Analysis of the heat recovery potential in the classroom

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Abstract. Buildings especially heating systems consume a prodigious amount of energy. In this case, the heated exhaust air from the premises is simply thrown out into the external environment, into the street. In this work, such air is considered as a secondary energy resource formed from the internal loads of the room. The study of the dynamics of changes in the power of internal loads and their influence on the operation of the heat exchanger installed on the exhaust was carried out using the Energy Plus software package. The simulation result showed the potential of using the heat of the exhaust air as an energy resource. The recovered heat from the extract air can be used to partially reduce the energy consumption for the heating system.

1. Introduction
More than one third of world consumption is for buildings and structures [1]. This leads to a global cost of resources, which, in turn, are not unlimited. To eliminate wasteful use of resources, it is necessary to develop both methods and efficiency of recycling, which can reduce both energy consumption and reduce the impact on the environment. One of these ways is heat recovery. An example of implementation is Stockholm Central Station [2], where about 250,000 people circulate every day, and the heat generated from them is used to heat a 17-storey office building. The created system converts excess body heat generated by a person into hot water through heat exchangers in the ventilation system. And then the heated water enters the heating system of the office building. The heat recovery system cannot fully heat the building, but it helps to reduce energy consumption by up to 10% [2]. In addition to reducing energy consumption, this method reduces the thermal emission of used air, which has a negative impact on the environmental issues associated with the widespread increase in the average daily temperature [9, 10].

2. Object and method of research
Presented research involves study of the relationship between the internal loads of the building and the capacity of the installed heat exchanger at the exhaust. To analyze the heat recovery process, the Energy Plus software package was used, which allows analyzing the building at the energy level, and identifying all the strengths and weaknesses of the project. For the calculation, 2 rooms were chosen, the Daikin laboratory and classroom 4212, which are located on the 2nd floor of one of the buildings of ITMO University. The model considers the thermophysical properties of the enclosing structures, the weather conditions of the environment associated with the geographic location, solar radiation, the parameters of the indoor air, as well as infiltration through the window openings.
Heat in the exhaust ventilation system is generating from human body, equipment, lighting, solar radiation and infiltration. From the point of view of loads, a room is a living object. Any room lives on schedule, people come and go, they can open a window, turn on and off lights and equipment. The loads in the room are calculated using the heat flow formulas. Infiltration calculation is based on Infiltration-Pressure Correlation: Simplified Physical Modeling.

The indoor heat balance is calculated using the following equation [3]:

\[ q_{lwX}^{\prime\prime} + q_{sw}^{\prime\prime} + q_{lws}^{\prime\prime} + q_{ki}^{\prime\prime} + q_{sol}^{\prime\prime} + q_{conv}^{\prime\prime} = 0 \]

where:
- \( q_{lwX}^{\prime\prime} \) – net longwave radiant exchange flux between zone surfaces;
- \( q_{sw}^{\prime\prime} \) – net shortwave radiation flux to surface from lights;
- \( q_{lws}^{\prime\prime} \) – longwave radiation flux from equipment in zone;
- \( q_{ki}^{\prime\prime} \) – conduction flux through the wall;
- \( q_{sol}^{\prime\prime} \) – transmitted solar radiation flux absorbed at surface;
- \( q_{conv}^{\prime\prime} \) – convective heat flux to zone air.

Infiltration occurs through window openings [4]:

\[ \text{Infiltration} = (F_{Schedule}) \frac{A_L}{1000} \sqrt{C_s \Delta T + C_w (\text{WindSpeed})^2} \]

where:
- \( F_{Schedule} \) – a value from a user-defined schedule;
- \( A_L \) – the effective air leakage area in cm that corresponds to a 4 Pa pressure differential;
- \( C_s \) – the coefficient for stack-induced infiltration in \((\text{L/s})^2 / (\text{cm}^4 \cdot \text{K})\);
- \( \Delta T \) – the absolute temperature difference between zone air and outdoor air;
- \( C_w \) – the coefficient for wind-induced infiltration in \((\text{L/s})^2 / (\text{cm}^4 \cdot (\text{m/s})^2))\);
- \( \text{WindSpeed} \) – the local wind speed.

In the simulated object, the audience and laboratory are equipped with a ventilation system with an air heating heat exchanger (Fig.1). To analyze the operation of the heat recovery system and obtain useful heat energy, a heat exchanger was built into the model, which cool down the exhaust air to 5 °C. The simulated system works according to the following principle. Air is taken from the street, the air parameters are prerecorded in the weather file, passing the supply fan, the street air enters the heat exchanger, where it heats up and enters the premises using a network of air ducts and air distributors. Air from the audience and laboratory is taken by an exhaust ventilation system and passed through heat recovery heat exchangers. The exhaust air then passes through the fan and discharged outside. In the developed model, the ventilation system operates around the clock without interruption, which allows you to analyze the effect of constantly changing loads in the room.
The power of the heat exchanger for heat recovery is calculated according to the following formulas:

\[ Q_{\text{total}} = (m_{\text{supply}})(h_{\text{outlet}} - h_{\text{inlet}}) \]
\[ Q_{\text{sensible}} = (m_{\text{supply}})(h_{\text{outlet}} - h_{\text{inlet}})HR_{\text{min}} \]
\[ Q_{\text{latent}} = Q_{\text{total}} - Q_{\text{sensible}} \]

where:
- \( Q_{\text{total}} \) — total energy transfer rate by the system;
- \( Q_{\text{sensible}} \) — sensible energy transfer rate by the system;
- \( Q_{\text{latent}} \) — latent energy transfer rate by the system;
- \( h_{\text{inlet}} \) — enthalpy of the air entering the unit at its inlet node;
- \( h_{\text{outlet}} \) — enthalpy of the air leaving the unit at its outlet node;
- \( HR_{\text{min}} \) — minimum of the inlet air and outlet air humidity ratio.

In order to trace the relationship between the internal loads of the room and the heat exchangers in the exhaust ventilation system, continuous operation of the ventilation system was established. Thus, when calculating the heat exchange in the room, only people, lighting fixtures, electrical equipment, infiltration and heat exchange through influenced external enclosing structures.

Different schedules for attendance and electrical equipment have been established for the two rooms. Also, the difference lies in the number of people and their heat release depending on the type of activity.

3. Results
The results of modeling the life cycle of premises for one year showed the dependence of the heat recovery process on the humidity in the room.

From the graph for one day, you can see that the relative humidity increased from 10% to 13% (Fig. 3), since 12 people entered the room, the result was an increase in power from 4,000 to 4,500 watts. From which we can conclude that an increase in relative humidity by 3% leads to an increase in the heat exchanger capacity by 12.5%.
The graph in Fig. 2 shows all instantaneous parameters for a year, without duplication, that is, you can see which parameters appear most often. From the presented graph it was established that for the whole year in the classroom the relative humidity most often ranged from 10 to 40%. Accordingly, in this regard, there was the possibility of heat recovery, the power of which ranged from 3,500 to 5,000
watts. If such a recuperation system is installed in a room where will be more than 12 people, as well as where the relative humidity is normalized, then the heat recovery power values will be much higher.

Let's consider the operation of the system in one month (Fig.4). We choose February as the month under consideration, because this is one of the coldest months of the year, and in order to study the heat recovery process for further heating the room, we need the winter period of the year, and we also need to take into account the reduced outside air temperatures and consider it as with such parameters the recuperation system will work. In the graph in Fig.4, you can see that at point 1, the outdoor temperature decreases from -10 to -25 °C, then at point 2 the relative humidity in the room decreases from 14 to 5%, and at point 3 the power of the heat recovery heat exchanger drops from 5,000 to 2,900 watts, the whole process took about 12 hours. Thus, a decrease in the outdoor temperature by 60% leads to dehumidification of the air in the room by 9%, which in turn reduces the exhaust capacity of the device by 42%.

Due to the fact that the air is highly dehumidified, it is necessary to install a humidifier, which will compensate for the percentage of dehumidification of the air in the room when warm air is supplied, since according to National State Standard 30494-2011 "Parameters of the microclimate in the premises", the optimal relative humidity in the room should be in the range from 30 to 45% in the cold

![Graphs of heat recovery power versus relative humidity and internal loads in the room.](image-url)
season, and from 30 to 60% in the warm season. Thanks to energy modeling, it is possible to estimate the operating cost of such equipment, the time of its use and the required power.

The program for energy modeling allows us to evaluate energy-saving measures and estimate energy costs both for an annual cycle and for a month, a day. As a result (Fig.5), the amount of recovered heat for the whole year reaches 80,546 kWh, and, for example, in January, 5,637 kWh of heat is generated from two premises. In summer, the recovered heat can be used to heat the supply water in the hot water supply system. An example of the use of recovered heat in the hot water supply system can be found in the article "Possibility of Heat Pump Use in Hot Water Supply Systems" [8].

![Figure 5. Total values of heat recovery power by month.](image)

4. Conclusions
The results of modeling the use of premises for the year revealed a significant potential in the use of heat from the exhaust air, as well as broad and far-sighted prospects for using the EnergyPlus / OpenStudio program for energy modeling. Thanks to such a tool, it will be possible to analyze an entire building or a separate building, a new room.

Research has shown that an increase in relative humidity of 3% leads to an increase in heat exchanger capacity by 12.5%.

Considering the 12-hour relationship between outdoor temperature, indoor relative humidity and heat recovery heat exchanger capacity, a 60% decrease in the first value leads to a 9% decrease in the second value, and a 42% decrease in the third value.

It is necessary to install an air humidifier to maintain optimal indoor climate parameters.

Wherever possible, infiltration should be avoided as it leads to unwanted heat losses to the environment and reduces both the ability to recover heat energy and the reduction in CO$_2$ emissions.

Based on the data obtained in the study, we can conclude that it is rational to install heat recovery systems in rooms where are many people, or in rooms with high traffic. Increased efficiency can be achieved if people are engaged in physical activity, for example, in a gym, that is, heat recovery from the human body increases. Pools are also a target for the installation of such systems, since calculations have shown that the higher the relative humidity in the room, the higher the recuperation power at the exhaust will be.

The heat recovery process in engineering systems depends on many factors. The change in the heat recovery capacity per year is from 1 to 40%. To use the recovered heat in practice, to select the optimal operating mode of the building's energy systems, it is necessary to conduct a thorough analysis of the operation of all engineering systems of the building. This is impossible without modern methods and tools for energy modeling, which are equipped with the OpenStudio program.
The data and tools in the presented study will be used in further work on a project to create an energy hub, in which a heat pump will be installed to convert the heat taken from the exhaust air and further transfer it to consumers such as hot water supply, heating system, etc.

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