Project of HVAC systems for the meteorological station




DAGMARA ĆWIEK
Warsaw University of Technology Student,
dagmaracwiek@gmail.com

TOMASZ KOLSICKI
Warsaw University of Technology Student

KAROLINA KOWAL
Warsaw University of Technology Student

BARTŁOMIEJ TOKARZEWSKI
Warsaw University of Technology Student

This project presents the three proposed design concepts of heating, ventilation and air conditioning systems for a new single-story government meteorological and housing building in the Diego Ramirez Islands (Islas Diego Ramirez) in Chile. It was created to participate in the 2017 Student Design Competition organized by American Society of Heating, Refrigerating and Air Conditioning Engineers. All design concepts were made in accordance with ASHRAE Standards, especially 90.1, 62.1, 55.1. The final aim of a thesis is to show the selection process of the best design option, based on a multi-criteria analysis, including Life Cycle Cost Analysis with a 50 years long Life Cycle. Considered design concepts shall address the following major design goals: low Life Cycle Cost, low environmental impact, comfort and health, creative high performance green design, synergy with architecture. The scope of study included creating the design of heating (including both room heating and preparing Domestic Hot Water), ventilation and air-conditioning systems for a given building.

Keywords: ASHRAE, heating, cooling, air-conditioning, mechanical ventilation, thermal comfort, concept design, BIM modelling, hourly analysis, life cycle cost analysis (LCCA)

The team from the Warsaw University of Technology has been awarded with the first-place prize at the 2017 Student Design Competition in the HVAC System Selection category. The competition is annually organized by the American Society of Heating Refrigeration and Air-Conditioning Engineers. It was the first time in history that a team from Poland participated in this competition. The team consisted of 4 students: Dagmara Ćwiek, Karolina Kowal, Tomasz Kolsicki and Bartłomiej Tokarzewski. The prize was handed out during the ASHRAE Winter Conference held in January 2018 in Chicago.

The students' task was to design the heating, ventilation and air-conditioning system for the meteorological station building in the Diego Ramirez Islands (Islas Diego Ramirez) in Chile, South America. The team was supposed to consider three different options and choose the optimal one, basing on a multi-criteria analysis, including factors like Low Life Cycle Cost (building's considered life cycle equalled 50 years), Low Environmental Impact, Comfort and Health, Creative High Performance Green Design, Synergy with architecture. The project was realized in compliance with American standards, especially 90.1, 62.1 and 55.1. The scope of study did not include designing water supply or sewage systems, it was also forbidden by the competition rules to interfere with the given attributes of the building envelope.

The building in the scope of study was a new, single-story, government meteorological and housing building. It included dwelling units for 8-people crew, office and a large car service hall along with a small garage, even though, in reality, Diego Ramirez Islands are inhabited and there is no infrastructure available there, all teams were supposed to assume that there are water and sewer district systems, natural gas and electricity grid available.

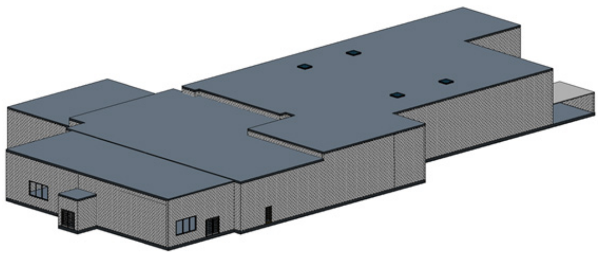

Figure 1. Meteorological Station Building 3D Model.

The climate of Islands is mild, with low DBT amplitude throughout the year. There is no clear boundary between summer and winter. Wind direction is focused and its speed is high enough to consider usage of wind generated energy. Due to geographical location and significant cloud cover, the values of solar radiation are relatively low, which suggests that using solar energy may transpire to be unprofitable.

Computer modelling

The team has created a parametric model of the building, in compliance with Building Information Modelling philosophy. The model contained information about the considered envelope, which was used for calculations and running detailed energy analyses. Students used *Integrated Environmental Solutions Virtual Environment (IES VE)* software for this purpose. It allowed them to create a dynamic, hourly analysis of all systems' behaviour during all year. Some calculations, were also handled manually in Microsoft Excel.

Baseline System

A baseline system was considered to compare all the other options to a basic and typically used one. This approach requires the designer to analyse all systems with the same design conditions. The baseline system was chosen in accordance with ASHRAE 90.1 Standard, considering the climate zone type and size of the building. The chosen system included Packaged Rooftop Air-Conditioner with fossil-fuel furnace. It covers building heat demand with a central hot-air heating system in a direct-fired technology. A Constant Air Volume system delivers warm air to all zones throughout the building. The system depends on a furnace, powered by natural gas. Domestic Hot Water is produced by Gas Storage Water Heater.

Option 1 – Brine-to-water Heat pump with sea water loop

Building is located on the Island surrounded by the Pacific Ocean. This fact created the possibility of using seawater as a source of energy for the heat pump. Main source of heat for this system is created by brine-to-water heat pump with sea water loop. An additional source of heat for the system is created by the server room. Heat recovery from the servers operating in the building has been applied.

Heat pumps pull heat out from the sea to heat the building, but to do so, heat pumps main component compressors need to be powered by the electricity. Electricity for the HVAC unit is supplied by the green energy coming from wind turbines and photovoltaic panels, but during the times when energy is not generated on site or energy demand is high, electricity is supplied from the grid.

The weather conditions on the island make it possible to effectively use wind turbines. The energy generated by the turbines supply the heat pump system that heats the building, as well as the electrical equipment in the building. This allows even greater reduction of primary energy consumption, which reduces the environmental impact and lowers the operating costs of the system.

Since the amount of renewable electricity produced is not constant and unrelated to the current demand of the building, energy accumulation was applied. When the amount of the produced energy exceeds the building's demand, it is possible to accumulate surplus energy, to use it later, for example during peak demand. This technology also creates the opportunity to use power from the grid only during periods of lower electricity prices, storage in the battery and consumption when the building's demand proves to be high.

Energy from renewable sources accounts for about 60% of the total energy demand of the building. As a result, the consumption of primary energy, produced using fossil fuels significantly decreases. It also allows reduction of greenhouse gas emissions, especially CO_2. However, a serious disadvantage of this solution is the large amount of refrigerant is used in the heat pump circuit.

Option 2 – Gas Heat Pump & Condensing Boiler

The system is based on a hybrid heat source – a gas-powered air-to-water heat pump combined with a condensing boiler. Heat source is equipped with advanced controls that automatically select the current most efficient way of operation. During warm days (outside temperature higher than 4°C a heat pump

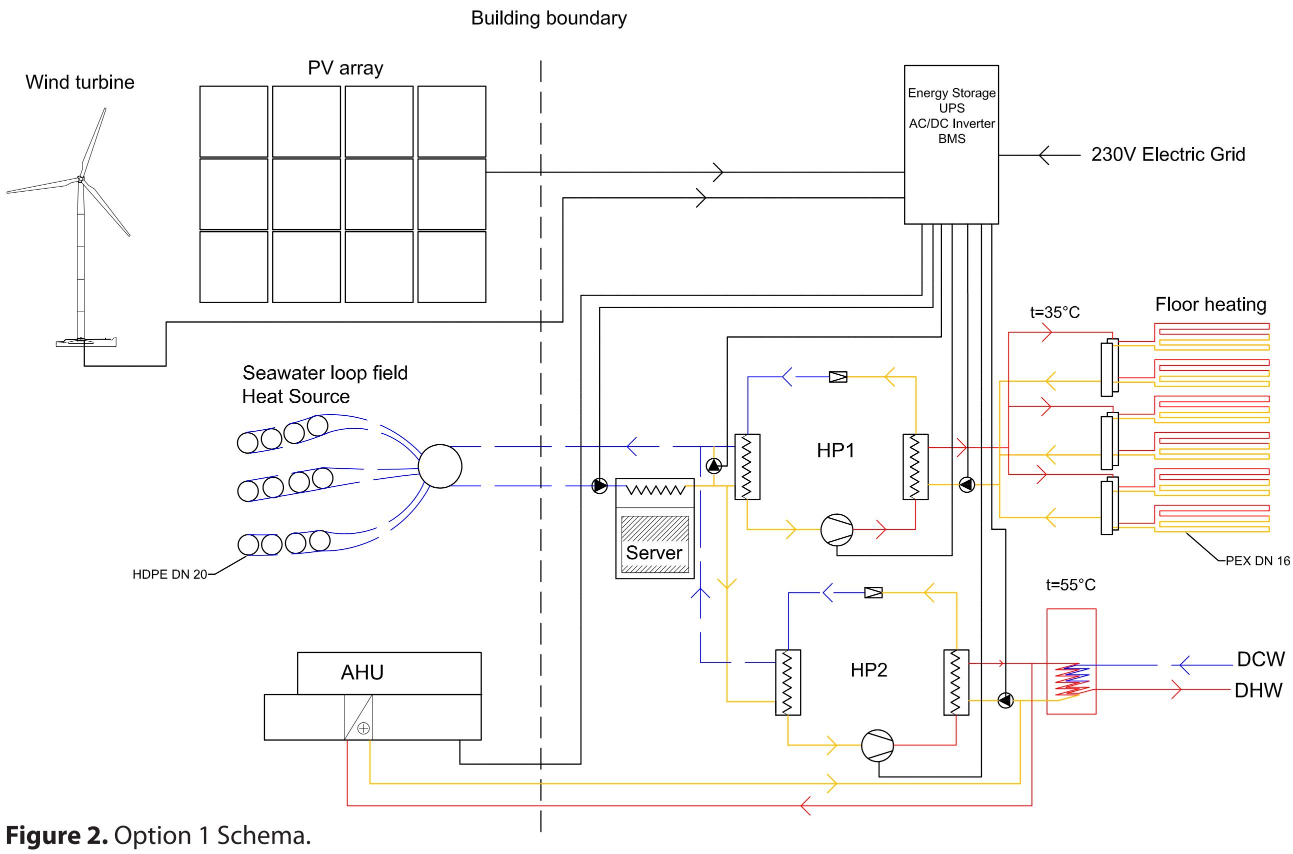

Figure 2. Option 1 Schema.

works efficiently, and its COP factor is high, so it works in a "heat pump only mode". As observed in considered weather data, in Diego Ramirez conditions it happens on 65% of year. When outside temperature falls (between −7 and +4°C), it automatically switches to a hybrid mode – a gas condensing boiler turns on and cooperates with a heat pump – it performs a supportive role. Device has also a third operation option – although, in given conditions it has a minor meaning. If temperature falls below minus 7°C it switches to a "boiler only mode" and this happens only for 11 hours a year what makes it almost unnoticeable. However, this system is flexible and could work efficiently even in lower temperatures, which is an advantage.

Gas boiler used in a hybrid device is a condensing one. It means that it recovers latent heat from exhaust fumes, rather than letting it directly to atmosphere, like in a conventional boiler. It allows this device to achieve efficiency as high as 97%.

The Heat Pump component of system contains R-410a refrigerant. It's widely used thanks to not being an ozone-depleting substance. However, it has a high Global Warming Potential. A disadvantage of this system is that it relies on a non-renewable energy source. GHP&CB system (option2 system) also involves using a refrigerant which is not fully environment neutral.

Additionally, thanks to combining two different appliances (a heat pump and a boiler) a total life expectancy of a hybrid device can get even doubled due to periodic heat source switching. Another advantage is that such systems are well known and easy to install, so it minimizes the risk of maintenance issues. It is important to notice that servicing and replacement of appliances is difficult on an isolated island.

Option 3 – Wind Energy Radiant Heating

In that option water systems were replaced by electrical heating. Wind turbines and photovoltaic panels supplied building with an electrical energy utilized to heat the building, domestic water and supply air. In case of peak demands, these renewable energy sources provide electrical energy simultaneously with grid.

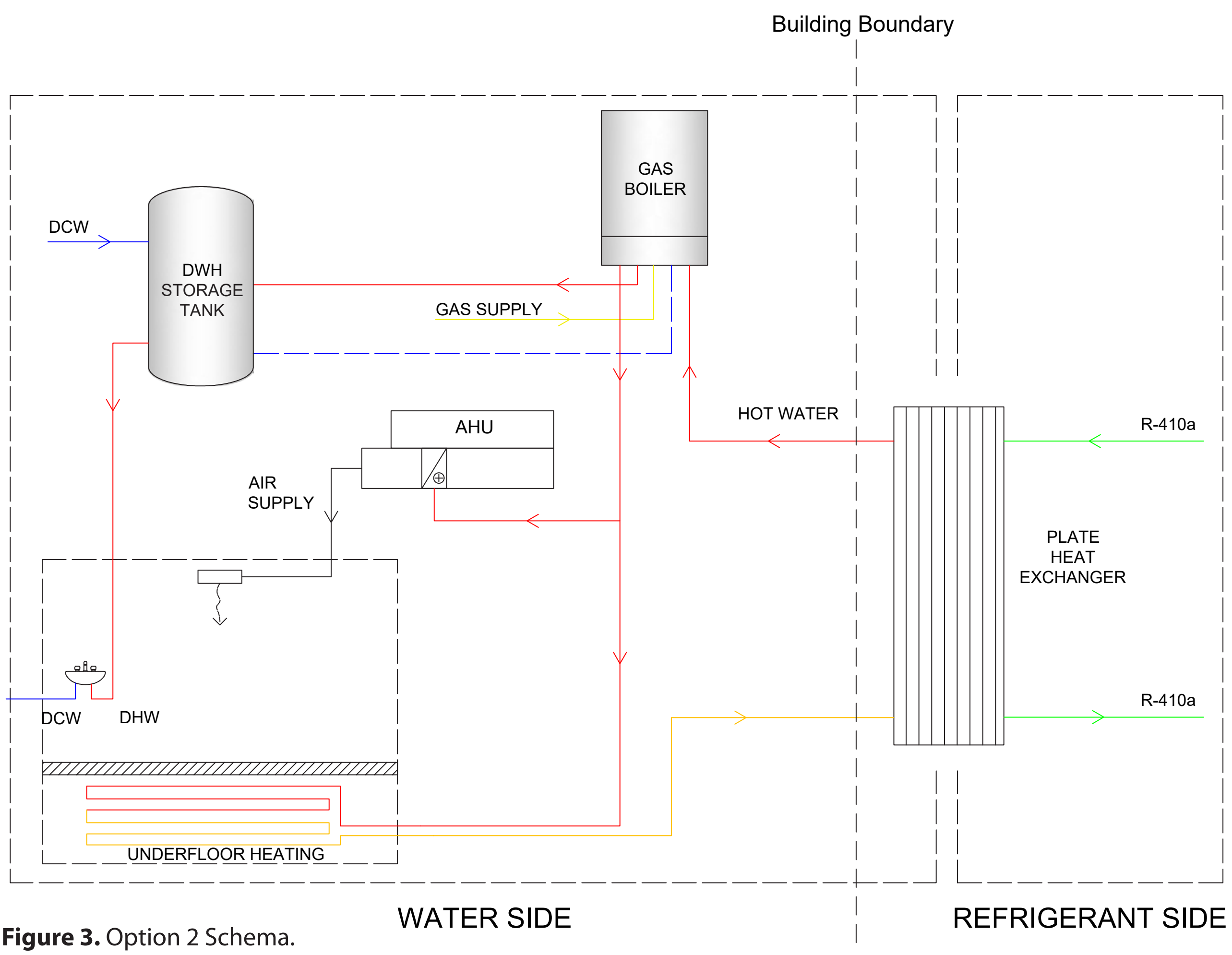

Figure 3. Option 2 Schema.

Nevertheless, it is a cost-effective solution. Moreover, excess energy can be sold to the grid, which compensate all expenses intertwined to on-peak periods.

Heat is distributed to spaces by electrical system. Electrical energy is transferred to heat energy by infrared panel heaters. To be precise, due to temperature difference these devices are radiating infrared heat through the air.

The disadvantages of this solution are high Initial Cost and noise generated by the turbines. It is important to carefully locate turbines on a site, preserving a proper distance from the building to minimize acoustic discomfort. The large size of turbines is also a significant factor, it makes them tamper with the natural landscape. On the contrary, the main advantage of the Wind Energy system is a big share of renewable energy – it leads to lowering CO_2 emissions and the Operational Cost.

Data Center

Another important part of the project was designing a system serving a small Data Center located in the building. Trying to find a solution that would be eco-friendlier and energy-efficient than conventional ones, the team decided to apply a two-phase immersion cooling, instead of widely used traditional air-conditioning systems. Servers are placed in semi-open containers containing directly a special fluid with a low boiling point. They are submerged in the fluid, so when they get warm while operating, the fluid starts to boil and cools down the electronic equipment. The fluid turns to vapour and due to buoyancy, it raises to the top of container and meets the condenser surface, where it turns to fluid again and passively recirculates to the bottom. The cycle is repeatable and doesn't require any external energy usage to keep the fluid circulating. This process happens under atmospheric pressure. Immersion cooling works with HFE fluids – they do not conduct electricity and have low Global Warming Potential, so it makes them environmental-friendly. This solution doesn't require preserving any specific conditions in the server room volume, just like in traditional systems. It doesn't occupy large volume of space, so it allows to locate server units in a more efficient, denser way. Immersion cooling allows achieving a significant energy efficiency – PUE can get as low as barely 1,02.

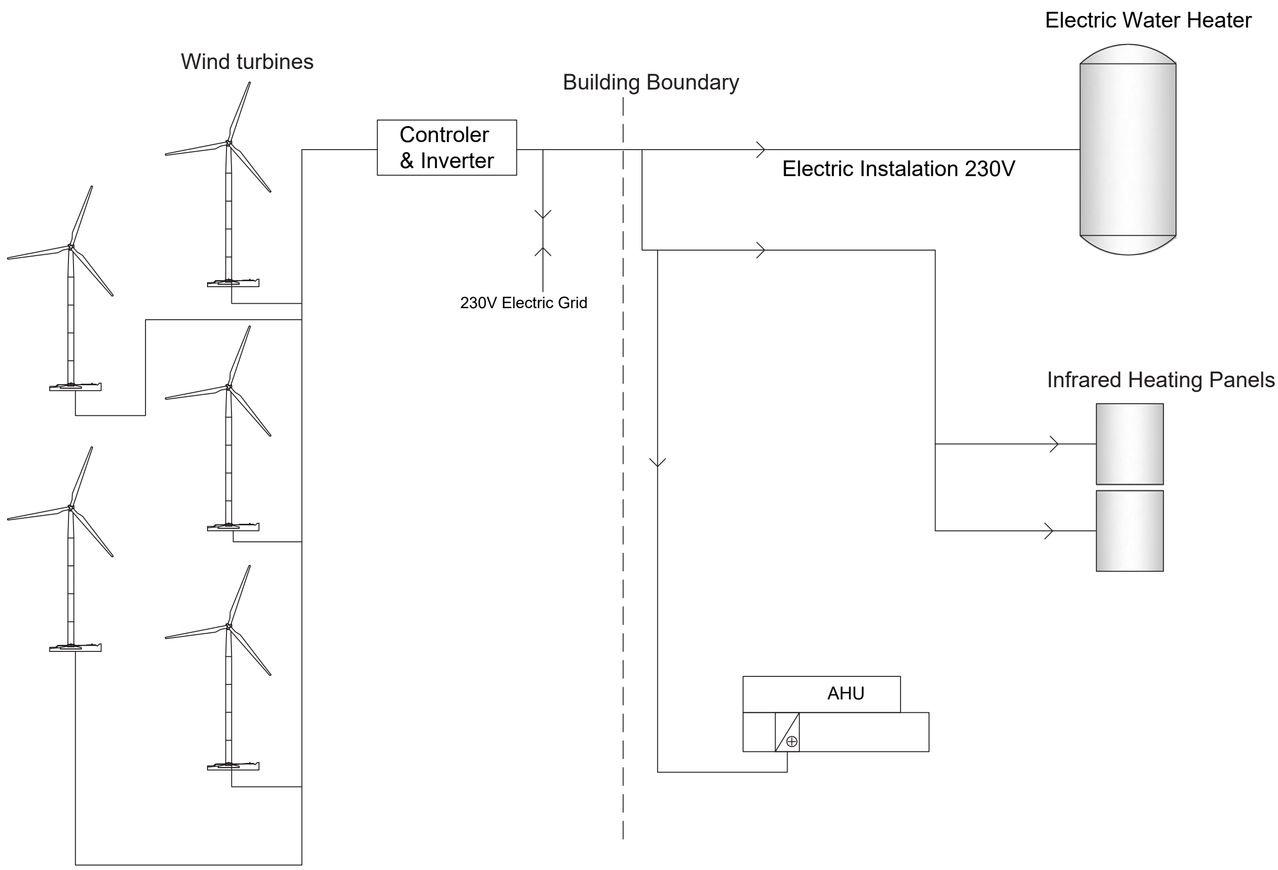

Figure 4. Option 3 Schema.

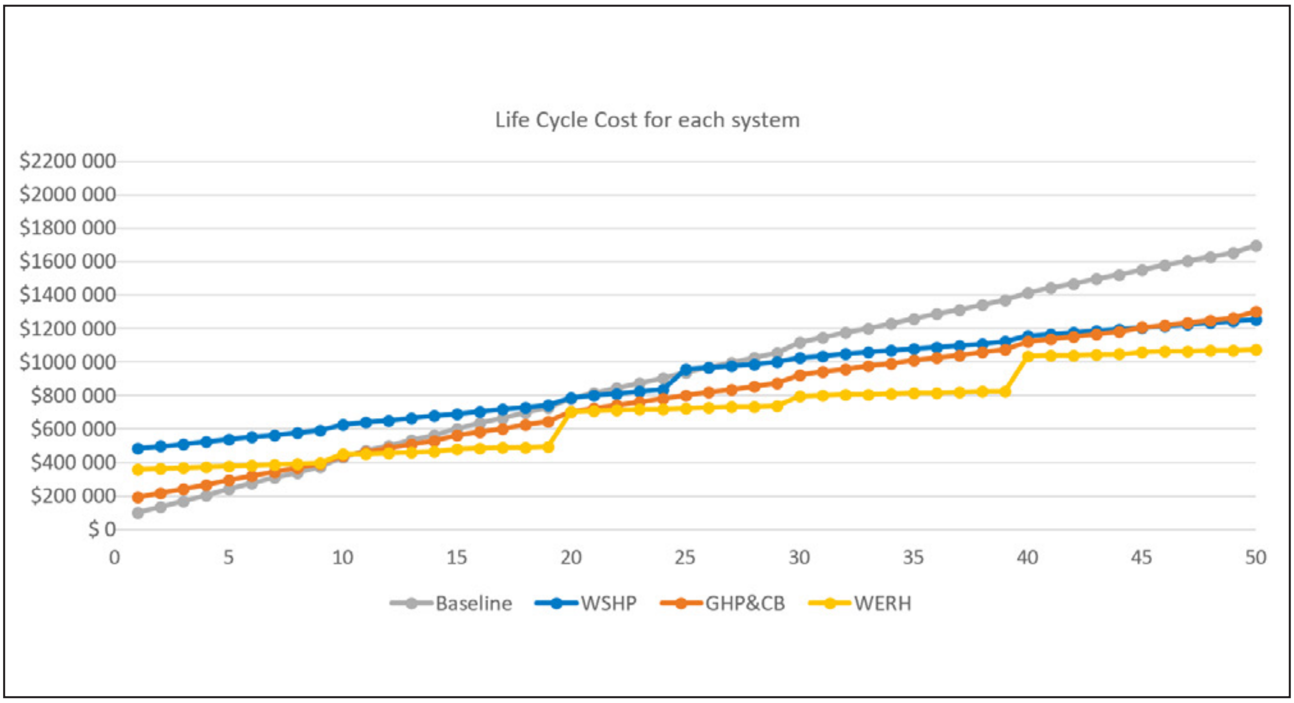

Figure 5. Lifecycle Costs.

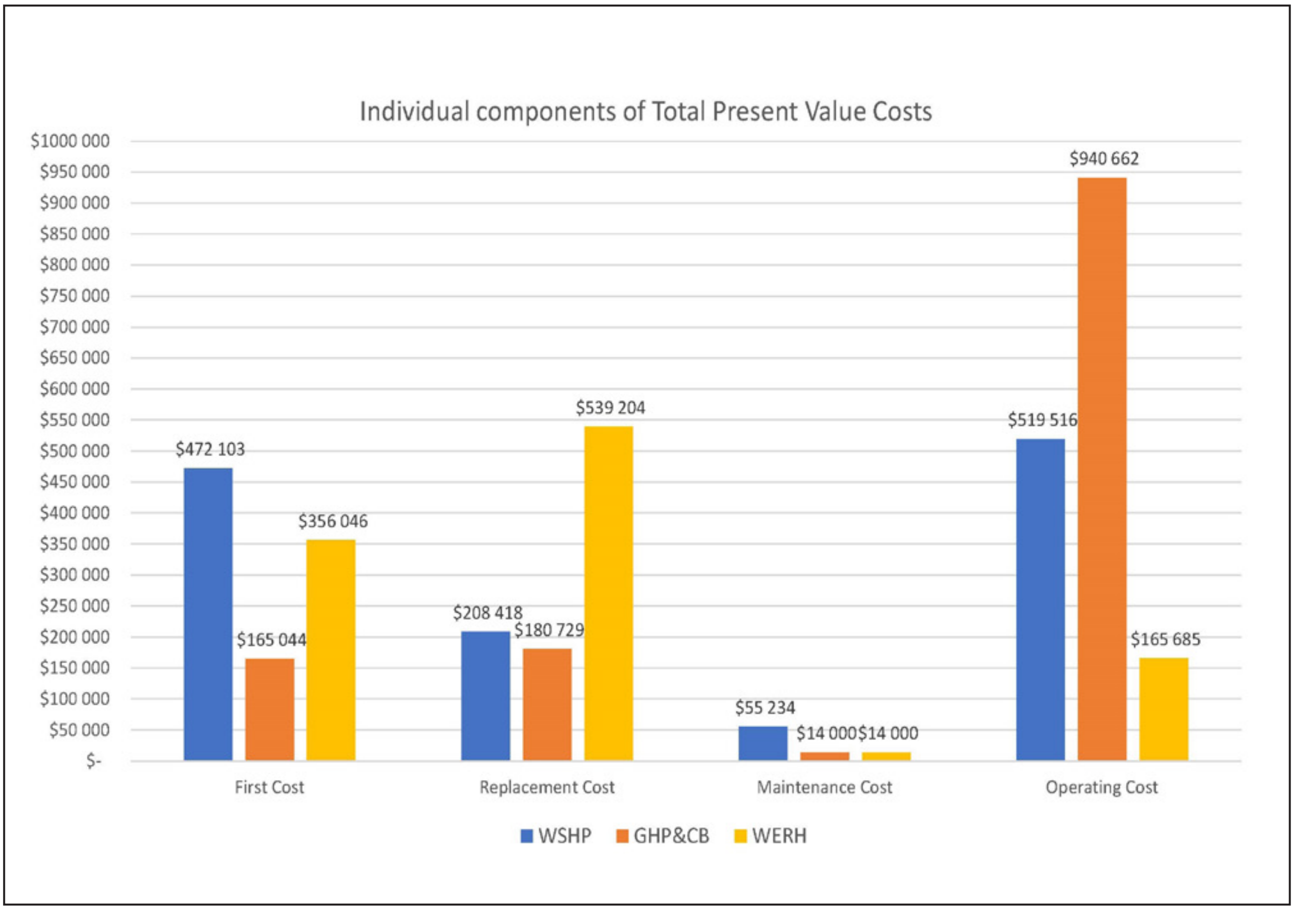

Figure 6. Components of Present Value Costs.

Choosing the best option

To choose the suitable system for considered meteorological station, the team has analysed a 50 year long building lifecycle. The costs of operating all of 3 concept systems were compared with the cost of the baseline option, including both initial and maintenance & operating costs. It was observed that WSHP system (Option 1) had the highest Initial Cost, while GHP&CB's (Option 2) was the lowest. WERH system (Option 3) has the highest Replacement Cost, because of using expensive wind turbines, that need to be replaced. The most evident difference between systems is observable in Operating Costs, where GHP&CB transpires to be the most expensive of all, due to usage of non-renewable, expensive energy source. At last, WERH system was estimated to have the lowest life cycle cost in general. The other systems are more expensive, and their costs have similar values, comparing one to another. The most expensive of all considered options was obviously the baseline system.

Moreover, all of systems were judged in accordance with the LEED v4 rating system. Only credits applicable to HVAC design, that matched the scope of study were taken into consideration.

All these factors, along with the quality of fulfilling major design goals, were taken into consideration when choosing the optimal solution. A multi-criteria matrix of evaluation was created to determine the best system.

The optimal solution – Wind Energy

Finally, it was concluded that the Wind Energy Radiant Heating is the optimal option. It gained the biggest number of points in multi-criteria analysis matrix created by the team and by the LEED Rating System. This system showed a 37% overall cost improvement over the Baseline, which is the best result of all considered alternatives. This system fulfils all design goals specified by the team. It has the lowest Life Cycle Cost from all considered options. Comfort of Indoor Environment is maintained. System fully meets sustainability requirements – is energy efficient, low-carbon and environmental-friendly. It relies on renewable energy sources – wind and solar power – they are main source of energy for the building, making it almost emission free. The only non-renewable resource consumed in this design is electricity from the power grid, used at the moments of high building power demand. However, it is used in an acceptable amount, in an efficient way, thanks to load shifting and energy accumulation strategy.

Conclusions

Thanks to incorporating modern technologies, following the rules of energy conservation and sustainable usage of natural resources, it was achievable to fulfil all the design goals. It is also crucial to take into consideration the whole lifecycle of the object, since the Initial Cost does not decide about the outcome of the analysis. It is also important to use System Benchmarking analysis, rather than focusing on a single solution, because as proven in this report, differences between systems are significant enough to be considered in a design process. One of the most important aspects of the design process was using BIM technology – it allowed the team to gather, analyse and manage all data about the designed building in an efficient way.

At the end, it is critical to continue an approach presented in the project during the following building life cycle phases – including construction and exploitation. Proper commissioning process must be ensured. Only such approach allows full usage of the proposed design potential. ■

Literature

ANSI/ASHRAE/IES Standard 90.1-2016 – Energy Standard for Buildings Except Low-Rise Residential Buildings

ANSI/ASHRAE Standard 55-2013 – Thermal Environmental Conditions for Human Occupancy

ANSI/ASHRAE Standard 62.1-2016 – Ventilation for Acceptable Indoor Air Quality

ASHRAE Standard 15-2013 – Safety Standard for Refrigeration Systems

ASHRAE Standard 34-2013 – Designation and Safety Classification of Refrigerants

ANSI/ASHRAE/USGBC/IES Standard 189.1-2014 – Standard for the Design of high-Performance Green Buildings

ASHRAE Green Guide – The Design, Construction, and Operation of Sustainable Buildings, 2nd edition

ASHRAE Advanced Energy Design Guide for Small to Medium Office Buildings

CEN – EN 15459-2007 – Energy Performance of Buildings – Economic Evaluation Procedure for Energy Systems in Buildings

2016 ASHRAE Handbook – HVAC Systems and Equipment

2015 ASHRAE Handbook – HVAC Applications

2014 ASHRAE Handbook – Refrigeration

2013 ASHRAE Handbook – Fundamentals

LEED v4 for Building Design and Construction