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ENERGY EFFICIENCY OPTIMIZATION OF ACTIVELY USED AND UNDERUSED BUILDINGS BASED ON DEMAND-CONTROLLED VENTILATION ACCORDING TO INDOOR CLIMATE

According to the preliminary research, many underused buildings are using as much energy as actively used buildings, or else the buildings have ventilation turned off to save energy, which is harmful to the building and its users. In addition, there are actively used buildings with unsuitable ventilation for their usage. Research is needed to optimize energy usage and to prevent health problems caused by poor indoor air quality. Optimizing energy usage also lowers CO_2 -emissions, which should be reduced to 20% of 1990 emissions by 2050, according to the European Union's energy and climate strategy.

The goal of this project was to optimize the energy efficiency of underused buildings and the ventilation of actively used buildings. New information and recommendations were formulated during the project for companies and the municipality sector. Sustainable development was the main theme of the project. In addition, equality has been taken into account by providing equal indoor climate for users.

The theoretical portion covers the principles of ventilation and heating. The practical part includes different measurements. The real temperature and electric consumption of the ventilation units are discovered. The interior study includes carbon dioxide concentration, temperature, and moisture content.

The results of the project are the improved energy efficiency of ventilation on demand-controlled ways, and the increased knowledge of optimizing energy usage in the examined buildings. New recommendations have been made for controlling ventilation to reduce carbon dioxide emissions. The results will create guidelines for optimal energy usage, which can be utilized nationally by companies and municipalities to promote energy savings and health.

Introduction

Improving energy efficiency will support the EU´ s climate and energy policy goals of saving natural resources, reducing greenhouse gas emissions, and at the same time mitigating climate change (Ympäristöministeriö 2018). The European Parliament and the Council adopted directives to improve the energy performance of buildings; low-emission heating systems, enhanced heat recovery and environmentally sound renewable energy sources are thus key energy efficiency improvement measures (Directive (EU) 30.5. 2018/844). Finland is one of the world leaders in many energy- saving measures and energy efficiency. Building regulations that guide construction are used in Finland for sustainable and good construction (Suomen rakentamismääräyskokoelma D1, D2, D5). A good building is based on good indoor air. Studies show that an energy efficient building has better indoor air than a conventional building (Kephalopoulos et al. 2017).

The Energy Efficiency Directive (EED) obliges EU Member States to draw up a National Energy Efficiency Action Plan every three years. Finland's fourth National Energy Efficiency Action Plan (NEEAP-4) was submitted to the European Commission in April 2017 (Motiva 2019a).

In Finland, companies and communities are subject to energy efficiency controls in connection with energy audits and voluntary energy performance agreements. Practical work to promote saving energy and the use of renewable energy sources is carried out by Motiva Oy, a Finnish state-owned company. Motiva will establish cooperative structures, for example, by training authorized energy auditors and supporting operators to join voluntary energy efficiency agreements, in addition to Motiva communicating and monitoring the impact of energy efficiency agreements (Motiva 2019a).

Energy audits under the Motiva model are mandatory for large companies every four years. To be defined as a large enterprise, at least two of the following conditions must be met: a staff of 250, a turnover of € 40 million, a balance sheet total of € 20 million (Taloushallintoliitto 2018). The voluntary energy efficiency agreements in use in Finland aim to improve energy efficiency in industry, energy and services, real estate, municipalities and properties currently heated by oil. Under certain conditions, the Finnish State or the Ministry of Employment and the Economy will support the implementation of an energy review under the Motiva model or investments promoting energy efficiency by a party to the Energy Efficiency Agreement (Energy Efficiency Agreement. 2018).

In Finland, 25% of the energy used to heat buildings (Tilastokeskus 2018). According to earlier studies, the thermal energy consumption of ventilation typically accounts for 60% of the thermal energy consumption of buildings. Therefore, it is wise to optimize the heating and ventilation of the building in relation to its purpose. The South-Eastern Finland University of Applied Sciences has studied practical examples of this topic in the European Regional Development Fund, the ETKOT project funded by the Regional Council of Kymenlaakso, through the optimization of energy efficiency. This article will look at the items considered during the project and the preliminary results of the energy-
saving potential.

Improving energy efficiency (HVAC systems)

Improving the energy efficiency of heating, ventilation and air conditioning (HVAC) systems is based on changes in control methods and investments that have an impact on energy consumption. Energy consumption in HVAC systems consists of space heating, ventilation and domestic hot water production.

The energy consumption of heating consists of heat production, transfer and the efficiency of end use. For ventilation, energy consumption consists of the amount of fresh air flow, the difference in temperature of the supply air produced by the post-heating radiator and the operating time of the ventilation machine (Figure 1). For water, the energy consumption consists of the amount of hot water production. Based on this information, changes can be made to reduce energy consumption while achieving cost savings (Motiva s.a.).

Figure 1 shows the building´ s thermal energy balance. The energy streams entering the building (green arrows) are equal to the streams leaving the building (red streams). Blue arrows depict currents that do not come with energy, but they bind energy and cause losses. If there were no thermal losses in the building, the building would not need heating. However, there are always losses due to heat lost through structures, waste air, warm water and boiler flue gases.

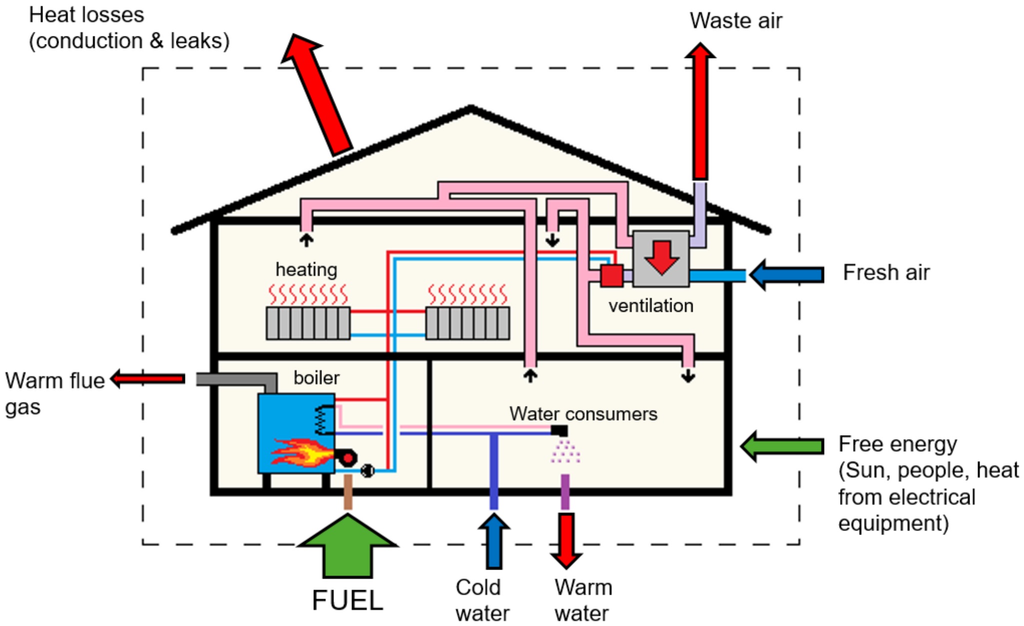

Figure 1. Building´s thermal energy balance.

The energy consumption from building heating is part of the end use efficiency of the heating, which can be influenced by the desired indoor temperature. In Finland, there are reference values for indoor temperatures by different building types (Rakennustietosäätiö. 2018).

The amount of energy required to heat a building varies with the outdoor temperature; the higher the outdoor temperature, the lower the energy requirement (Syke 2018). A decrease of 1 ° C in the indoor temperature reduces the heating costs by 5%, so it is profitable to keep the indoor temperature within the limits set by the indoor climate rating (Motiva 2019b).

The air quality in the room should be healthy, safe and comfortable for the user. The purpose of building ventilation is to bring clean air into the building and remove impurities through the exhaust air (Figure 2). The energy consumption of the ventilation unit consists of the amount of air flows, the difference in supply air temperature generated by the post-heater and the operating time of the ventilation unit. It must be possible to control and monitor the ventilation performance values and make changes to improve energy efficiency (Suomen rakentamismääräyskokoelma D2).

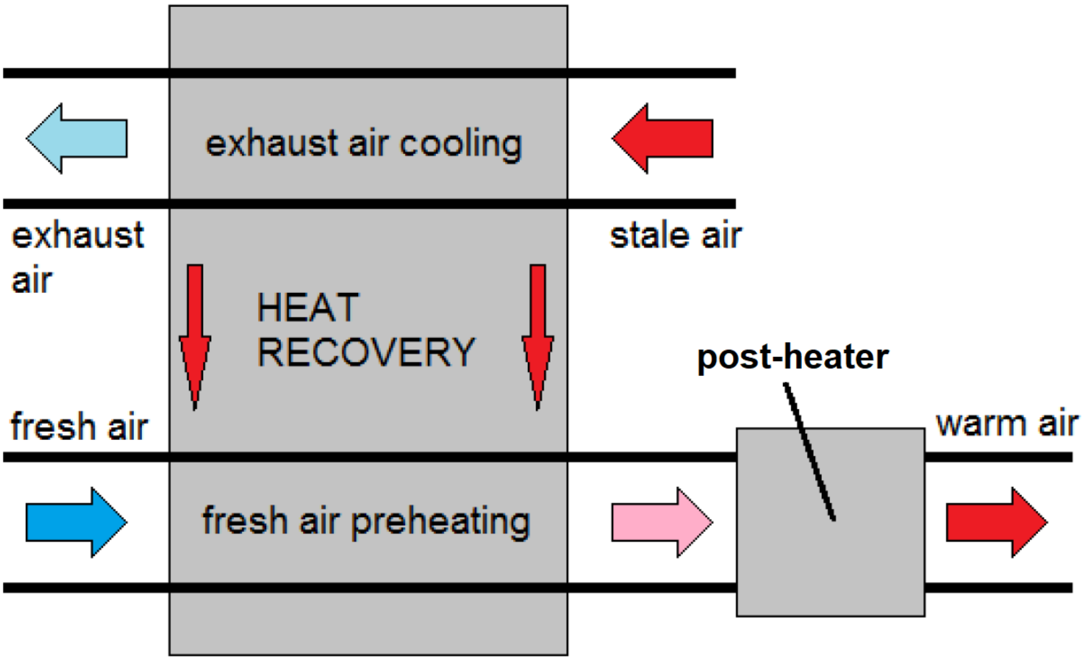

Figure 2. The principle of operation of ventilation equipment.

The volume flows of ventilation air are designed according to the required indoor climate. In addition in Finland the minimum volume flows are based on building regulations (Suomen rakentamismääräyskokoelma D2). Occasionally the air flow may be too high, wasting unnecessary amounts of thermal energy for heating the supply air and electrical energy for the air flows produced by the fans. Too much air flow has no effect on the indoor air quality compared to the air flow required in the room. In this situation energy consumption can be reduced by reducing air flow (Seppänen 1996, 228). Nowadays the air flow of ventilation machines can be controlled according to the carbon dioxide content of the indoor air. In this situation the ventilation flows are always optimized for energy efficiency and carbon dioxide content in indoor air (Suomen rakentamismääräyskokoelma D2).

The operation of the ventilation unit's heat recovery system affects the temperature of the air entering the post-heater. Energy consumption cannot be influenced if the heat recovery operates as planned. If the heat recovery does not work as planned, the temperature of the air entering the post-heater will be lower than normal and the post-heater will then have to produce a larger temperature difference than normal. If the ventilation unit does not have a heat recovery system at all, it is a good idea to consider having one (Seppänen 1996, 240-241, 285-286).

During the heating season, the temperature blown into the rooms corresponds to the temperature of the air leaving the post-heater. Often this temperature is set too high, which results in higher energy consumption for the post-heater. The supply air blown from the ventilation unit should be a few degrees cooler than the room air. The cooler supply air is heavier and mixes efficiently with the lighter and warmer air in the room. From the point of view of reducing energy consumption, the supply air temperature should be as low as possible and the heating of the room should be carried out with separate heating radiators (Figure 1) Seppänen 1996, 153-154, 164-165).

By monitoring the running times of the ventilation unit, it is possible to identify potential energy savings. From the point of view of energy use, the running times of the ventilation machines can be adjusted according to the use of the building. Outside the actively used areas of the building, the ventilation unit does not have to be switched on in the same way as during operation.
In some cases, the ventilation unit can be completely shut down, eliminating energy consumption. In this case, a periodic program is created, at which intervals the ventilation unit runs at rated power for one hour (Sisäilmayhdistys 2019).

Underused buildings

The purpose of a building may change during its life cycle. An under-utilized building is a building whose occupancy rate has been reduced or completely lost as a result of the changes. In Finland, there is a problem with underused buildings, and half of the municipalities in Finland have a vacancy rate of at least 20% (Huuhka 2016). In addition, there will be unoccupied non-residential buildings. Annual energy costs in an old school or town hall can be more than € 10,000 (Linkoranta 2018). The primary purpose of an underused building should be to find a new use, which is far from the original use; in this case, the energy use of the underused building should be adapted to the occupancy rate. The energy consumption of an underused building can be reduced by lowering the indoor temperature and changing the operating values of the ventilation units.

When lowering the indoor temperature, the relative humidity of the indoor space should be taken into account. Too- high relative humidity causes condensation of water on surfaces and structures, making moisture conditions favorable for mold growth (Sisäilmayhdistys 2018). In this case, the temperature of the air is below the dew point temperature (Seppänen 1996, 190-191). The indoor air humidity should be considered on a building-by-building basis to determine the relative humidity of a building at a given temperature. The characteristics of humid air are usually illustrated with the help of the Mollier chart, which shows the dew point temperature of the air (Lampinen 2010, 11-18). The diagram shows the temperature limit to which the indoor temperature of the building can be lowered so that too high a relative humidity is not exceeded (Seppänen 1996, 190-191). For example, in winter relative humidity is low and room temperature can be decreased to 10 ° C without indoor climate problems. Room temperature cannot be decreased this much in autumn because of a more humid ambient temperature.

The operating values of the ventilation units in an underused building can be changed according to volume flows and operating times. The minimum volumetric flow rate in an empty building is determined by the surface area recommended by the Finnish Indoor Air Association to be 0.15 dm^3 / (s m^2). The running times of the ventilation unit can be reduced when sufficient average ventilation in the building is taken into account (Sisäilmayhdistys 2019).

The use of energy according to need

In the Kymenlaakso Finland area, studies have been carried out on the necessary use of energy in buildings. There were two research topics, one on optimizing energy use of underused buildings and the other on optimizing the ventilation of actively used buildings based on CO_2 content. Three buildings were examined in each survey, totaling six in the Kymenlaakso region of Kotka and

Miehikkälä during the heating season 2018-2019. The reviews included practical measurements of the target buildings, which were used as the basis for calculating the energy-saving potential of the conversion measures.

The first research topic was optimization of energy use in underused buildings. Three different cases were considered for this study. The use of the first building was completely phased out, the second case was on seasonal use and the third one was partly unused while part of it was used daily. This publication takes a closer look at the school building, which has been completely out of use for a few years. The school building has two floors and is ventilated with three supply and extract air units. Practical measurements were made in the school building to determine the baseline and to calculate energy-saving measures. Measurements included determination of room temperature and humidity, ventilation flow, temperature, and electrical energy. Figure 4 shows the measurement results for the room temperatures of the second and first floors. The figure shows that the indoor temperatures between the floors vary but remain almost constant, as they should, over the measurement period. The average temperature in the second layer is 18 °C and in the first layer 20 ° C.

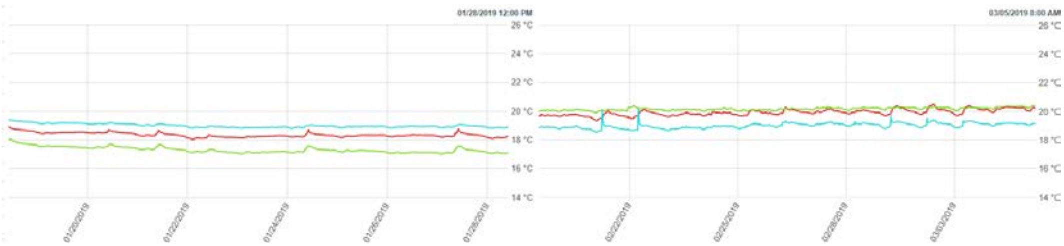

Figure 4. Room temperature measurements of the second and first floors of the school building under review. (Temperatures on y-axis, time on x-axis).

The relative humidity of the second and first floor rooms is presented in Figure 5. The relative humidity of the second floor reaches a peak of 25% during the measurement period and the first floor peaks around 30%.

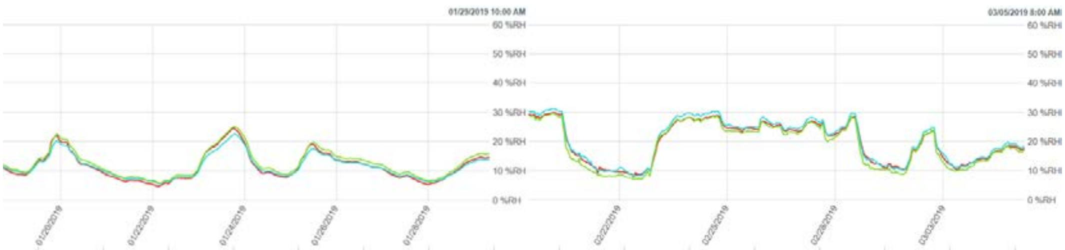

Figure 5. Relative humidity measurement results for the second and first floors. (Relative humidity on y-axis, time on x-axis).

Based on the field tests, the indoor temperature can be lowered so that the desired relative humidity level of the indoor air during the heating season reaches 30-40%. Relative humidity should not exceed 45% during the heating season. If this value is more than 45%, water may begin to condense on the cold structures of the outer casing of the house. Long-term high humidity increases the risk of microbial growth in structures, equipment and surfaces (Seppänen 1996, 24). According to the study the temperature of the first floor can be lowered to 15 °C during the heating season and the temperature of the second floor to 11 °C. Savings in ventilation air flow are minimal because the ventilation units are manually adjustable with three positions, 100%, 50% and off. Currently the machines run at 50% air flow rate. If temperatures are decreased, a total annual energy savings of approximately 140 MWh can be achieved in the building (with the indoor temperature and the lower energy consumption of the two post-heaters), which corresponds to an annual savings of € 8, 400 assuming a district heating price of € 61/MWh. The savings potential is about 140 MWh/a which is almost 30% of the total heat consumption of the building (Figure 6).

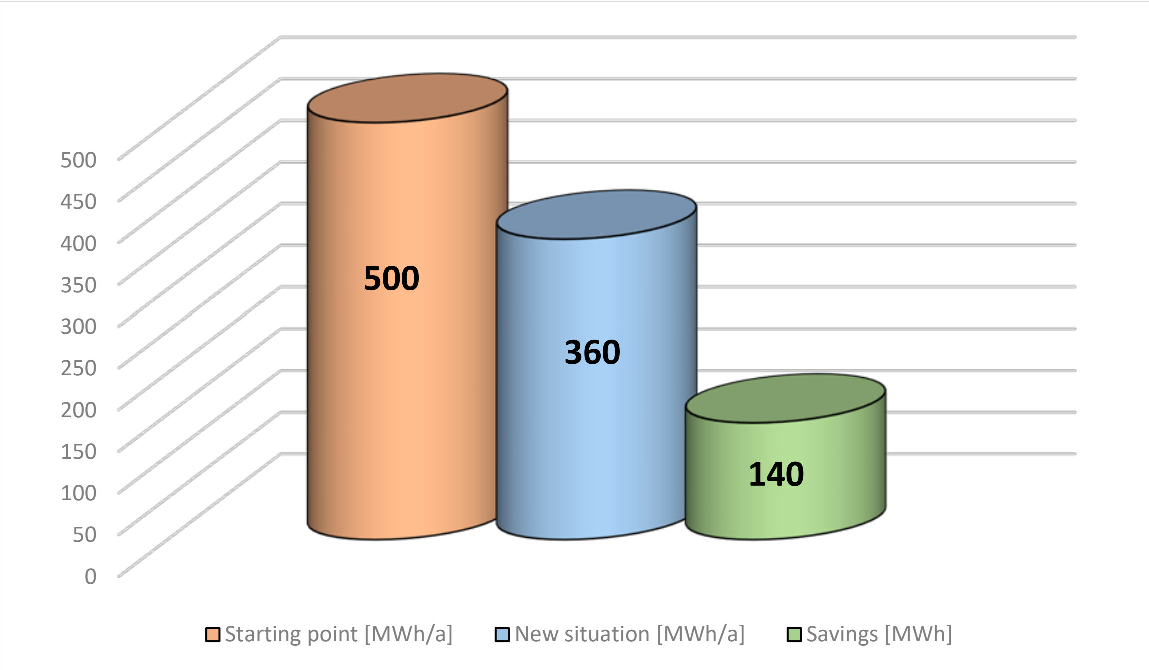

Figure 6. Savings potential of thermal energy in an underused school building.

The second aim of the study was controlling the ventilation according to the carbon dioxide content. Three different cases were considered for this study, one of which had a regular weekly use. The two cases examined were occupied daily but the number of occupants and the uses varied. This publication examines the results of one case in more detail. The Kotka school property is used daily during the school year, but the number of users and the purposes of use vary, especially in the school's gym. The school has supply and exhaust air ventilation, which is carried out with six ventilation machines. In addition, the school has one powered supply air fan and several smaller exhaust air fans. Currently, the use of ventilation machines is controlled by programmable timers. The service area of one ventilation unit is the school gym. As a practical measure, the school carried out a CO_2 measurement with measuring points on the walls of the gym and at different heights in the exhaust air duct of the ventilation unit that controls the gym. In addition, electricity consumption and temperatures and volume flows of ventilation inlet and outlet machines were examined. School gym use and exercise modes vary, so carbon dioxide- based ventilation would be suitable for gym use. Figure 7 shows the results of a short-interval measurements from the gym´s wall and exhaust air duct.

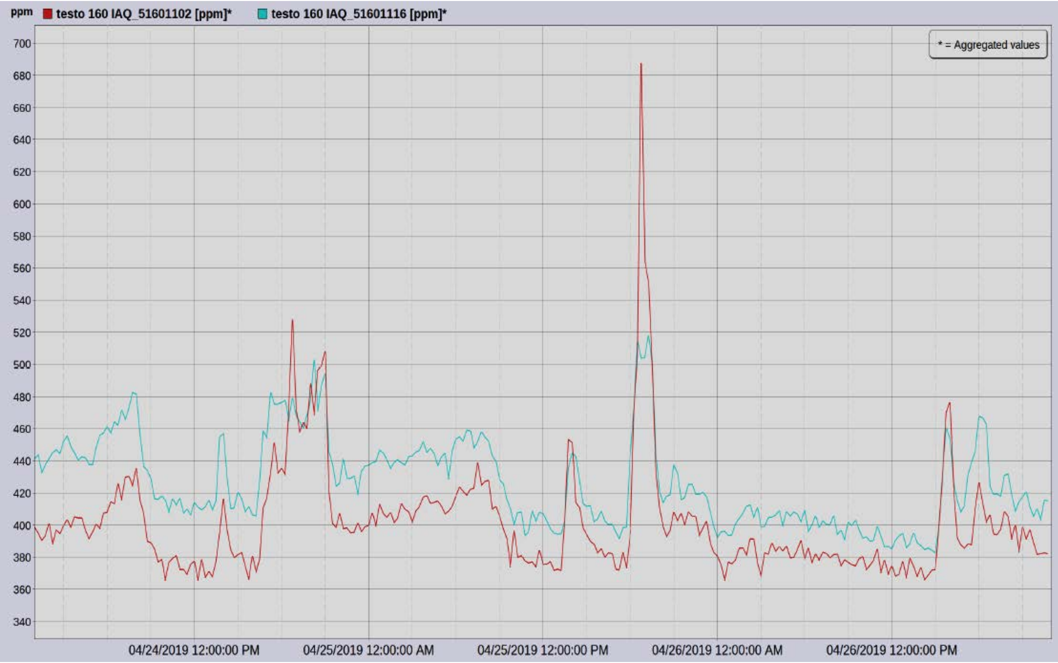

Figure 7. Carbon dioxide content of the gym between Wednesday 24 April 2019. 00.00 - Friday 26.4.2019 00.00.

On the basis of the analysis, the carbon dioxide-based control offers an annual savings of 70 MWh in thermal energy and 36 MWh in electric energy compared to the current control, which corresponds to annual savings of approximately € 7,800 (€ 61.1/MWh for heat and € 100/MWh for electricity), as shown in Figure 8.

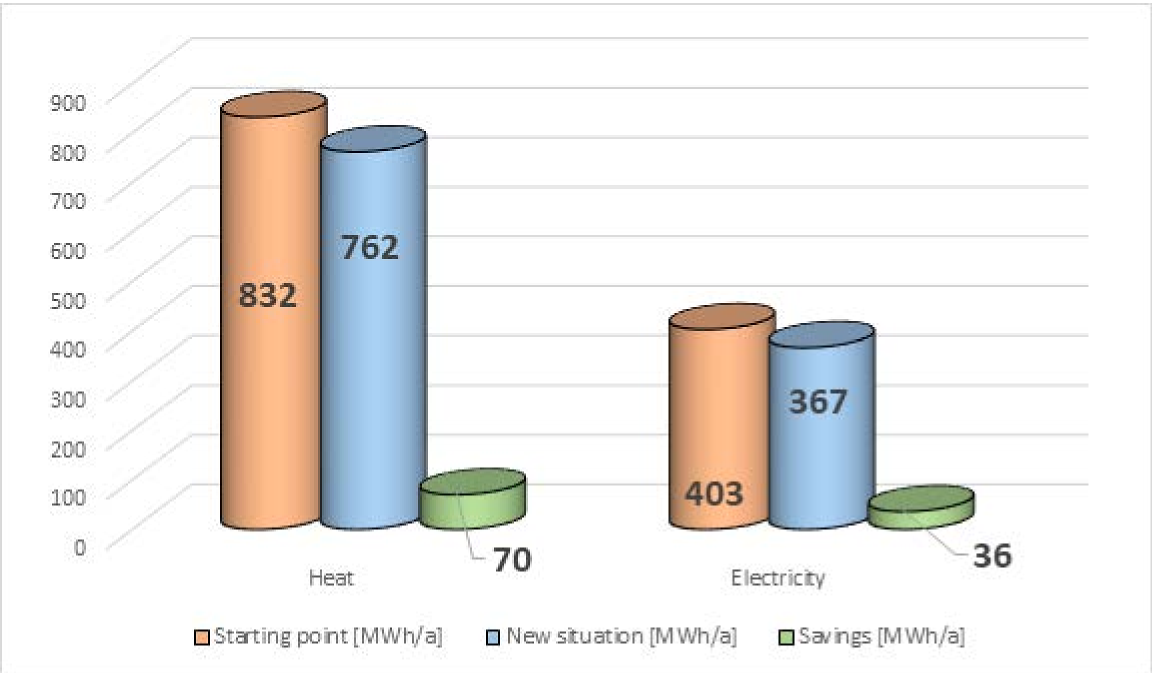

Figure 8. Savings potential of the school building gym's with carbon dioxide based control compared to 2018 consumption of the entire school building.

Summary

The aim of this sustainable development study was to optimize the energy efficiency of underused buildings and to improve the ventilation of actively used buildings. New information and instructions were formulated for the companies and the municipality sector.

The theoretical part covers the principles of ventilation and heating while the practical part covers different measurements. The interior study includes carbon dioxide concentration, temperature, and moisture content.

According to the study, several actively used and underused buildings have the potential to optimize their energy use. With the necessary ventilation and proper indoor temperature, it is possible to reduce the energy consumption of a building. In Finland building regulations and good indoor air recommendations have defined minimum requirements for indoor climate, which are theoretically invoked in this report.

Principles of heating and ventilation are discussed, and the buildings´ thermal energy balance and the principle of ventilation system operation is presented. The indoor climate measurements were carried out (temperature, CO_2 content) as field tests during the heating season.

The received thermal energy savings in the underused school building were 140 MWh, and the thermal and electrical savings in the actively used school were 70 MWh and 36 MWh. The savings potential in both heating and electricity consumption was 8% compared to 2018 levels.

It is noted that the project objectives have been achieved. The results will create guidelines for optimal energy usage, which can be utilized nationally by companies and municipalities to promote energy savings and health.

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REPORTS PRODUCED DURING THE PROJECT
Aittakorpi school building, in Kotka, spring of 2019
Karhuvuori sports hall, in Kotka, spring of 2019
Jylppy old school building, in Kotka, autumn of 2019
Jylppy old fire station, on Kotka, autumn of 2019
Borough Hall, in Miehikkälä, autumn of 2019
Salpa Line Museum, in Miehikkälä, autumn of 2019