Elements of energy infrastructure modernization of buildings and cities

R R Perepelitsa and K D Sergeeva
National Research University "MPEI",
Institute of energy efficiency and hydrogen technologies,
Russia, 111250 Moscow, Krasnokazarmennaya, 14

PerepelitsaRR@mpei.ru,
SergeevaKD@mpei.ru

Abstract. The formation of effective energy technological systems of buildings and cities in new economic conditions requires comprehensive analysis of dynamic of their developing, complex of diverse conditions of their function, diverse factors of their changes. The need for a systematic approach to the analysis of the functioning of complex technical systems is difficult to dispute. Methodologically, the task is to select from the many approaches the most appropriate for achieving the assigned engineering tasks. This implies the need for a comprehensive analysis of the subject area of the studied systems and the choice of the necessary system equipment, commensurate with the complexity of the selected objects. This article presents a number of elements and technologies for the modernization of the infrastructure of buildings and cities, which in practice shows their energy efficiency: fuel cells, recuperators, heat pumps, thermoactive building systems, and a predictive management with using of weather data - an intelligent tool for controlling the building's air conditioning.

1. Fuel cells
At the moment energy conservation has become a priority in the world for development in such a global industry as energy. The implementation of appropriate policies is associated with a number of problems. First, it is the shortage of basic resources, second, it is the increasing cost of their production and third, it is the global environmental problems, that have emerged recently.

Now there is continuing issue of reducing of energy loses in Russia. Why? And how can we increase energy efficiency? The introduction of new technologies, the relevant elements of modernizing the infrastructure of buildings and cities makes it possible to transform these problems into potential growth points, and new approaches to managing urban development, the effective integration of urban infrastructure elements and the involvement of qualified personnel allow us to modernize the energy industry households.

The interest in the issue of highly efficient energy conversion methods is growing now. The heart of this problem is the conversation of one type of energy into another with the complete exclusion of mechanical energy from this process, in other words, without intermediate stages. Such methods include the conversion of thermal energy into electrical energy, based on the Seebeck thermoelectric effect or direct production of cold from electricity using the inverse of the previous Peltier effect, the direct generation of electric energy from light in photocells and conversion of chemical energy of fuel into an electric in fuel cell.
In all these methods fuel cell is the most relevant one. This is due to the fact that its development requires relatively more modest efforts than, for example, for the fission or synthesis of nuclear fuel. In addition, the fuel cell efficiency is much higher, which can significantly save the reserves of conventional fuels, such as coal, natural gas, oil. Fuel cell is a large perspective for the development of electric transport, which does not make noise and smell during the movement. Also speaking about the advantages of fuel cell, we have to note absence of radioactive reaction products, the possibility of accumulating excess energy with its subsequent use at peak loads and the possibility of using it in military equipment.

We will use hydrogen as an example of a fuel for fuel cells use. Successful works in the field of hydrogen technologies has shown, that this using leads to the absolutely new indicators in the operations of plants and systems, and studies have shown, that despite the fact, that hydrogen is a secondary energy store, its using is economically justified and effective in most cases.

Such increased interest in hydrogen as a fuel and as an energy store may be justified by several distinguishing characteristics:

- Firstly, hydrogen reserves around the world are practically unlimited;
- Secondly, hydrogen is absolutely universal energy resource. It can be used as fuel for the production of electricity in various types of duty cycles and as an energy store for transportation in a gaseous, liquid, and bound state;
- Thirdly, as mentioned above, with the help of hydrogen, it is possible the accumulating of energy;
- Fourthly, among organic fuels, hydrogen is characterized by the highest calorific value per unit mass and the least negative impact on the environment, which is very important in our time.

Hydrogen reserves are not limited, but of course it does not occur in nature in pure form. Hydrogen is produced by extracting it from either hydrocarbon or water. It is important, that the energy of 1 g of hydrogen is equivalent to the energy of about 3 g. petrol. Using hydrogen in fuel cells, due to its high efficiency, the efficiency of hydrogen as a fuel become higher in 4-10 times compared to internal combustion engines.

There are many examples of the introduction of fuel cells in the city infrastructure today.

The hotel «Nagoya Sakae Washington Hotel Plaza» was built in Nagoya, Japan. It designed for 308 numbers. The hotel has a combined system for the production of heat and electricity based on a fuel cell. The fuel cell «FP-100» with a rated power 100 kW manufactured by «Fuji Electric» was used.

![Figure 1](image1.png)  ![Figure 2](image2.png)

**Figure 1.** The hotel «Nagoya Sakae Washington Hotel Plaza» (Nagoya, Japan).

**Figure 2.** The fuel cell «FP-100» with the capacity 100 kWt is produced by «Fuji Electric».

The cell has been in continuous using since March 1999 and shows high efficiency and reliability, providing ensuring a 14% reduction in energy consumption. For example, burning natural gas, to
produce the same amount of energy, would increase emissions of CO2 by 17%. Overall efficiency of the setting is over 70%.

In this model of the fuel cell produce two types of thermal energy: high-temperature in the form of hot water with a temperature of 90 °C and low-temperature in the form of cold water with a temperature of 50 °C. The low-temperature water, which is produced by the fuel cell, is used for preheating the water, supplied to the water heater, and the higher-temperature water is used as a source of thermal energy of heating, air conditioning and hot water supply.

As a result of structural improvements and optimization in the fuel cell sample, the number of heat exchangers was reduced by half compared with the prototype. To reduce operating costs, a water treatment system based on ion-exchange resins has been optimized.

In size the installation is placed inside the building, and the mass allows transporting on a cargo platform with a lifting capacity of 15 tons.

The fuel cell is connected to a gas main, and also to the city power grid through protective devices. It all makes possible to direct excess electricity to the city electric grid during a low nominal load, that is, at this time the hotel is not a consumer of electricity, but a producer. Such scheme allows using of the fuel cell even more efficiently.

![Diagram of system heat- and power supply of the building of the hotel with the fuel cell «FP-100».](image)

Considering this example, may be noted that using of the fuel cell has reduced the cost of heat and electricity by about 40%.

2. **Recuperators**

Heat recovery in the supply and exhaust ventilation is not a new phenomenon, but it is still not widespread in our country. From a technical point of view, recovery is the most common heat transfer process. The word "recovery" itself is of Latin origin and means "return of the spent".

The next element in the modernization of building infrastructure is the enthalpy recuperator. It is used to recover heat and moisture from the exhaust air to the supply. Also with the transfer of moisture, part of the implicit heat is transferred from the exhaust air to the supply air, thereby increasing the enthalpy efficiency of the recuperator. The working area is made of a polymer membrane, which passes water molecules from the exhaust air and transfers it to the supply air. Mixing of exhaust and supply air in the recuperator does not occur, because moisture is passed through the membrane through diffusion. Efficiency of three-stage heat recuperators is 80-85% for heat and 40-50% for moisture.
The above-mentioned element of the modernization of the infrastructure was applied to solve a number of problems at the next Moscow facility.

The Analytical Center for the Government of the Russian Federation is a nonprofit federal state institution providing information-analytical and expert-analytical support for the activities of the Russian Government and undertaking related research.

The supply and exhaust setting with a three-stage recuperation of heat and moisture with a capacity of 14,000 m³/h was made by the company «Turkov» (a Russian manufacture of climatic equipment) for the specified facility. The setting was designed as an air heating system with a mixture of supply air. This decision allowed not only ventilating the assembly hall, but also heating it. The efficiency of heat return from the exhaust air to the supply air in the three-stage TURKOV enthalpy recuperators is 80-85%.

Supply and exhaust equipment the Zenit 14 000 EL / EL HECO SW consists of three enthalpy recuperators, two EBM-PAPST fans, a supply and exhaust filter (class F5), a water heater with a mixing unit, a mixing chamber and the necessary automation.

The scheme of the work is next:

- The duct exhaust air temperature sensor measures the temperature of the indoor air in the room, if this temperature is lower than the setpoint for the temperature of the indoor air, the setting enters the recirculation mode, in other words work in indoor air. In this case, the supply of fresh air does not stop. There is a mixture of the supply purified air and heated air in the recuperator with recirculated air. Combining the ventilation system with the air heating system allows us using the classic heating system, which would work continuously during the heating season.

### 3. Heat pumps

Heat pumps are included in the “List of facilities and technologies, that relate to facilities and technologies of high energy efficiency” (approved by the Decree of the Government of the Russian Federation №6 June 17, 2015).

In addition, “the creation of a complex of technological equipment and the development of standard technical solutions for the use of heat pumps in heat supply systems in large cities and urban entities” have been identified as one of the priority areas of scientific and technological progress in the energy sector in the activity “Heat supply” in the Energy Strategy of Russia for the period until 2030.

The heat pump assembly can be mainly used in the following ways:
- additional connection to the heating systems of new heat consumers;
- connection to heating systems of consumers of cold;
- improvement of heat power plants of heating systems.

One of the most efficient scheme decisions, providing the simultaneous solution of a number of problematic issues of the heat pump assembly, is using of ring systems.

These problematic issues include:
- costs of supplying or rejection low-potential heat from the heat pump assembly cycle (for example, creating a geothermal circuit);
- the need for providing variable loads - the maximum heating load is 50-100% higher than the average seasonal, and the maximum HWS load is 2-5 times higher than the average daily;

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**Figure 4.** The scheme of the supply and exhaust unit with a three-stage heat and moisture recovery.
mismatch in the schedule of the required loads and the possibilities of supplying or rejection from the heat pump assembly cycle - for air conditioning systems cold is required during the daytime hours when the capacity of the outdoor units of the air conditioners is minimal.

We can observe a good example of solving these issues for one building and using of ring systems - it is the building «Iris of Congress Hotels» in Moscow.

In each of the rooms, where air conditioning is provided, or next to it, a heat pump is installed. Its power is selected in accordance with the parameters of the room, its purpose, characteristics of the necessary supply and exhaust ventilation, the possible number of people present, is installed other equipment and other factors. All heat pumps are reversible, in other words they designed for both cooling and air heating. All of them are connected by a common water circuit – pipes, in which water circulates. Water is at the same time a source and receiver of heat for all heat pumps. The temperature in the circuit can vary from 18 to 32 °C.

![Figure 5. The scheme HPA as a part of the ring system.](image)

Developing of the heat pump assembly in Russia has a number advantages of very a different plan in our days: saving fuel and air emissions, decreasing of costs for heat and cold supply, utilization of thermal waste and effluents.

4. Thermo Active Building Systems

In modern public buildings, the amount of internal heat generation reaches large values, and even in the conditions of our country during the heating period it can exceed transmission heat losses. Traditional air conditioning systems are characterized by high energy consumption and capital costs, occupy a significant area for equipment placement, require large spaces for laying air ducts and careful elaboration of air distribution schemes. In this regard, systems that implement new approaches to room climate control, such as thermoactive systems (Thermo Active Building Systems, “TABS”), which allow both cooling and heating the room by cooling or heating massive concrete structures of the building, have a great interest.

The Thermoactive Building System (“TABS”) is a water-based panel-radiant heating and cooling system in which pipes are monolithic into massive concrete structures of a building.
Figure 6. The example of construction of thermoactive system «TABS».

There are the main TABS system advantages:

- the need for cooling is distributed over a longer period in the daytime and partially shifts from daytime to nighttime. This allows reducing peak loads and using air conditioning units of lower power;
- refusal from false ceilings allows to reduce the height of the building, providing significant savings in building materials;
- the opportunity of using heating and cooling systems with temperatures close to room temperature. This increases the energy efficiency of heat pumps, condensing boilers, solar collectors, soil heat exchangers;
- night cooling can be used for cooling;
- low cost of installation, operation and maintenance.

Thermoactive systems of building use high thermal inertia of concrete slabs to smooth out peak loads, that is, for reducing peak cooling capacity, which allows cooling the building structure during periods of absence of users (for example, in offices at night).

It allows reducing energy costs, because at night lower rates are usually applied. At the same time, it is possible to reduce the size and power of the components of the heating or cooling system. The system uses water with a temperature close to room temperature, the efficiency of coolers and heat pumps increases, and energy consumption decreases in the cooling mode.

In summer period during a day time, when the temperature of the supply air is lower than the temperature of the exhaust air, the heat is partially taken from the used rooms by the ventilation system, and most of heat is accumulated in the concrete floor slabs. Then, during the night time, the intensity of ventilation air exchange decreases, and the cold water circulating in the pipes monopolized in the floor slabs assimilates the accumulated heat. The thermoactive system can be used together with natural or mechanical day or night ventilation, with or without dehumidification, depending on the outdoor climate and the amount of internal moisture.

“TABS” are mainly used in multi-story buildings such as office buildings, museums, hospitals, etc. One example of use is given below. The four-story house of arts in the Austrian city of Bregenz is Kunsthaus Bregenz, which is equipped with a double ventilated front-house with an external open glass wall. The main goal of the air conditioning system is to maintain a given level of relative humidity, as well as to prevent noise and dust.
As a result, it was decided to use the cooling ability of internal concrete structures in the building. Peak offset night-time cooling loads were not the main goal of this project. On the contrary, since the cooling potential of groundwater is always available and the shift of cooling at night will cause a sufficiently large amplitude of temperature fluctuations, cooling works during the all day.

The refrigerant of the cooling system is a water circuit built into 24 piles 18 m deep, located in soil with a high content of groundwater. Plastic pipes are monolithic in all external walls of the building. The walls are equipped with external thermal insulation and are characterized by very high rates of thermal protection.

Supply air consumption is 750 m³/h. Air is supplied to the room at a constant temperature and humidity through slotted air inlets in the floor according to the principle of displacement ventilation.

In addition, increased comfort is achieved for people in the building, thanks to the radiant component (as in panel-radiant heating or cooling systems). However, such systems are inertial, they do not allow to quickly respond to changes in outdoor temperature or the intensity of solar radiation. Rapid heating and cooling are not possible. For this reason, it is recommended to use thermoactive elements only to cover the base load that exists all day or which can be calculated in advance.

5. Conclusion

The development of above-mentioned elements of infrastructure of buildings and cities in the world, and in particular in Russia, has a number of different advantages:

- the economy of fuel;
• reduction of atmospheric emissions, which improve environmental situation;
• receiving of thermal energy at the equipment installation site;
• the universality in relation to the type of primary energy (HPA use various sources of low-potential energy of natural or technogenic origin);
• the ability to provide thermal energy to objects that are not connected to centralized heat supply systems, as well as remote regions and objects;
• the absence of the need to lay fuel (gas) pipelines, the organization of fuel depots and smoke removal or ash removal systems;
• the ability to provide climate control of different objects with one technological solution - both heating in cold seasons and cold supply in warm seasons;
• using of several of the indicated technological solutions gives a synergistic effect, and relatively cheapens the implementation.

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