while in 2020 the export of products is projected at the level of $300 million.

In the first half of 2020 $113.8 million worth of products were exported, which is 1.3 times more than during the same period of 2019, while household appliances exports increased 2.5 times.[12]

Table 7. Indicators of refrigerator and air conditioner production in Uzbekistan

Product range	2016	2017	2018	2019	2020
Refrigerators (thousand units)	190	265	417	502	721
Consumption of electrical energy for the production of refrigerators (kWh)	2,622,000	3,657,000	5,755,000	6,928,000	9,950,000
Air conditioners (thousand units)	117	202	242	340	389
Consumption of electrical energy for the production of air conditioners (kWh)	2,918,000	5,038,000	6,035,000	8,480,000	9,702,000

[11] https://web.mit.edu/ebm/www/Publications/MITEI-1-a-2010.pdf
[12] https://review.uz/post/razvitie-elektrotexniki-itogi-i-perspektiv

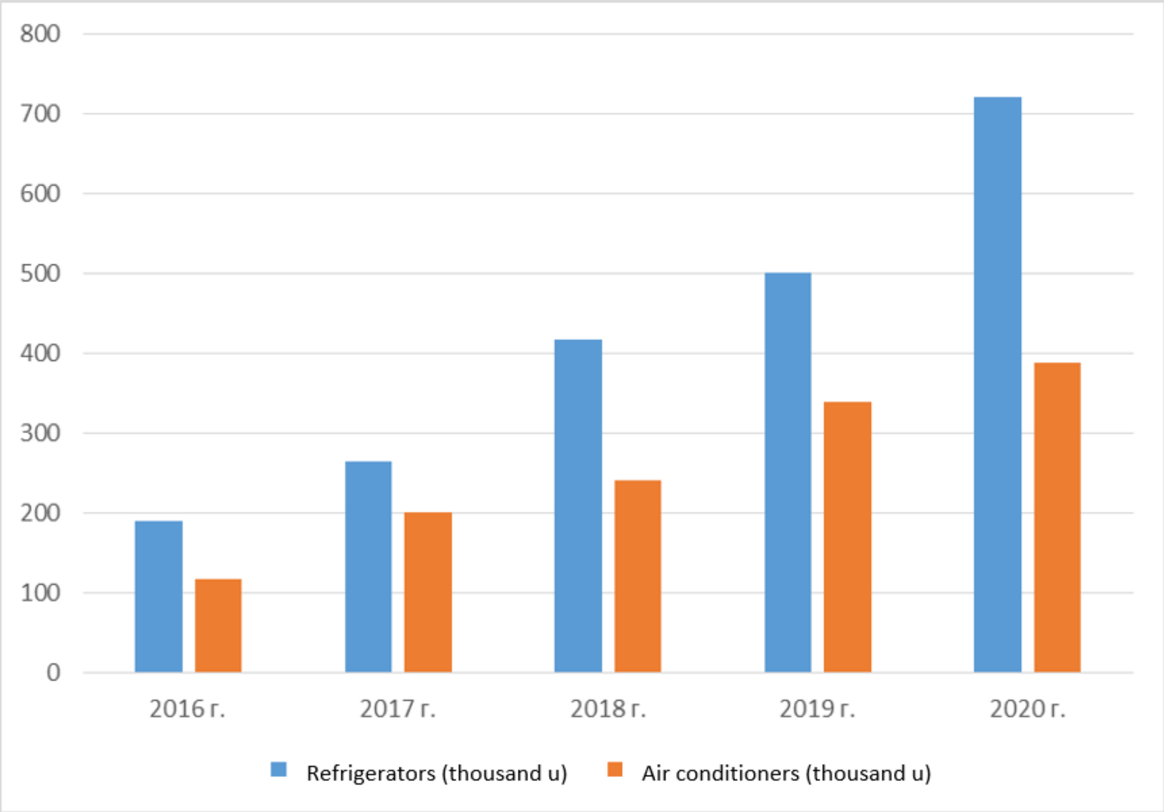


Figure 6. Production of refrigerators and air conditioners in Uzbekistan

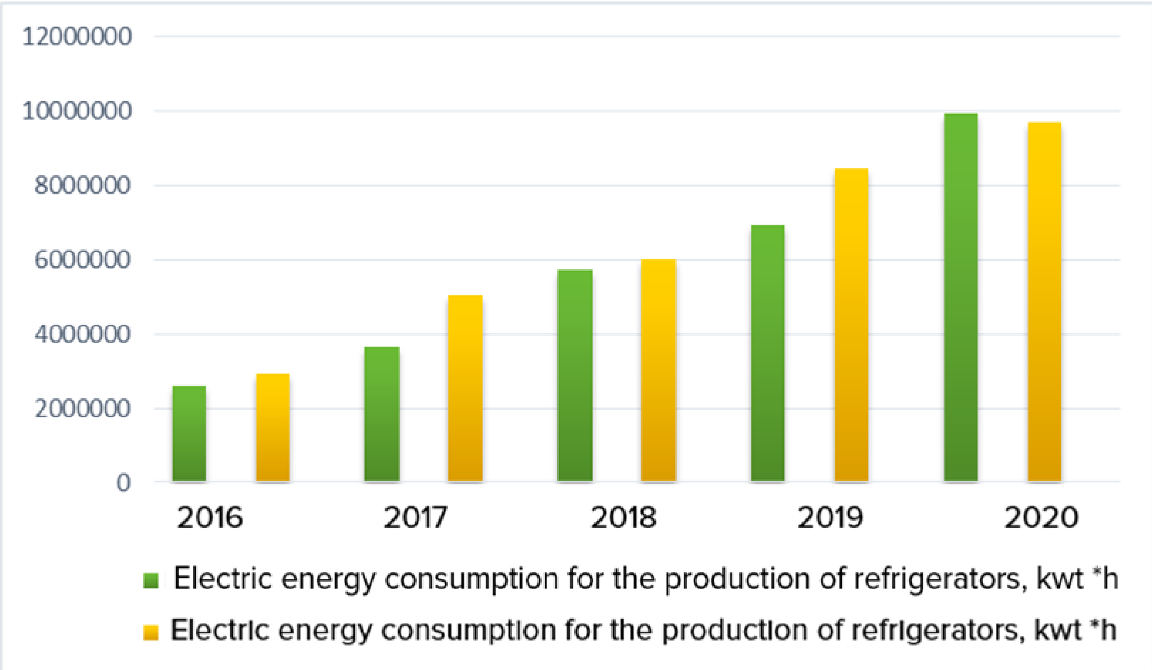


Figure 7. Electric energy consumption for the production of refrigerators and air conditioners

Air conditioning and refrigeration equipment for the household sector

Air conditioners range from small window units which cool a single room, to large rooftop installations that cool an entire building (often as part of an overall HVAC system). All packaged air conditioners, also known as unitary systems, contain both a condenser and an evaporator in a single box that draws hot air out of a building and produces cold air inside.

Split-air conditioning systems range from small room units to large systems that can cool a large building complex. In all cases, the condenser is located outside the building and is separated by pipes that carry the refrigerant to the evaporator or ventilation unit inside the building.

A chiller is a refrigeration unit used for cooling and heating in central air conditioning systems, which can be air handling units or fan coil units. Compression cycle chillers can use centrifugal, reciprocating, rotary or absorption mechanisms.

In the conditions of Uzbekistan's dry hot climate, architectural, planning and construction parameters in building design, aimed at combating summer overheating due to intense solar radiation and high outdoor temperatures, must be linked to the requirements arising from the characteristics of winter weather.

In order to reduce energy consumption in existing buildings, which can consume 100-120 kWh/(m2•year), a new European concept of an energy-efficient house has been developed with a maximum annual energy consumption rate of up to 50 kW*h/(m2•year).[13] In accordance with the developed concept, when designing an energy-efficient building, several fundamental architectural and building principles need to be observed.

In terms of improvement of energy efficiency:

- Optimization of the architectural forms of the building, taking into account the possible effects of wind.
- The optimal location of the building relative to the sun, providing the possibility of maximizing the use of solar radiation.
- Increasing the thermal resistance of the building envelope (external walls, coatings and roofing slabs) to the highest technically-possible level.
- Minimizing the amount and thermal conductivity present in the design of thermal bridges.
- Ensuring the necessary air-tightness of the building structure relative to the inflow of outside air.
- Increasing thermal resistance of translucent enclosing structures to the maximum technically-possible level.
- Creating a ventilation system for supplying fresh air, removing exhaust air, distributing heat in a room, and allowing for ventilation air heat recovery.

Comfortable living in Uzbekistan's hot climate requires installation of air conditioners. In 2020, their provision per 100 households was 40 units.[8] In Uzbekistan, electricity consumption for air conditioning, according to CENEF (Centre for Energy Efficiency, www.cenef.ru/file/FINAL_EE_report_rus.pdf), averaged 236 kWh/households per year.

[13] Energy efficiency in buildings: a hidden resource for the sustainable development of Uzbekistan. UNDP, Tashkent, 2014.

Electricity consumption for air conditioning in 2020 amounted to 2,093 million kWh per year.[8]

Table 8 shows data on the provision of refrigerators and air conditioners to the population (per 100 households, based on sample surveys of households by units). The table also shows the annual electricity consumption of refrigerators and air conditioners by households for the period of 2016-2020.

An average new refrigerator consumes approximately 261 kWh per year in Uzbekistan. Electricity consumption by refrigerators and freezers in 2020 reached 2,477 million kWh.[8]

Table 8. Providing Uzbekistan's population with refrigerators and air conditioners

Product range	2016	2017	2018	2019	2020
Refrigerators per 100 households	102	101	103	106	107
Air conditioners per 100 households	34	34	35	39	40
Number of households	6,143,500	6,317,600	6,565,800	6,742,400	8,871,412
Number of refrigerators (units)	6,266,370	6,380,776	6,762,774	7,146,944	9,492,411
Electricity consumption by the population for refrigerators (million kWh per year)	1,636	1,665	1,765	1,865	2,477
Number of air conditioners (units)	2,088,790	2,147,984	2,298,030	2,629,536	3,548,565
Electricity consumption by the population for the needs of air conditioning (million kWh per year)	1,232	1,267	1,356	1,551	2,093

The electricity consumption of equipment depends on the following factors:

- total working area
- unit performance
- indoor and outdoor temperature difference

The power spent regulating the temperature in a building is the main indicator of the performance of the air conditioner and is determined by the influx of heat from windows, ceilings, walls or household appliances.

A high performance of air conditioners is achieved only with closed windows and doors.

It should be noted that all the above calculations are approximate and calculated purely for climate units with a performance value of 12,000 BTU / hour. Predicting the exact consumption of electricity is very difficult. The consumption of energy resources by equipment depends on the cold or heat outside the window, the mode and time of operation, the type of system, the size of the room, and many other factors that can affect the functioning of the air conditioner and its energy usage.

The promotion and implementation of modern non-traditional absorption refrigeration units, at enterprises with thermal emissions, is of great relevance. Absorption refrigerators have lower energy efficiency and lower cooling capacity compared to vapor compression refrigerators. However, they produce cold air by direct combustion of fuel, or other heat sources, to the required temperature.

An analysis of previous works has shown that, under certain conditions, absorption heat converters of various types can be used to create energy-saving systems.[14]

A special role in the application of new energy-saving technologies belongs to energy and heat supply enterprises. The use of absorption refrigeration units, which use the thermal discharges of energy supply facilities as external energy, makes it possible to increase the degree of thermodynamic perfection of energy conversion systems.

Currently we do not have specific information on the degree of introduction of modern absorption refrigeration units in the Republic of Uzbekistan, both for modernization and for new industrial enterprises with thermal discharges. But we want to remind stakeholders that the main advantages of such installations are the reduction of operating costs by reducing the consumption of relatively expensive electricity and the use of waste heat, as well as improved environmental safety through eliminating the use of refrigerants based on chlorofluorocarbon and hydrochlorofluorocarbon.

[14]K.F. Karimov et al. Design analysis and efficiency of absorption chillers - https://www.researchgate.net/publication, 2019.

CHAPTER 2. IDENTIFYING TECHNOLOGICAL OPTIONS FOR INCREASING ENERGY EFFICIENCY AND LOWERING CARBON INTENSITY IN THE REFRIGERATION AND AIR CONDITIONING SECTOR

2.1. Case studies and best practices applied in Uzbekistan

This section presents some of the joint developments co-funded by UNDP and stakeholders in the field of refrigeration and air conditioning.

Improving components or equipment designs to make them more energy efficient tends to increase manufacturing costs due to more costly materials or more complex manufacturing. However, with energy consumption typically accounting for around 80 percent of total lifecycle costs (purchase and operation), consumers can gain significant overall savings from increased efficiency even as equipment costs increase. Moreover, an increase in manufacturing costs for more efficient equipment does not necessarily lead to an increase in retail price for the consumer.

Foreign studies have shown that, over time, inflation-adjusted prices decline significantly despite the small short-term effects of new standards. Researchers attribute these price cuts to economies of scale, technological learning and innovation.

In 2017, the Republican Research Centre of Emergency Medicine (RRCEM) implemented the project 'Replacing the outdated chiller of the centralized air conditioning system of the RRCEM operating on the ozone-depleting refrigerant HCFC 22 with a chiller operating on the natural refrigerant ammonia (R717)'.

During the project's preparation, it was established that:

1. The total cooling capacity of the chiller operating on HCFC 22 (R22) was 1,710 kW, at a cold-water outlet temperature of + 60C and a cooling water temperature at the condenser outlet of + 35C.
2. The refrigeration station included two ***Climaveneta 3000*** chillers based on semi-hermetic compressors of the ***D8DJ-600x Copeland*** brand with a volumetric capacity of 181 m3/hour (Figure 8).

Figure 8. General view of an obsolete chiller running on R22

Each chiller has six semi-hermetic compressors. By 2017, only one of these two chillers was functioning and only at 70 percent capacity, since only four of the six compressors were working properly. In this regard the refrigeration station could not cope with the heat load in the summer, which led to an increase of the air temperature in hospital buildings.

In order to demonstrate alternative technologies and technical solutions, the possibility of replacing chillers operating on HCFC 22 with chillers of similar cooling capacity operating on ammonia (R717), an ozone-friendly refrigerant was considered. Thus, two ***ChillPAC 112L chillers from SABROE*** were purchased (Figure 9). Currently, the Danish company Sabroe is part of Johnson Controls.

Figure 9. General view of the new chiller running on R717.

The new chillers, with a total cooling capacity of 1,756 kW and operating on the environmentally-friendly R717 refrigerant, are noticeably superior in their thermodynamic properties to R22. When operating compressors with the same volume, the cooling capacity of a compressor operating on R717 was noticeably greater than that of a compressor operating on R22. Accordingly, the COP of an R717 unit is higher than that of an R22 unit. The results of the comparative analysis are given in chapter 2.2.

Ammonia, an environmentally-friendly refrigerant, was discovered over two centuries ago and has been used as a refrigerant for over 150 years due to its unique properties. Its ozone depletion potential (ODP) and global warming potential (GWP) are zero. Ammonia is a natural, affordable and cheap refrigerant, which has the best thermodynamic properties compared to known refrigerants which ensures the energy efficiency of the refrigeration systems operating on it. The characteristically unpleasant smell of ammonia is more of an advantage than a disadvantage, as it affords the opportunity to detect even ultra-small leaks (from 3 mg/m3). Ammonia production is organized at the enterprises of the chemical industry of the Republic of Uzbekistan, in the cities of Chirchik, Fergana and Navoiy. This is another significant argument in favour of expanding its use as a refrigerant in Uzbekistan.

The disadvantages of ammonia as a refrigerant include its toxicity and flammability, requiring certain safety measures. For this reason, its application has been limited exclusively to the industrial sector.

This project also has a social and economic effect. About 45-50 thousand patients, of which more than 60 percent are women, receive emergency medical care at the RRCEM during each year. Creating comfortable conditions for them and for the staff (3,000, of which 1,900 are women) when operating an energy-efficient refrigeration unit is of great importance, especially during the hot season, which lasts for at least six months for Tashkent city.

The demonstration of this chiller, which runs on an energy-efficient and environmentally friendly refrigerant, should influence the choice of entrepreneurs when making decisions on the construction of new climate control and refrigeration systems.

Another important step in the promotion of 'green' technologies is the conversion of small refrigeration systems (household and commercial refrigeration equipment) from HCFCs and HFCs to natural refrigerants. According to preliminary surveys, there are several dozen enterprises in Uzbekistan that produce household and commercial refrigeration equipment. One of such enterprises is the 'Xiva Maishiy Texnika' LLC in the Khiva region of Khorezm, where the production of freezers and display cases has been launched. Previously the units were operating on CFC, HFC and HCFC refrigerants.

Figure 10. Products of the 'Xiva Maishiy Texnika' LLC

With the support of UNDP, the demonstration project 'Replacement of a production commercial small-scale HCFC refrigeration line with a zero-ODS and low-GWP technology operating on natural refrigerants - propane (R290) and / or isobutane (R600a)' was completed. Currently refrigeration units are produced with components operating on environmentally-friendly refrigerants.

Improved knowledge of refrigeration and air conditioning installation and maintenance practices that help reduce refrigerant leaks will also improve energy efficiency, the environmental friendliness of installations, and reduce operating costs by decreasing the need for the equipment owner to visit service centres.

Institutional strengthening and scientific capacity building activities have traditionally included the training of service sector technicians, and the training of regional networks, and the undertaking of public awareness campaigns that direct consumer choice towards environmentally-friendly products. Such activities in the field of energy efficiency complements other programmes and activities.

The Tashkent State Technical University (TSTU) is the largest technical educational institution of the Republic, educating specialists across various fields. At the Faculty of 'Refrigeration and Cryogenic Engineering' of the Tashkent State Technical University, ***350 students (of whom 11 are women)*** are studying for a bachelor's degree in the ***technological machines and equipment (refrigeration engineering)*** speciality, while ***10 students (including 1 woman)*** are completing their masters in ***machines and units of refrigeration, cryogenic technology, and air conditioning systems***.[15] Since 2000, the faculty, in close cooperation with UNDP, has been increasing its research in improving the energy efficiency of refrigeration systems.

In addition to providing higher degrees of education, the faculty is working to improve the skills of specialists in refrigeration and climate technology. For these purposes, a special training centre has been established (Figure 11).

Figure 11. Training centre for advanced training of specialists in refrigeration and climate technology at the Tashkent State Technical University

[15] http://tdtu.uz/kafedry

In 2017, with UNDP's financial assistance, the centre updated its technical base. Special tools for the installation, repair and maintenance of refrigeration equipment were purchased (Figure 12).

Figure 12. Special tools for servicing refrigeration equipment

In international scientific-technical, patent and advertising literature published over recent years, the number of publications on the issue of reducing the consumption of electricity and fuel in the processes of heat and cold supply of residential and administrative buildings, as well as in industrial and agricultural technological processes using heat pump units (HPU), has increased significantly.

HPUs are more effectively used in hot water supply and heating systems for household and administrative premises that are not connected to a combined heat and power plant (CHP), are located away from gas lines, and are in areas with low building density. The use of HPU for hot water supply and heating was constrained by competition from less expensive gas and oil boilers, until the price of liquid and gas fuels increased.

A rapid increase in oil and gas prices, outpacing the growth rates of electricity prices, will ensure that feasibility studies for further improvement of HPU for hot water, heating and air conditioning systems are all undertaken.

The use of HPU, instead of local boilers operating on gas or oil fuel, reduces pollution in residential areas and decreases the level of thermal pollution, which are important factors and one of the advantages in their implementation. The successes achieved in the field of refrigeration engineering are the basis for the creation of more advanced heat pumps. As a result, the industry of the leading countries producing heat pumps has recently experienced rapid growth.

The operation of a HPU not only requires energy consumption for the drive, but also the energy of additional heat sources and temperature levels that prevent optimal usage, i.e. temperatures below 400C. Such heat sources include waste heat and the energy of the surrounding space.

Energy sources from surroundings include the soil, ground and surface water, the energy of the sun and the air. The lower limit of the use of water sources is the freezing point of water, and for air, the temperature of frost formation on the surface of the air cooler (heat receiver).

An assessment of the energy efficiency of new fluids in existing and developed refrigeration and heat pump equipment, as well as the development of new technologies using ozone-friendly refrigerants, is possible on the basis of gathering information of the thermodynamic properties of these substances through experimentation.

In pursuit of these goals, within the framework of UNDP's 'Initial Implementation of Accelerated HCFC Phase Out in the Countries with Economies in Transition – Uzbekistan' project, the training centre of the Tashkent State Technical University received a CO_2 air-to-water heat pump (Figure 13) and a split air conditioner (Figure 14), operating on environmentally-friendly refrigerants.

Currently the preferred alternative refrigerants for refrigeration and heat pump applications are natural hydrocarbons and ammonia. Carbon dioxide (CO_2) is also widely used as a refrigerant in heat pumps.

Figure 13. Air-to-water heat pump operating on an environmentally-friendly CO_2 refrigerant (R744)

Carbon dioxide - CO_2 (R-744), as a natural refrigerant, is one of the most promising alternatives to existing refrigerants. It is non-flammable, does not deplete the ozone layer (ODP = 0) and has a low global warming potential (GWP = 1).

The faculty members and postgraduates of the Department of Refrigeration and Cryogenic Engineering have developed a special stand based on this heat pump, and have conducted scientific research to compare and determine energy efficiency. The results of their study is presented in section 2.2 of this chapter.

The practice was also applied in the transformation of this stand into a heating and cooling unit. During the warm period, this unit can operate in air conditioning mode with simultaneous heating of water for hot water supplies.

Figure 14. Split air conditioner operating on a natural refrigerant - propane (R290)

Currently, the Department of Refrigeration and Cryogenic Engineering is working on the creation of laboratory facilities for testing split-air conditioners operating on R22, R410A, R32 and R290. After the completion of the installation work, there are plans to undertake related research work for PhD degrees. One of the objectives of these studies will be to determine the economic benefits of using natural refrigerants in air conditioners.

Increasing the economic potential of the refrigeration and air conditioning industry indirectly depends on the knowledge of the operating personnel of these installations. The effectiveness of professional and economic training of personnel is measured by comparing learning outcomes with the costs of the personnel training system, which by their nature are preliminary, and also the one-time costs incurred until the effectiveness of training can be analysed.

Costs are incurred for:

- Creation and use of an educational and material base for personnel training;
- Development and production of educational and methodological equipment of the educational process;
- Research into, improvement of and searching for new forms and methods of professional and economic training for workers;
- Payment of the expenses of educational institutions of the state and the sectoral system of personnel training and remuneration of workers involved in educational and pedagogical activities in production.

The calculation of economic efficiency is carried out based on a comparison of technical and economic indicators of the production activities of workers before and after training.

Currently, active work is underway in Uzbekistan to train, retrain and improve the skills of technical specialists in the field of refrigeration and climate technology. In 2021, together with the Ministry of Employment and Labour Relations of Uzbekistan, training monocentres were opened in the cities of Gulistan, Bukhara and Fergana.

For these centres, with the support of UNDP, and in addition to technical equipment, educational and methodological materials have been developed in two languages (Russian and Uzbek):

1. 'Training module (educational and methodological materials) for the retraining of technicians in the field of refrigeration and air conditioning' - Tashkent, 2020
2. 'Training module (educational and methodological materials) for the advanced training course for workers in the field of refrigeration and air conditioning' - Tashkent, 2020
3. 'Curriculum for training trainers of training centres for retraining and advanced training in the field of refrigeration and air conditioning' - Tashkent, 2021

Prior to the launch of monocentres, workshops were held at the Tashkent State Technical University and in special classrooms and at enterprises.

Figure 15. Training at the training centre of the Tashkent State Technical University

Particular attention is also paid to the training of women in the RAC specialty. In 2021, classes were held in 'online' and 'offline' modes, specifically for women students.

For this purpose, a special educational and methodological programme has been developed in the state language, titled 'Curriculum on refrigeration and air conditioning for teaching women' (Tashkent, 2021).

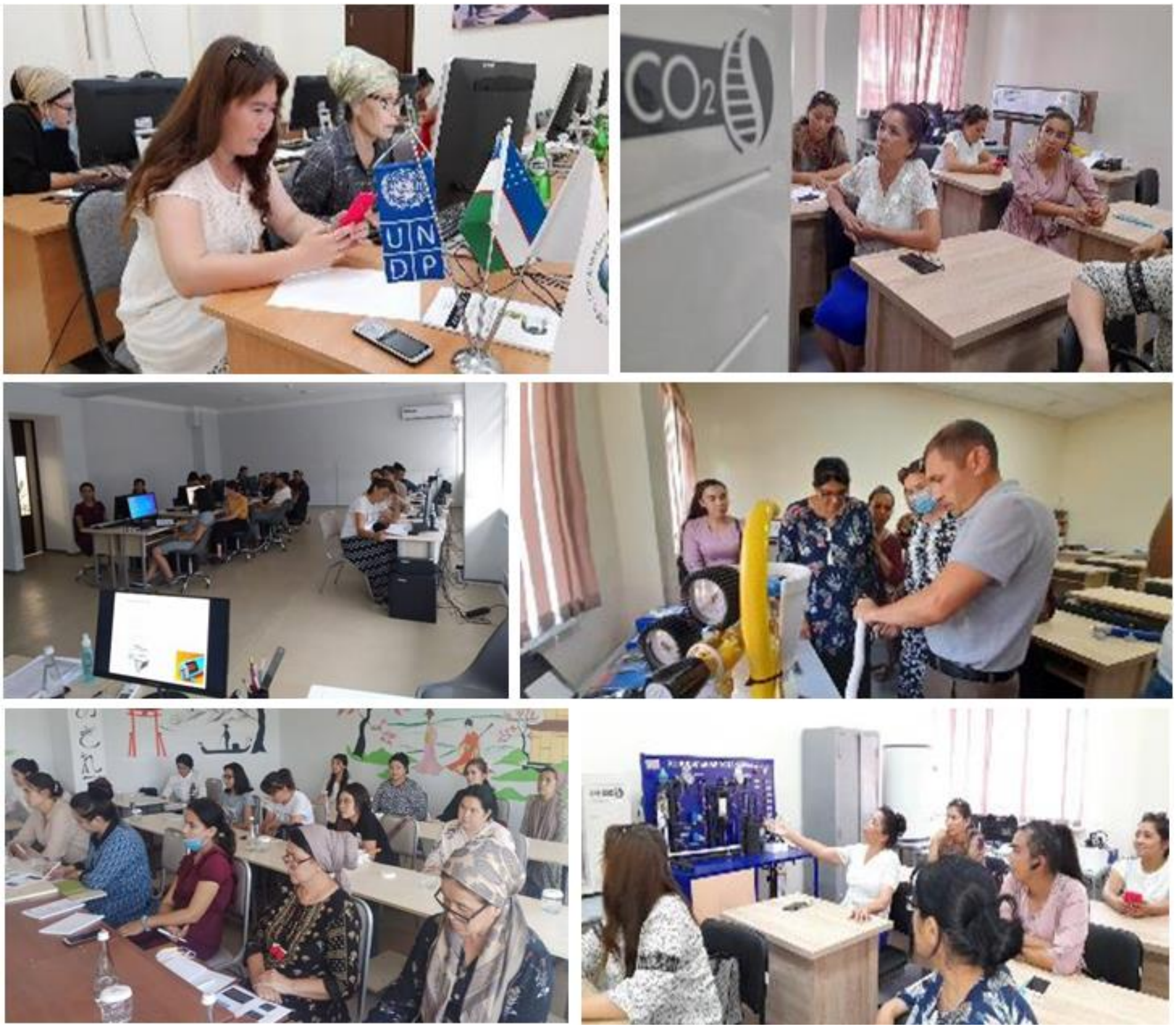


Figure 16. Trainings for women students

2.2. Comparison of energy-saving, ozone-friendly RAC technologies with low global warming potential

The task of reducing the consumption of non-renewable energy resources, associated with both technical and economic solutions, and an increasing degree of environmental problems, is becoming increasingly important for energy-intensive refrigeration equipment.

Let us consider successive transformations in the circuit of a thermal power plant, including power transmission lines and equipment, for a refrigeration unit. If we take the efficiency of a power plant of 0.45, a power line of 0.9, and a refrigeration unit of 0.35 (i.e., the average value of modern equipment), then 1 kWh of cold will 'cost' approximately 7 kWh. This means that a kilowatt at different places on the energy chain is far from being equivalent: saving 1 kWh in a refrigeration plant is equivalent to saving 7 kWh in a power plant.

If we consider the total cost of electricity, including non-energy costs, then the non-equivalence will increase even more. It follows that even relatively-small energy savings in refrigeration are extremely cost effective. The main directions of energy and resource saving in refrigeration are the improvements in processes and equipment design, as well as the use of efficient heat exchangers and refrigerants.

To conduct research on chillers operating on various refrigerants, the operational and technical data of the factory test were used at the RRCEM. The following parameters were taken as design modes of operation:

- average daily coefficient of working hours from 0.25 to 0.38
- working days in a year from 125 to 150
- chilled water temperature at the outlet of the chiller: +6^{0}C
- temperature difference of the cooled water: 5^{0}C
- temperature of condensation of refrigerants: +40^{0}C
- temperature of the refrigerant at the outlet of the condenser: +38^{0}C

Analytical studies of chillers for HCFC 22 and R717 provided the following results:

a) The energy efficiency coefficient for chiller cold on R22 was $COP_{\mathbf{R22}}$= 3.62. Likewise, for a chiller operating on ammonia $COP_{\mathbf{R717}}$= 5.49, which means a 1.5-fold reduction in the specific energy consumption for cold generation.

b) The negative difference in annual electricity consumption due to the use of the new chiller ranged from 91,400 to 109,670 kWh, depending on the average summer ambient temperature.

The project 'Replacement of the outdated chiller of the RRCEM centralized air conditioning system operating on the ozone-depleting refrigerant HCFC 22 with a chiller operating on the natural refrigerant ammonia (R717)' made it possible to save 100,000 kWh/year of electricity.

As mentioned in chapter 2.1, the production of freezers and display cases using environmentally friendly refrigerants has been launched at the 'Xiva Maishiy Texnika' LLC enterprise in the Khiva region of Khorezm.

To determine effectiveness, we defined the parameters of work and analysed the results of a study of freezers and showcases operating on HCFCs, HFCs and natural refrigerants. The parameters were taken under the same operating conditions of the objects under study.

As a comparative parameter, the consumption of electricity and COP cooling of each installation was measured. The results of the study are shown in table 9.

Table 9. Results of studies of freezers and refrigerated display cases at the 'Xiva Maishiy Texnika' LLC enterprise

№	Unit name	Refrigerant	Operation mode	Electric power of the unit, W	COP in cooling
1	Freezer	HFC 134a (R 134a)	Nominal (storage of frozen products)	139	0.72
2	Freezer	Isobutane (R 600a)	Nominal (storage of frozen products)	115	1.15
3	Refrigerated display cases	HCFC 22 (R 22)	Nominal (refrigeration of products)	807	1.53
4	Refrigerated display cases	HFC 404A (R 404A)	Nominal (refrigeration of products)	825	1.49
5	Refrigerated display cases	Propane (R 290)	Nominal (refrigeration of products)	710	1.74

The research generated the following results:

- Freezers equipped with R134a refrigeration units consume 17 percent more electrical energy than R600a units. COP of the unit on R600a is 37 percent higher than on R134a.
- Prior to the use of natural refrigerant in refrigerated display cases, there was a partial replacement of HCFC22 with HFC404A. This development led to an increase in electricity consumption by 2.2 percent and a decrease in energy efficiency by 2.68 percent. Thus, for the climate of Uzbekistan, replacing R22 with R404A does not provide economic benefits.
- Refrigerated display cases that ran on R404A units were replaced with propane units. The cooling capacity of these refrigerated display cases in the nominal mode was 1.227-1.231 kW. As can be seen from the table, the electric power of new samples is 14 percent less, which contributed to a 1.17 times increase in energy efficiency. If R22 were initially replaced with R290, then 12 percent of electricity could be saved.

Assuming that this practice is applied to the production of 500 freezers and 500 refrigerated display cases by replacing HFCs with natural refrigerants, the economic benefit from operation will be 104,250 kWh per year.

To compare the efficiency of HP and traditional heat generators, for example in boiler houses, it is recommended to use a more generalized criterion - the primary energy utilization factor 'K': the basis of comparison is the primary energy. Primary energy refers to the energy of primary energy carriers. The primary energy utilization factor is found as the ratio of useful energy to supplied primary energy. 'Useful' energy is that which comes at the disposal of the consumer after the last technical transformation, and is used for technological needs. The supplied primary energy is measured as the calorific value of the consumed fuel (for reference fuel 29.3 GJ/t.f.e.).

From this point of view, direct electric heating is the least effective at K_{el} = 0.27 - 0.39, since at a thermal power plant 70 percent of primary energy is lost in the generation of electricity and its transportation through networks [15].

Heat supply by direct combustion of fuel in a boiler house leads to a loss of 20 percent of primary energy. The coefficient of use of primary energy is approximately equal to the efficiency of the boiler, being K = 0.75-0.85.

Heat pumps, unlike other heat supply systems, can provide savings in primary energy; i.e., K>1. The primary energy utilization factor for HP with electric drive is equal to:

$$K_{HP} = COP * K_{el},$$

where *COP* is the HP efficiency factor, as described in detail in Section 1.1.

K_{el} is the coefficient of primary energy use in electricity generation.

Thus, at COP=2.6, the efficiency of the HP is equalized with that of the boiler house.

Table 10 gives comparative results of calculating the annual costs of heating a house through different systems. Energy tariffs are those for 2021.

Table 10. Annual costs of heating a house through different systems

Type of heat generator of the heating system	Fuel combus-tion heat	Annual demand	Energy carrier price	Energy carrier cost, UZS/m²	Costs for a house with an area of 300 m², UZS
Gas boiler	10.1 kWh/m³	19.9 m³/ m²	380 UZS/m³	7,562	2,268,600
Liquid fuel boiler (diesel oil)	10.2 kWh/l	20.2 l/m²	9,665 UZS/l	195,233	58,569,900
Electric boiler	-	191.5 kWh/m²	295 UZS / kWh	56,492.5	16,947,750
Heat pump	-	67 kWh/m²	295 UZS / kWh	19,765	5,929,500

The following factors were assumed in the calculations: house heat loss of 60 W/m², hot water consumption of 10 percent, annual duration of 2,900 hours, and heat pump energy efficiency coefficient of COP=2.86.

Fuel savings when comparing heat supply using HP with any alternative method:

$$\Delta G = G_{al}\left(1 - \frac{K_{al}}{K_{HP}}\right),$$

where G_{al} - fuel consumption with an alternative method of heat supply in tons of reference fuel (t.f.e), K_{al}, K_{HP} - coefficients for the use of primary energy of an alternative method and HP.

From an economic point of view, the use of HP can be justified if the cost of the saved energy (fuel) exceeds the increase in the non-electric part of the annual costs (capital costs, maintenance, and repair costs), which are higher when HP is used as more complex and expensive.

For the HP, the revenue part can be estimated as:

$$\Delta З = З_{al}\left(1 - \frac{Э_{эel}K_{al}}{Э_{F} * COP}\right)$$

where $З_{al}$ is the cost of consumed energy (fuel) with an alternative method of heat supply, sum; $Э_{el}$ - cost of electricity, UZS/kWh; $Э_{F}$ - the cost of fuel in terms of its calorific value UZS / kWh. Savings $\Delta З > 0$ are possible only under the condition:

$$1 > \frac{Э_{el}K_{al}}{Э_{F} * COP}$$

Its implementation is largely determined by the ratio of tariffs $Э_{el}/Э_{F}$. Foreign experience shows that an acceptable payback period for electric HPs (2.5-3.5 years) is provided at $Э_{el}/Э_{F}$ = 2.5. In Germany and Sweden, this ratio is 2.2 and 1.3, respectively. In Uzbekistan, these ratios are currently constantly changing.

For the city of Tashkent, the cost of 1m^3 of natural gas was 380 UZS (for 2021), which, in terms of its calorific value, is equivalent to 38 UZS / kWh. At the same time, electricity is supplied to the population at 295 UZS/kWh. From this we can see the unprofitability of the use of electrically driven HPs today, despite the significant savings in primary energy compared to a boiler running on natural gas.

However, in Uzbekistan over the past 15 years the dynamics of growth in the natural gas price has outstripped the growth in electricity prices. If in 2021 the use of HP for a house of 300m^2 was 2.6 times more expensive than a gas boiler, then in 2006 this figure was 7.43. A further increase in tariffs for natural gas and electricity, as well as improving the energy efficiency of heat pumps, could increase the volume of operation of heat pump installations. Especially for objects located far from gas pipelines, the use of heat pump heating installations is an economically justified solution.

CO_2 systems are characterized by their efficiency being more highly dependent on their application and climatic conditions, compared to systems using other refrigerants. The decrease in system efficiency with increasing condensing temperature is characteristic of all refrigerants, and CO_2 is one of the refrigerants for which this decrease is most noticeable. Good thermophysical properties of CO_2, to a certain extent, compensate for this disadvantage.

CO_2 has a high energy content at elevated temperatures, and if the heat generated can be recovered for domestic water heating or similar purposes, the overall efficiency of the system becomes very high.

To test the heat pump for CO_2, a special stand was created with a measurement and data processing system. This stand was developed based on the SANDEN heat pump, which belongs to the ERP environmental organization of France. The entire SANDEN heat pump system complies with European Directive 2002/95/CE regarding the restriction of the use of certain hazardous substances in electronic equipment and electronics.

The unit is a single-stage machine operating on carbon dioxide, CO_2 (R744), with systems for supplying water to the gas cooler and air to the evaporator.

The stand was tested at various ambient temperatures. The experimental data were processed, and such indicators were determined as the dependences of the heat output Q_H and the electric power of the compressor N_{el}, as well as COP, specific power consumption, and thermodynamic efficiency depending on the outdoor temperature of incoming water temperatures of 10°C, 30°C and 45°C.

When the ambient temperature changes from -14°C to +21°C, the heat output of the unit increases. In the zone of negative air temperatures, the increase in heat output was much more intense than in the zone of positive temperatures.

When the ambient temperature changes from -14°C to +21°C, the electric power of the unit decreases. At an inlet water temperature of 45°C there were high energy consumption values, and at a water temperature of 10°C relatively low energy consumption values were observed.

As well as the heat output, when the ambient temperature changes from -14C to +21C, the COP of the installation increases. The best result of a COP value, of 4.5, was achieved when the unit used colder water (10°C) which is 55 percent higher than when operating on water with a temperature of 45°C.

The specific power consumption of the installation (a) decreased with increasing ambient temperature. In the region of negative temperatures, a has higher values than at positive temperatures.

Costs (specific) at a water temperature of 10°C was on average 48, being 59 percent less than when using water with a temperature of 45°C. When water enters the installation with a temperature of 30°C, the costs are 4.8 (14 percent more than at 10°C).

The temperature level of the maximum values of thermodynamic efficiency falls on the interval of -5°C to +7°C at all temperatures of water entering the gas cooler of the plant.

Higher efficiency ratings were observed when water was supplied with a temperature of 30°C. In addition, it was observed that with a broader temperature range (-10°C to +12°C) the efficiency value exceeded 40 percent.

In the mode up to an air temperature of +10ºC, the installation when working with water t_W = 45ºC was inferior to the operating mode t_W = 10ºC. After this temperature, the efficiency became higher.

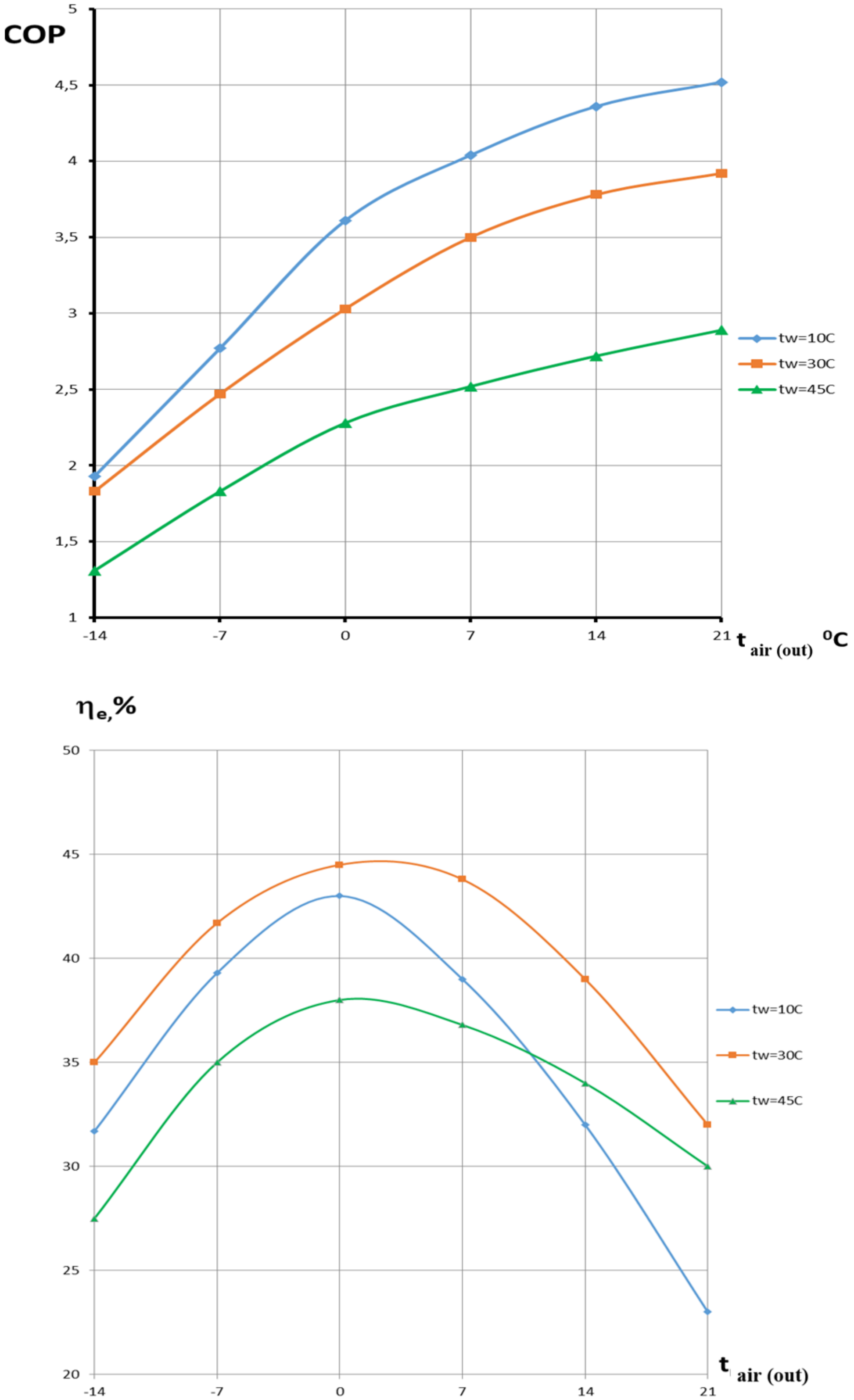


Figure 17. Dependence of COP and thermodynamic efficiency of the installation on the outdoor air temperature at fixed inlet water temperatures t_w

In warm and hot seasons, this stand applied the practice of the beneficial use of indoor air as a low-potential source. In this case, the unit was simultaneously used as an air conditioner and a heat pump, producing both cold and heat. This practice made it possible to ***increase the COP of the combined cycle by 1.5 times, and reach a value of 6 or more. The resulting savings in electrical energy from the implementation of this practice amounted to 277 kWh/year.***

The climatic conditions of Uzbekistan require not only heating of household premises in the cold season, but also cooling in the warm season. At the same time, the duration of the cooling period is 4,512 hours, while the heating period is 3,144 hours. Therefore, in relation to climatic conditions, preference should be given to integrated heating and cooling systems that provide air conditioning (cooling and dehumidification) during the warm period, heating during the cold period of the year, year-round supply of hot water for domestic needs, and that use renewable energy (for example, heat of the air removed from the premises).

The heat pump of heat supply systems should be designed for each specific facility, depending on the energy loads, soil and climatic conditions of the construction area and the cost of energy carriers. The use of heat from the surrounding air and solar energy as the only sources of low-grade heat should be used in combination with other more stable sources.

Conclusions and recommendations

This report presents data on the consumption of electricity in the Republic of Uzbekistan by region in the period of 2016-2020. Most of the electricity is consumed by industry, households and agriculture. In 2020, the consumption of electrical energy for the production of household refrigerators and air conditioners amounted to 9,950,000 and 9,702,000 kWh, respectively.

In Uzbekistan, by 2020 the number of households had reached 8,871,412.[8] Electricity consumption by refrigerators and freezers in these households reached **2,477 million kWh which is 3.71 percent of the total electricity generated that year.** In Uzbekistan, electricity consumption for air conditioning, according to the Centre for Energy Efficiency, averaged 236 kWh/households per year. Electricity consumption for air conditioning in 2020 amounted to **2,093 million kWh per year (3.15 percent of all electricity generated in 2020).**

Effective promotion and information campaigns play an important role in encouraging consumers to purchase household appliances with a high energy efficiency class.

Currently, household refrigerators in Uzbekistan are produced using environmentally friendly refrigerant R600a (isobutane), and household and industrial air conditioners are produced using HFC refrigerants. For the cold supply of central air conditioners and fan coil units (fan radiators), the production of chillers for HFC R410A has also been launched.

The phaseout of HCFC and HFC consumption in the refrigeration and air conditioning sector can lead to significant improvements in energy efficiency. The implementation of two joint demonstration projects (RRCEM and the 'Xiva Maishiy Texnika' LLC) with UNDP for refrigerant replacement have resulted in savings in electrical energy consumption of ***204,250 kWh per year***.

In 2019, more than 1,165 hospitals operated in Uzbekistan.[16] During the COVID-19 pandemic, their number increased even more. Assuming that 10 percent of these institutions will apply the same practice as the RRCEM, then the annual economic effect would be **12 million kWh**. Preliminary calculations showed that the application of the practice of the 'Xiva Maishiy Texnika' LLC throughout Uzbekistan could provide economic benefits of **1.5 million kWh / year. The total economic effect - 13.5 million kWh / year is 0.022 percent of the annual electricity generation of Uzbekistan. This means there would be a reduction in carbon dioxide emissions by 2030 (considering possible small annual leaks) by more than 66,000 tons.** It should be emphasized that these calculations do not include all social facilities in Uzbekistan using HCFC and HFC refrigerants.

Stakeholders, including the Ministry of Health and manufacturers of electrical equipment should strive to gradually replace existing and purchase new refrigeration and climate control equipment based on natural refrigerants.

[16] https://www.rbasia.uz/zdravohranenie-sector-uzbekistan. Overview of the healthcare market in Uzbekistan.

By introducing energy efficiency into the refrigerant replacement process, Uzbekistan can reduce import and fuel consumption costs, local producers can increase their competitiveness and expand their markets, consumers can save money on energy bills and spend these savings locally, and citizens can breathe fresher air due to reduced air pollution.

Improved equipment installation and maintenance practices that help to reduce refrigerant leaks will also improve equipment energy efficiency and reduce operating costs by decreasing phone calls to service centres.

New equipment using natural refrigerants cannot contribute to the reduction of electricity consumption alone. Also, refrigerant leaks in equipment that occur during installation, operation and repair of equipment lead to the release of CO_2 into the atmosphere. The HFCs used in this equipment have high GWPs, over 1,000 times the GWP of natural refrigerants.

Using statistical data on manufactured and imported RCA equipment (domestic refrigerators, split air conditioners and chillers), it was found that the transition from HFCs to natural refrigerants gives the Republic ***12,554.44 tons of carbon dioxide emissions reduction per year***. It should be noted that this figure refers only to three types of RAC equipment. Given the replacement of functioning installations with new environmentally-friendly ones, as well as taking into account other types of RAC**, this indicator will be very high.**

The Government of the Republic of Uzbekistan is recommended to implement measures for a successful transition to the production of RAC equipment with green technologies and to provide financial support, with the involvement of non-state donors for the re-equipment of enterprises.

Institutional strengthening and capacity building activities have traditionally included training of service sector technicians, training of regional networks and public awareness campaigns to direct consumer choice towards environmentally friendly products. Such activity in the field of energy efficiency harmoniously complements other programmes and activities.

The study and analysis of curricula at both secondary vocational and higher education levels show that there are no topics on improving energy efficiency and working with natural refrigerants in these educational programmes. In the developed educational and methodological guidelines for educational institutions of the Republic, there is limited information on safe work with flammable refrigerants.

The Ministry of Higher and Secondary Specialized Education, together with the Ministry of Employment and Labour Relations, have been recommended to develop training programmes aimed at learning how to improve energy efficiency in the RAC sector, and ways of working with flammable refrigerants. Standard curricula for RAC should emphasize courses and programmes on

energy efficiency and modernization of refrigeration and air conditioning systems.

To conduct educational processes in the relevant institutions, it is necessary to develop literature in the state language. We believe that this task should be performed by the teaching staff of the Department of Refrigeration and Cryogenic Engineering of the Tashkent State Technical University.

Trade and purchasing policies can also be used to encourage imports of more efficient products.

To prevent the import of low-energy efficient goods and components, the Government of the Republic of Uzbekistan is recommended to apply a robust national energy efficiency policy for imported new and used, recycled and refurbished refrigeration units, and any such locally manufactured units or used equipment.

It is necessary to consider the objectives holistically when designing buildings and structures using energy-saving technologies, including the installation of heat pumps using the heat of secondary energy resources and non-traditional energy sources. Heat pump systems and heat supplies should be specifically designed, depending on the energy loads, soil and climatic conditions of the construction area and the cost of energy carriers. The use of the heat of the surrounding air and solar energy as sources of low-grade heat should be combined with other, more stable sources.

Academic and research institutions of the Republic of Uzbekistan are recommended to expand research work to identify the efficiency of using HPU in climatic conditions and tariffs for energy carriers in Uzbekistan.

The promotion and implementation of modern non-traditional, in particular, absorption refrigeration units, at enterprises with thermal emissions is of great relevance. An analysis of the work performed earlier showed that, under certain conditions, absorption heat converters of various schemes can be used to create energy-saving systems.

Energy and heat supply enterprises need to consider the possibility of using new energy-saving technologies. The use of absorption refrigeration units that use thermal discharges of energy supply facilities as external energy makes it possible to increase the degree of thermodynamic efficiency of energy conversion systems and reduce thermal pollution of the environment.

One important step in gaining attention and support from key government departments is how the benefits of energy efficiency are presented. In addition to the technical rationale for improving energy efficiency and reducing greenhouse gas emissions, decision makers are interested in basic financial indicators and cost-saving measures.

Budget organizations, including hospitals, pay their utility bills with funds allocated from the state budget, developed by the Ministry of Economic Development and Poverty Reduction and the Ministry of Finance of the Republic of Uzbekistan. If they save electricity from the implementation of effective measures, they will receive less money in the next year's budget, and there is no mechanism for obtaining the saved funds for their own needs.

To strive to improve the energy efficiency of their RAC installations, budgetary organizations must have financial benefits. To this end, the Government of the Republic of Uzbekistan is recommended to provide financial incentives for improving energy efficiency, and the Ministry of Economic Development and Poverty Reduction and the Ministry of Finance of the Republic of Uzbekistan should both act as main stakeholders responsible for managing the country's budget and its execution. We consider it appropriate to present this convincing analysis and arguments to the responsible ministries, as saving energy will allow the allocation of budgetary funds for more pressing needs, and the possibility of re-directing fuel resources for export or domestic use in the future.

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