Catalogue of best alternatives for improving the Building Energy Efficiency:

HVAC System Improvements

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BIM4Energy Project

Catalogue of best alternatives for improving the Building Energy Efficiency: HVAC System Improvements

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1 – Aims

A Catalogue of best alternatives for improving Building Energy Efficiency: HVAC System Improvements tutorial aims to equip participants with a comprehensive understanding of the newest and in trend energy-efficient heating, ventilation, and air conditioning (HVAC) systems. The objectives of this Catalogue of best alternatives for improving Building Energy Efficiency: HVAC System Improvements tutorial are as follows:

- Understanding the Building Energy Efficiency (BEE).
- Understanding the scientific ratings of the best HVAC systems and equipment.
- Strategies to optimize HVAC systems to improve energy efficiency.
- Building Automation Systems.
- HVAC systems with renewable energy integration.
- Real-world examples of efficient HVAC systems.

2 - Learning methodology

The teacher will give an explanation about the best alternatives for improving Building Energy Efficiency: HVAC System Improvements of about 30 minutes.

Students will read this tutorial and follow the steps shown in the tutorial, namely:

- Building Energy Efficiency;
- Scientific metrics of HVAC systems;
- Strategies to optimize HVAC systems to improve energy efficiency;
- Renewable energy integration in HVAC systems;
- Historical data and forecasts for renewable heat consumption;
- Energy-Efficient HVAC Systems in Practice.

In order to evaluate the success of the application, we suggest a questionnaire to be held for the students.

3 - Tutorial duration

The implementation described in this tutorial will be carried out through the BIM4ENERGY Project website by self-learning.

3 lesson hours are suitable for this training.

4 – Necessary teaching recourses

Computer room with PCs with internet access.

Required software: Microsoft Office.

5 – Contents & tutorial

5.1 – Building Energy Efficiency (BEE)

Before diving into specific HVAC system improvements, it's essential to understand what the Building Energy Efficiency is and how it's measured. The BEE is a standardized measure of a building's energy performance, typically expressed on a scale from A to G, with A being the most energy efficient. Several factors influence a building's BEE rating, including its HVAC system.

The BEE provides a valuable tool for assessing and improving the energy performance of buildings. By understanding the factors that influence a building's BEE, property owners and managers can make informed decisions about upgrades and renovations to enhance energy efficiency, reduce costs, and contribute to a more sustainable future.

The BEE is a standardized measure of a building's energy performance. It essentially grades a building's energy consumption, much like how we grade students in school. Building energy efficiency is often rated on a scale, typically from A to G, with A representing the most energy-efficient buildings and G representing the least. This system helps consumers and policymakers understand a building's energy performance immediately.

Common Building Energy Efficiency Scales:

- Energy Performance Certificates **(EPCs):** Widely used in Europe, EPCs provide a standardized assessment of a building's energy performance. The A-G scale is commonly used, with A being the most efficient and G being the least.
- Home Energy Rating System **(HERS):** Used in the United States, the HERS Index provides a score from 0 to 100, with 0 being the most energy efficient. A score of 100 represents a baseline code-minimum home.
- National Fenestration Rating Council **(NFRC):** This system rates the energy performance of windows and doors, using a U-factor (heat transfer coefficient) and Solar Heat Gain Coefficient (SHGC). Lower U-factors and SHGCs generally indicate better energy efficiency.
- **LEED** (Leadership in Energy and Environmental Design)**:** While not a simple A-G scale, LEED provides a certification system for green buildings, with various levels of certification (Certified, Silver, Gold, Platinum) based on a comprehensive set of criteria, including energy efficiency.

- **BREEAM** (Building Research Establishment Environmental Assessment Method) uses a distinct rating system to evaluate the sustainability performance of buildings. BREEAM assesses various aspects of a building's sustainability, including energy, water, materials, waste, ecology, transport, health and well-being, management, pollution, and innovation. BREEAM certification is awarded by independent assessors, providing a reliable and impartial evaluation of a building's sustainability performance.

The specific calculation methods for determining a building's BEE can vary depending on the region or country. However, key factors generally considered include:

- **Building envelope:** Insulation, windows, and air tightness.
- **HVAC systems:** Heating, ventilation, and air conditioning efficiency.
- **Lighting systems:** Efficiency of lighting fixtures and controls.
- **Renewable energy sources:** Integration of solar, wind, or geothermal energy.

Why is the BEE Important?

1. **Reduced Energy Costs:** More energy-efficient buildings translate to lower utility bills for owners and occupants.
2. **Environmental Sustainability:** Lower energy consumption means a reduced carbon footprint and a smaller contribution to climate change.
3. **Increased Property Value:** Energy-efficient buildings are often more attractive to tenants and buyers, potentially increasing property value.
4. **Improved Comfort:** Efficient HVAC systems can lead to more comfortable indoor environments.
5. **Compliance with Regulations:** In many areas, there are building codes and regulations that mandate minimum energy efficiency standards.

5.2 – Scientific metrics of HVAC systems

HVAC systems are fundamental to maintaining comfortable indoor environments by regulating temperature and air quality. However, their energy consumption can be substantial. Optimizing these systems is crucial for reducing operational costs and minimizing environmental impact. In fact, studies have shown that HVAC optimization can lead to energy savings exceeding 50%. For owners or occupants of the building, it directly correlates to improved air quality, utility bills, and enhanced comfort. Nevertheless, a strategic approach is needed for this optimization.

Catalogue of best alternatives for improving the Building Energy Efficiency:

HVAC System Improvements

HVAC systems encompass a broad range of technologies designed to regulate indoor temperature, humidity, and air quality. A specific type of HVAC system, that has gained significant traction in recent times, that can both heat and cool a space are the heat pumps. Unlike traditional systems that rely on burning fuel for heating, heat pumps utilize a refrigeration cycle to transfer heat. In cooling mode, they extract heat from the indoor air and release it outdoors. Conversely, in heating mode, they extract heat from the outdoor environment, even in cold temperatures, and transfer it indoors. This unique ability to move heat in both directions makes heat pumps highly energy-efficient and environmentally friendly. While HVAC systems can include various heating and cooling methods, heat pumps provide a versatile and sustainable solution for maintaining a comfortable indoor climate.

Evaluating the performance ratings of HVAC systems is paramount when selecting the most suitable equipment. These ratings provide valuable insights into a system's operational efficiency. Common metrics used to assess the performance of heating and cooling systems include Seasonal Energy Efficiency Ratio (SEER), Energy Efficiency Ratio (EER), Heating Seasonal Performance Factor (HSPF), Coefficient of Performance (COP) or Seasonal Coefficient of Performance (SCOP) [1].

- **SEER** measures the cooling output (in British Thermal Units) produced by air conditioners and heat pumps over a typical cooling season, divided by the energy input. A higher SEER rating indicates greater energy efficiency and lower operating costs [2]. To find a unit's SEER, check the outdoor unit for a yellow and black Energy Guide sticker, or inspect the indoor unit for a paper with the rating, or refer to the model number (e.g., "XV20i" suggests a maximum SEER of 20). If these methods fail, contact the manufacturer with the unit's model and serial numbers.
- **EER** also quantifies cooling output (in BTUs) per unit of energy input (in kilowatt-hours). However, EER assesses efficiency under controlled laboratory conditions, while SEER reflects real-world seasonal performance. For example, an EER of 14 means that the system produces 14 BTU of cooling for every watt of electricity consumed.
- **HSPF** evaluates the overall heating efficiency of a heat pump. It represents the ratio of heat output (in BTUs) to the electrical energy consumed (in kilowatt-hours) during a typical heating season. A higher HSPF indicates greater energy efficiency.
- **COP** measures the efficiency of a heat pump, specifically how much heat energy it can move for a given amount of energy input. A higher COP indicates a more efficient heat pump, meaning it can provide more heating or cooling output for the same amount of energy consumed. COP is calculated by dividing the heating or cooling output (in units of energy) by the energy input (also in units of energy).

- **SCOP** measures the energy efficiency of a heat pump over an entire heating or cooling season. Unlike the Coefficient of Performance (COP), which measures efficiency at a single point in time, SCOP considers the varying outdoor temperatures and operating conditions throughout the entire heating or cooling season. SCOP is calculated by dividing the total amount of heat delivered (for heating) or removed (for cooling) by the total amount of energy consumed over the entire season.

Essentially, the metrics aim to determine how effectively an HVAC system or heat pump converts energy into cooling, with higher values indicating greater efficiency. By understanding these efficiency ratings is crucial for making informed decisions when comparing different HVAC systems. Prioritizing systems and components with higher values can maximize energy efficiency and achieve significant energy savings.

5.3 – Strategies to optimize HVAC systems to improve energy efficiency

Optimizing HVAC systems is crucial for both energy conservation and cost savings. Here are several strategies to enhance their efficiency:

1. Regular Maintenance

- Clean or Replace Filters: Clogged filters restrict airflow, forcing the system to work harder, leading to increased energy consumption. Regularly clean or replace filters according to manufacturer's recommendations.
- Inspect and Clean Coils: Dirty evaporator and condenser coils reduce heat transfer efficiency. Regular cleaning ensures optimal performance.
- Check Refrigerant Levels: Improper refrigerant levels can significantly impact system efficiency and lead to costly repairs. Ensure refrigerant levels are within the specified range.

2. Upgrade to Energy-Efficient Equipment

- High-Efficiency Units: Consider replacing older, less efficient units with newer models that meet ENERGY STAR® standards. These models often have advanced features like variable-speed motors and improved insulation, resulting in lower energy consumption.
- Smart Thermostats: Smart thermostats offer precise temperature control and scheduling, optimizing energy usage based on occupancy and time of day. They can also learn your preferences and adjust settings accordingly.

3. Optimize Air Distribution and Ventilation

- Seal and Insulate Ducts: Leaky ducts can waste a significant amount of air conditioning. Seal and insulate ducts to prevent energy loss and improve system efficiency.
- Balance Airflow: Ensure proper air distribution throughout the building by balancing airflow in different rooms. This prevents hot or cold spots and even ensures temperature distribution.
- Demand-Controlled Ventilation: Utilize demand-controlled ventilation systems that adjust ventilation rates based on occupancy levels, reducing energy waste associated with over-ventilation.

4. Implement Building Automation Systems

- Centralized Control: Building automation systems (BAS) provide centralized control over HVAC systems, allowing for efficient operation and monitoring.
- Data-Driven Optimization: BAS can collect data on energy consumption and system performance, enabling data-driven optimization of HVAC settings.
- Integration with Other Systems: BAS can integrate with other building systems, such as lighting and shading controls, to further enhance energy efficiency.

Having extensively examined foundational strategies for enhancing HVAC system efficiency in our previous tutorial, “Efficient HVAC Systems and Energy Vectors”, which included the critical importance of regular maintenance, the strategic implementation of smart thermostats, and the optimization of air distribution, we will now embark on a more in-depth exploration of Building Automation Systems (BAS).

This section will delve into the intricacies of **BAS design**, implementation, and operation, highlighting their pivotal role in achieving significant energy savings and enhancing overall building performance.

BAS aims to centrally manage environmental conditions within a facility via a user interface. To achieve this, a network of field devices and mechanical actuators is installed throughout the building, all controlled by a central controller. Effective communication between the controller, field devices, and actuators is paramount.

Successful BAS implementation hinges on interoperability between components. Traditionally, utilizing equipment from a single manufacturer simplified this process, as all devices adhered to the same communication protocol. However, with the standardization of communication protocols, interoperability across different vendor products has become more feasible.

Building automation systems typically consist of four distinct functional layers (see Figure 1). Maintaining the integrity of these layers is crucial for system interoperability. Any deviation from established standards by a manufacturer can hinder the compatibility of their components within the broader ecosystem of global building automation systems.

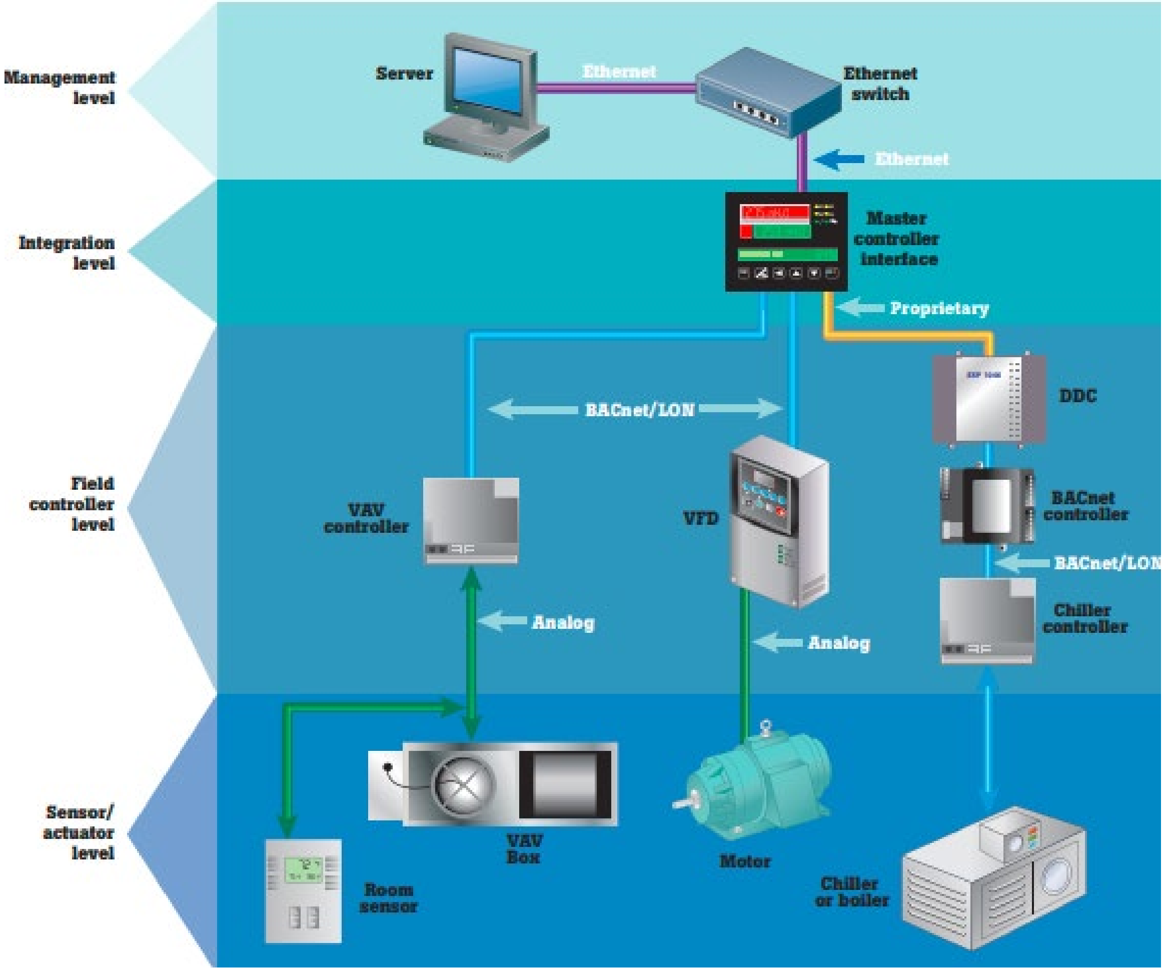

Figure 1. The four layers of BAS architecture [3]

The **Management level** provides an interface between the BAS software application and the network. This layer allows data transfer between the application and the network. The application layer within a BAS defines a set of rules that govern the activation or deactivation of system objects. These objects, which represent physical entities like air handlers, possess properties that describe their characteristics and relevant parameters. When an object performs an action, it activates associated parameters, such as a control valve or Variable Frequency Drive (VFD) for a fan.

The **Integration level** or the supervisory layer plays a crucial role in ensuring reliable data transmission across the system. It encompasses both software and hardware components.

Software within this layer defines the format and content of messages exchanged between devices. These messages convey critical information such as device status, temperature readings, and blower speeds.

Hardware components within this layer facilitate the physical transmission of data between devices. A variety of communication mediums, each with unique characteristics, can be employed. It's essential to carefully consider the chosen medium, as variations in data transmission can lead to discrepancies in readings, resulting in inaccurate information.

The **Field controller level** serves as the foundation for data acquisition within the BAS. This layer houses field devices strategically positioned throughout the facility, which continuously monitor and measure critical physical parameters.

To facilitate data transmission, the field controller layer enables these devices, such as sensors and transmitters, to transmit collected data to the supervisory layer for subsequent processing and the execution of necessary control actions. This data exchange is typically triggered by signals received from the supervisory layer, initiating the data transmission process.

The **Sensor / actuator level** or Input/Output (I/O) layer constitutes the interface between the physical world and the system's digital realm. This critical layer encompasses all physical devices responsible for data acquisition, such as sensors, actuators, and communication interfaces.

The I/O layer serves two primary functions:

1. Data Acquisition: It collects real-time data from various sources, including temperature sensors, humidity sensors, pressure sensors, and occupancy detectors. This raw data is then transmitted to the central controller for processing and analysis.
2. Command Execution: It receives commands from the central controller and translates them into actions for physical devices. For instance, it might activate a valve to control water flow, adjust the speed of a fan, or switch on/off lighting fixtures.

The I/O layer must accommodate diverse communication protocols and data formats. While some devices may transmit data directly to the controller, others might utilize industry-standard protocols like Modbus or BACnet. This layer ensures seamless integration and interoperability between various devices and the central control system.

In essence, the I/O layer acts as a bridge, connecting the physical components of the building to the intelligent control logic of the BAS, enabling effective monitoring, control, and optimization of building operations.

Across various sectors, a trend towards standardized practices is evident. This standardization offers numerous advantages, including enhanced interoperability and improved access to technical support in the event of system malfunctions. The layered architecture within Building Automation Systems (BAS) directly supports this trend. By adhering to this layered structure, advanced manufacturers are designing devices that seamlessly integrate with the overall BAS framework.

5.4 – Renewable energy integration in HVAC systems

The **integration of renewable energy** sources into HVAC systems is a crucial step towards a sustainable and energy-efficient future. By harnessing clean energy sources, we can significantly reduce our reliance on fossil fuels, minimize environmental impact, and lower operating costs.

Key renewable energy sources for HVAC include:

- **Solar Energy**, which can be harnessed through Photovoltaic (PV) Panels to directly power electric heat pumps, fans, and other components, or through Solar Thermal Collectors to heat water for absorption chillers or radiant heating systems.
- **Geothermal Energy** utilizes the stable temperature of the Earth to provide both heating and cooling through geothermal heat pumps.
- **Wind Energy** can be used to generate electricity to power various HVAC components, particularly in areas with consistent wind resources.
- **Biomass Energy** involves the combustion of organic materials like wood and agricultural waste to produce heat for space heating or to power absorption chillers.

Renewable energy sources can be **directly integrated** into HVAC equipment, such as using solar PV panels to power electric heat pumps or wind turbines to drive fans. **Hybrid systems**, combining renewable energy sources with traditional energy sources, offer increased reliability and efficiency. For instance, a geothermal heat pump can operate in conjunction with a backup gas furnace. Moreover, integrating **energy storage systems**, such as batteries or thermal storage, enables the utilization of renewable energy even during periods of low or no generation, ensuring a consistent and reliable energy supply for HVAC operations.

Integrating renewable energy sources into HVAC systems offers numerous **advantages**. By minimizing reliance on fossil fuels, these systems significantly reduce greenhouse gas emissions, thereby contributing to a reduced carbon footprint. Furthermore, utilizing free or low-cost renewable energy sources, such as solar and wind power, leads to lower operating costs and reduced energy bills. Additionally, integrating renewable energy sources increases energy independence by reducing reliance on the grid and enhancing self-sufficiency. Ultimately, these systems promote the use of clean and sustainable energy sources, contributing to a healthier and more sustainable environment.

The integration of renewable energy sources into HVAC systems presents several **challenges**. Firstly, the intermittent nature of solar and wind energy, which fluctuates depending on weather conditions, requires careful planning and may necessitate the inclusion of energy storage systems or backup power sources. Secondly, the initial investment costs associated with renewable energy systems can be higher compared to traditional systems, although these costs are gradually decreasing. Finally, integrating renewable energy sources into existing HVAC systems often requires specialized expertise and careful planning to ensure optimal performance and compatibility with existing infrastructure.

The integration of renewable energy into HVAC systems offers numerous **environmental and economic benefits**. By embracing these technologies and overcoming the associated challenges, we can create more sustainable and energy-efficient buildings that contribute to a cleaner and healthier future.

5.5 – Historical data and forecasts for renewable heat consumption

Heat consumption remains a dominant sector in global energy consumption, accounting for nearly half of the total and contributing approximately 40% of energy-related CO_2 emissions in 2023. Between 2017 and 2023, global heat demand witnessed a substantial increase of 7% (14 exajoules). However, the **growth of modern renewable heat sources** lagged behind, meeting only half of this escalating demand. Consequently, heat-related CO_2 emissions increased by 5% during this period, with the industrial sector being the primary contributor to this rise [4].

The dynamic landscape of renewable heat markets in 2023 was significantly impacted by several factors. These included elevated interest rates, inflationary pressures, a decline in construction activity across many nations, a resurgence of lower natural gas prices, and evolving policy frameworks. While technologies like heat pumps, solar thermal, and geothermal heating systems offer the advantage of low operating costs, their substantial upfront investment poses a significant barrier for households. Consequently, the sales of these technologies exhibit pronounced sensitivity to fluctuations in borrowing costs and prevailing consumer sentiment.

The global heat pump market experienced a slowdown in 2023 following a period of robust growth. This decline, estimated at 3% compared to the previous year, can be attributed to several factors.

In Japan, a mature heat pump market, air-to-water heat pump sales witnessed a 10% year-over-year decrease, primarily due to the combined impact of high inflation and subdued consumer spending. Similarly, the United States observed a 15% decline in air-to-air heat pump sales. This downturn can be linked to rising borrowing costs, increased consumer apprehension towards significant investments, and the anticipation of forthcoming state-administered rebates under the Inflation Reduction Act, which are expected to become available in the coming years. These rebates, designed to incentivize the adoption of energy-efficient technologies, may have prompted some US consumers to defer their purchase decisions.

The European heat pump market, while still a strong performer, experienced a 6.5% year-over-year decline in 2023, necessitating operational adjustments and job reductions for several manufacturers. This downturn, however, was not uniform across the continent. While Germany (+59%), the Netherlands (+43%), and Belgium (+72%) saw substantial growth in heat pump sales, Italy (-44%), Finland (-42%), and Poland (-39%) witnessed significant contractions.

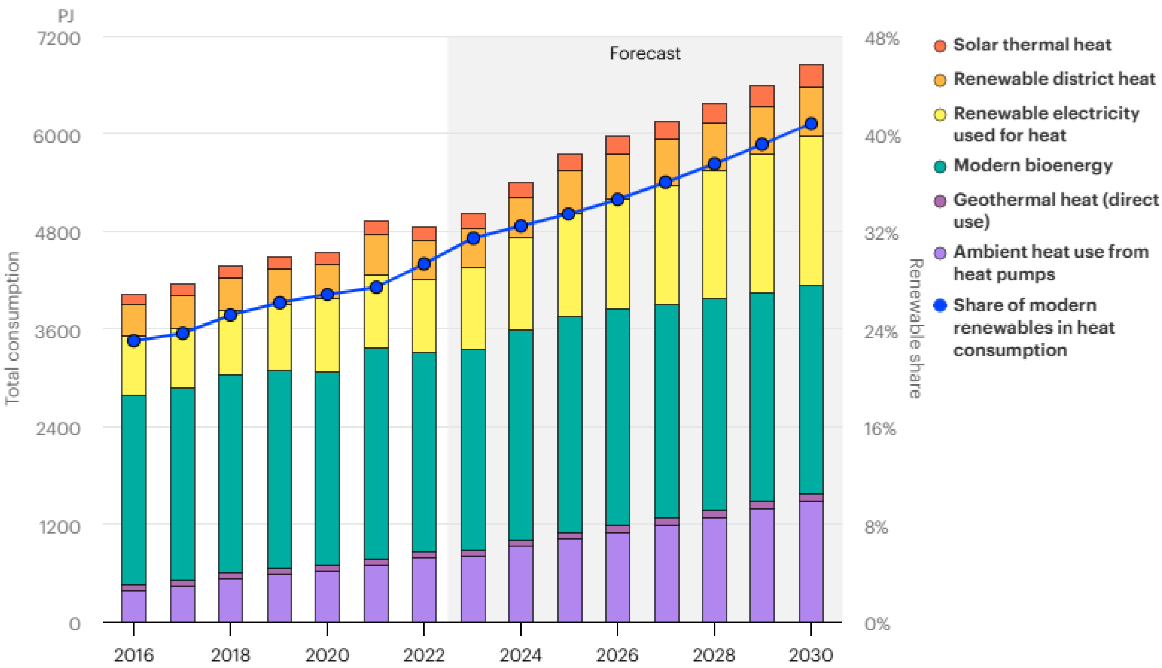

Figure 2 – Renewable heat consumption in buildings in Europe [5]

However, heat pumps continued their market share expansion in Europe last year, surpassing fossil fuel boilers in most countries, with notable exceptions including Italy, Poland, and Finland. This trend saw heat pumps account for nearly one-third of all heating system sales in 2023.

Global renewable heat consumption is projected to exhibit substantial growth between 2024 and 2030, exceeding a 50% increase (15 EJ).

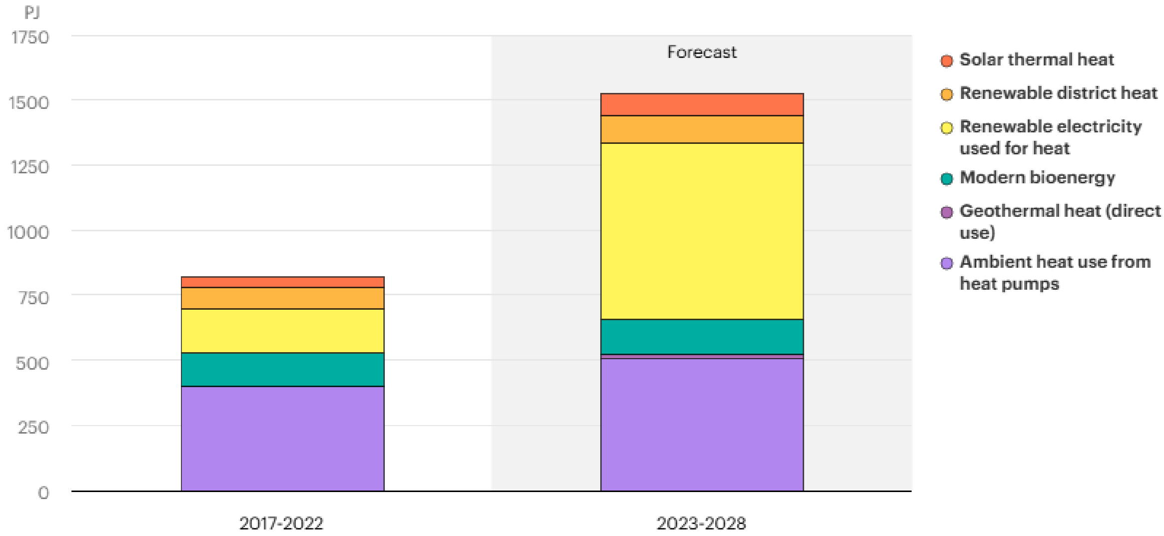

Figure 3 – Consumption growth, Buildings by heating technology, Europe [5]

This growth rate surpasses the previous six-year period by a factor of 2.4. However, this significant expansion in renewable heat utilization is insufficient to fully offset the projected surge in overall heat demand. Consequently, the reliance on fossil fuels for heat generation is expected to persist, leading to a 4% increase in annual heat-related CO_2 emissions by 2030.

Furthermore, cumulative heat-related emissions over this period are anticipated to surpass 100 Gt CO_2, a figure that constitutes nearly 30% of the remaining carbon budget for a 50% probability of limiting global warming to 1.5°C.

5.6– Energy-Efficient HVAC Systems in Practice

The following section will present a detailed examination of several prominent HVAC systems, with a particular focus on their scientific performance metrics. This in-depth analysis will provide a comprehensive overview of each system's capabilities, enabling readers to gain a deeper understanding of their respective advantages and disadvantages.

5.6.1. Air to water Chiller

The chiller is equipped with high-efficiency compressors featuring Variable Frequency Drive (VFD) technology for precise capacity modulation and Variable Volume Ratio (VVR) capability, enabling optimal performance across a wide operating range. It utilizes environmentally friendly R-513A refrigerant, boasting a significantly reduced Global Warming Potential (GWP) compared to traditional refrigerants. This advanced chiller offers simultaneous heating and cooling capabilities, providing flexible and responsive temperature control to meet the diverse and evolving needs of various applications.

Its capacity range is from 400 to 800 kW in both cooling and heating modes, with a Total Energy Efficiency Ratio (TER) of up to 7.89. It operates in ambient temperatures from -18°C to +50°C, with chilled water temperatures ranging from -8°C (with a water/glycol mixture) to +20°C, and heating water temperatures from +30°C to +60°C.

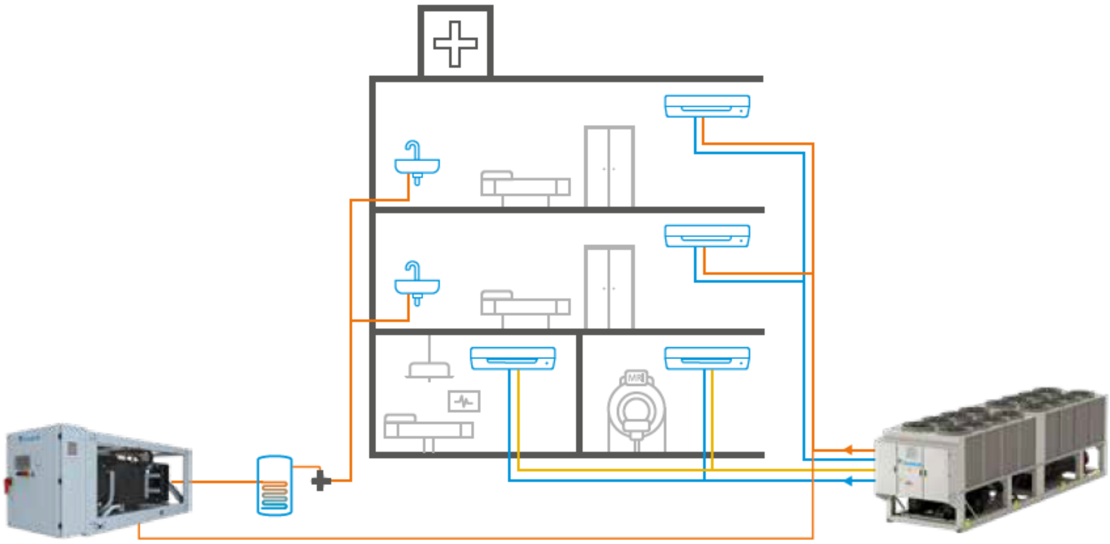

Figure 4 – Simultaneous heating and cooling chiller by Daikin [6]

Table 1 – Technical specifications of an air to water chiller

Technical specifications		Unit of measure	Value
Cooling capacity		kW	393.1
Heating capacity		kW	403.1
Power input	Cooling	kW	135.55
	Heating	kW	126.76
SEER			4.55
EER			2.90
COP			3.18
SCOP			3.21
Refrigerant		GWP	630

The chiller can be extensively used across various applications, from industrial to commercial buildings, hotels, and hospitals. It ensures reliable operation and optimal performance in a wide range of locations and weather conditions.

5.6.2. Air Handling Units

This comprehensive control solution offers seamless integration for a wide range of HVAC systems. It encompasses air flow and temperature control, encompassing both supply and return air, as well as ambient temperature monitoring. Cooling systems are expertly managed, including chilled water and DX cooling, with the added benefit of free cooling integration for energy efficiency. Furthermore, the system incorporates CO2 automatic control for optimal indoor air quality. It supports both Variable Air Volume (VAV) and Constant Air Volume (CAV) systems, providing flexibility and adaptability to diverse HVAC needs.

The Air Handling Unit (AHU) has an air flow ranging from 750 m^3/h to 144,000 m^3/h to accommodate all customer needs. Available in both indoor and outdoor versions, these units are custom designed for easy transport and on-site assembly. The smooth interior surface enhances Indoor Air Quality (IAQ). Integration with DX cooling systems is seamless, including compatibility with VRV IV and ERQ coupling.

A variety of heat recovery systems are offered, including heat wheels (sensible, enthalpy, or sorption), crossflow and counter-flow plate heat exchangers, and run-around coils. A wide selection of fans is available, including EC, AC plug, and belt-driven options with forward curved, backward curved, and backward airfoil blades.

The heating/cooling coil section features a stainless-steel condensate tray with drip protection. Various humidifiers are available to suit specific customer requirements. Premium efficiency filters are equipped with a factory-mounted differential pressure manometer.

The profile is crafted from anodized aluminum with or without a thermal break. The base frame is available in Galvanized steel, Aluminum, Stainless Steel 430, or 316. Panel insulation options include polyurethane foam or mineral wool. A range of materials can be selected for the internal and external panel skin: Pre-coated, Aluzinc, Aluminum, Stainless Steel 304, or 316.

Figure 5 – D-AHU Professional by Daikin [7]

The supply side includes a damper section with ventilation grilles and factory-mounted actuators, premium efficiency filters with a factory-mounted differential pressure manometer, a heat recovery system (cross flow and counter flow plate heat exchanger or rotary heat exchanger), a mixing box with a damper and factory-mounted actuators, a heating/cooling coil section with a stainless steel condensate tray and drip protection, and a supply air fan with EC technology (with a hinged door, opening drive monitoring, mounted and cabled lighting and ON/OFF switch).

The return side includes premium efficiency filters with a factory-mounted differential pressure manometer. It also features an exhaust air fan utilizing EC technology, equipped with a hinged door, opening drive monitoring, mounted and cabled lighting, and an ON/OFF switch. The system incorporates a mixing box with a damper and factory-mounted actuators. A heat recovery system (either crossflow and counter-flow plate heat exchanger or rotary heat exchanger) is included. Lastly, the return side comprises a damper section featuring ventilation grilles and factory-mounted actuators.

Given the D-AHU Professional's high degree of customization to suit diverse applications, Table 2 provides a summary of its key technical specifications to offer a comprehensive understanding of its capabilities.

Table 2 – Technical specifications of AHU

Technical specifications	Unit of measure	Value
Airflow	m^3/h	15,000.0
Temperature efficiency winter	%	78.2
Power input	kW	7.61
SFPv(1)	$kW/m^3/s$	1.551

(1) SFPv is a parameter that quantifies the fan efficiency (the lower it is the better will be). This reduces if airflow decreases.

The HVAC system features a thermally broken construction, eliminating thermal bridges across the entire AHU for enhanced energy efficiency. The smooth interior surface promotes improved Indoor Air Quality (IAQ) by minimizing dust accumulation and facilitating easy cleaning. This commitment to IAQ is further solidified by compliance with the stringent VDI 6022 hygiene guideline.

The AHU comes with the Daikin on Site platform (see Figure 6) which offers different features and functions to monitor and control the unit. The monitoring system makes available dashboards, remote access, scheduling, online graphics, diagnostics, and software upgrades.

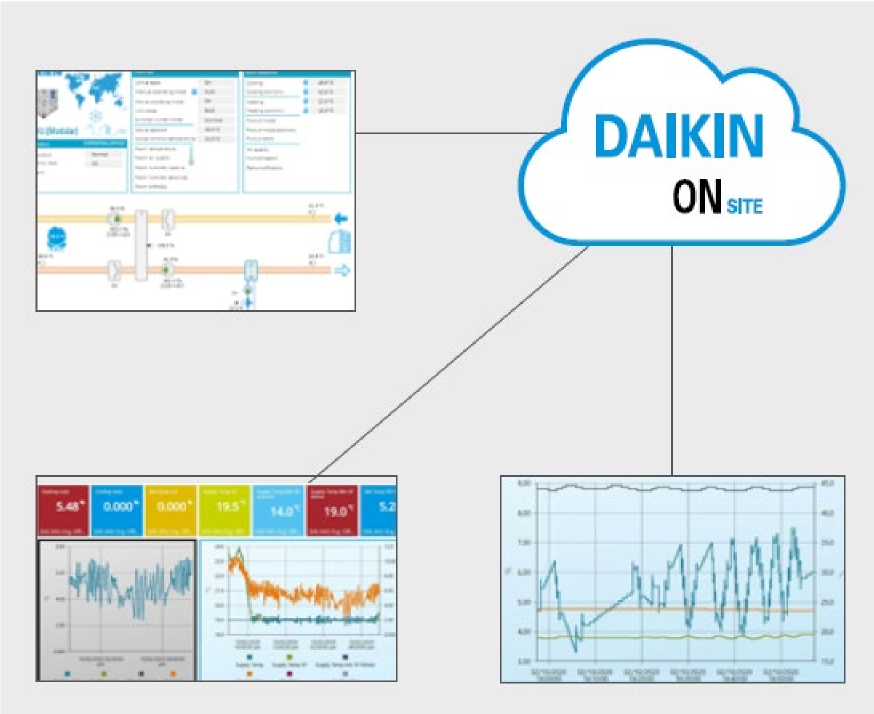

Figure 6 – Control platform of the AHU [7]

The manufacturer can also provide a Building Automation System (see Figure 7). Smart energy management monitors if energy use is according to plan and helps to detect origins of energy waste. Powerful schedules guarantee correct operation throughout the year. Energy can be saved by interlocking A/C operation with other equipment such as heating. Peak Power Cut off Control, activated within the schedule function, allows users to operate the outdoor unit in 4 settings: 100%, 70%, 40%, and 0%.

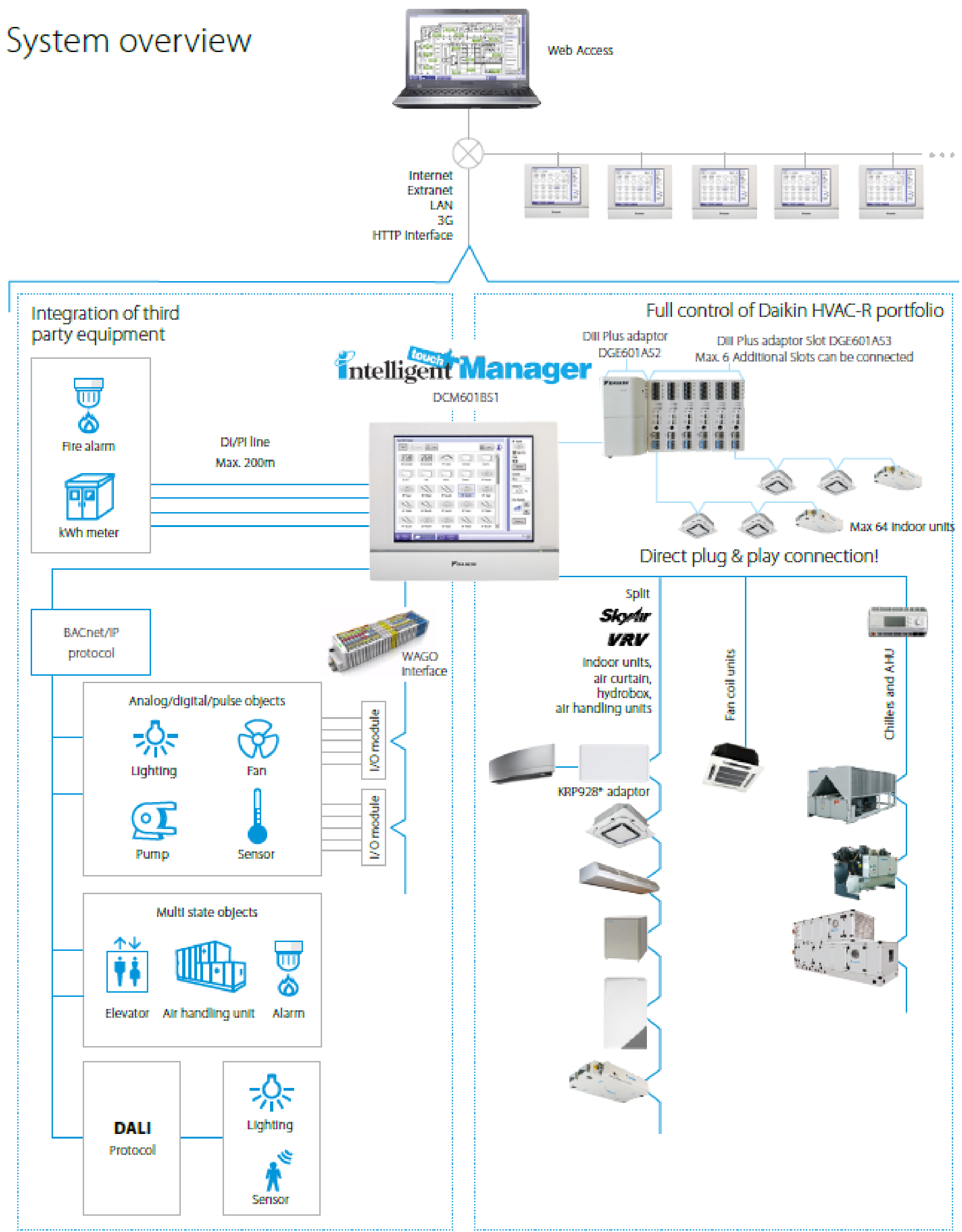

Figure 7 – Building management system [7]

The Daikin fresh air package provides a complete solution, including all unit controls (expansion valve, control box and AHU controller) and sensors factory mounted and configured. To have higher efficiency integrating the AHU with a heat recovery system (see Figure 8) is even more effective since an office system can frequently be in cooling mode while the outdoor air is too cold to be brought inside in an unconditioned state. In this case heat from the offices is merely transferred to heat up the cold incoming fresh air. Daikin ERQ and VRV units respond rapidly to fluctuations in supply air temperature, resulting in a steady indoor temperature and resulting in high comfort levels for the end user. The ultimate is the VRV range which improves comfort even more by offering continuous heating, also during defrost.

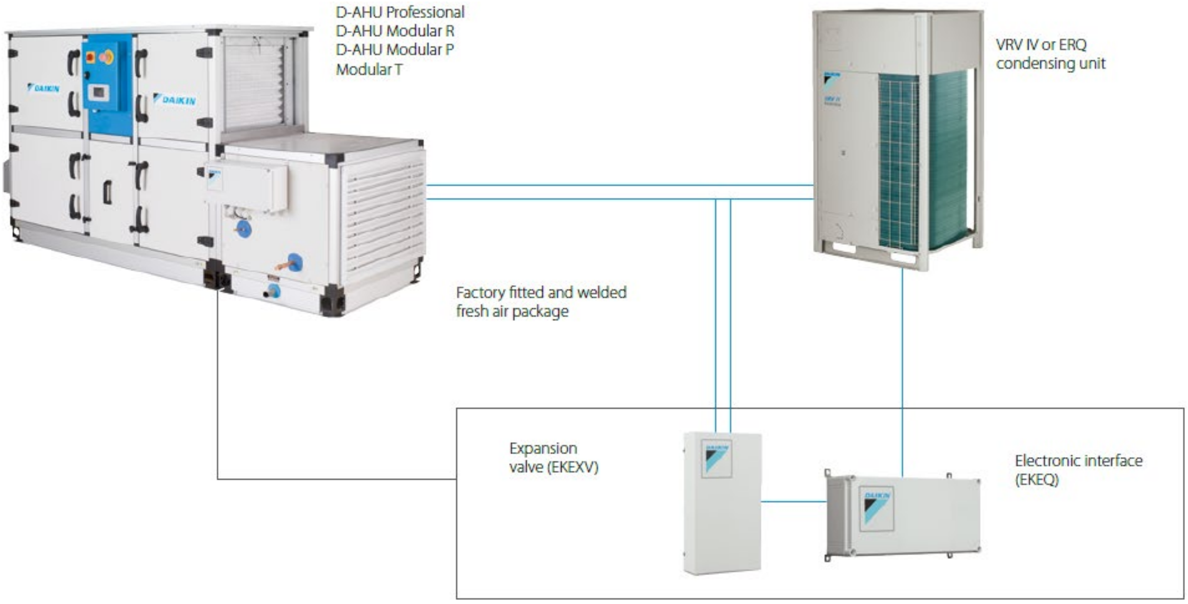

Figure 8 – Integration of an AHU with a heat recovery system [7]

5.6.3. HVAC system with Variable Refrigerant Volume (VRV) with heat recovery

In the VRV system with heat recovery the energy efficiency is enhanced through several key features. Heat recovery transfers heat from areas where cooling is needed to locations where hot water or heating is required, maximizing energy utilization. Variable Refrigerant Technology optimizes comfort and boosts seasonal efficiency by up to 28% compared to alternative solutions by dynamically adjusting refrigerant temperature based on the cooling load. The inclusion of original 3-pipe technology significantly increases energy efficiency during heat recovery mode.

VRV 5 Heat Recovery (see Figure 9) offers a best-in-class solution for both efficiency and comfort. It reduces CO2 equivalent emissions using lower GWP R-32 refrigerant and a reduced refrigerant charge. This system utilizes a single-component refrigerant, making it easy to reuse and recycle. Sustainability is maximized throughout the entire lifecycle thanks to market-leading real-life seasonal efficiency. "Free" heating is achieved through efficient 3-pipe heat recovery, transferring heat from cooling zones to heating zones.

The technology enables the system to effectively address small room applications. Specially designed indoor units for R-32 ensure low sound levels and maximum efficiency. Simultaneous cooling and heating provide optimal personal comfort for guests and tenants. Installation flexibility is maximized with piping lengths up to 165 meters and a total length of 1,000 meters. Sound pressure levels can be as low as 40 dB(A) thanks to 5 low sound steps. The system offers an ESP of up to 78 Pa, allowing for flexible ducting options. A wide operating range of up to +46°C in cooling and down to -20°C in heating ensures reliable performance in diverse climates. VRV 5 Heat Recovery incorporates advanced technologies inherited from VRV IV+, such as Variable Refrigerant Temperature, continuous heating, a 7-segment display, full inverter compressors, a 4-side heat exchanger, a refrigerant-cooled PCB, and a new DC fan motor.

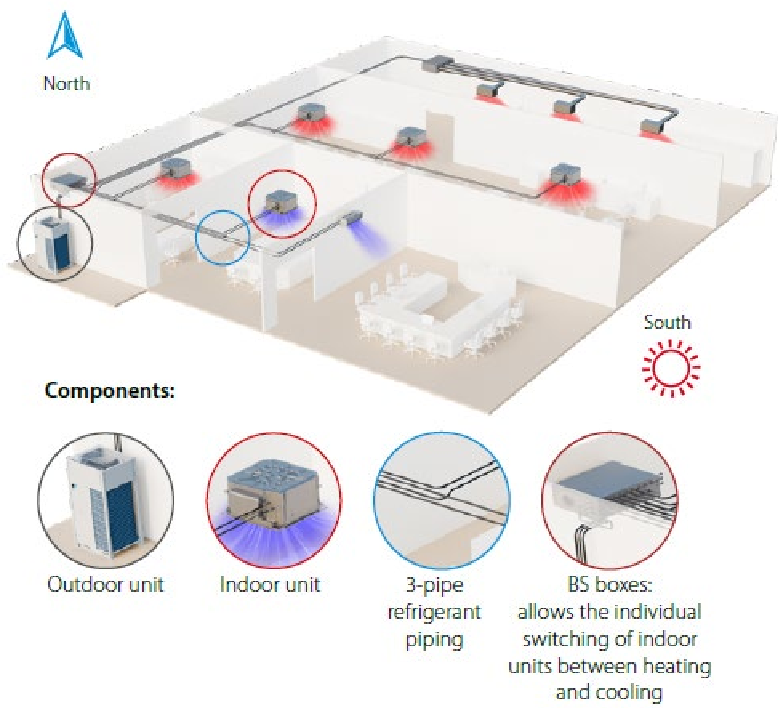

Figure 9 – VRV heat recovery system [7]

For a better understanding and comparison in Table 3 are provided technical specifications of a VRV heat recovery system of the outdoor unit.

Table 3 - Technical specifications of the VRV heat recovery model REYA8A by Daikin

Technical data	Unit of measure	Value
Capacity range	HP	20
Cooling capacity	kW	55.9

Heating capacity	kW	62.5
SEER	-	7.27
SCOP	-	4.38
Sound pressure level	dBA	56.3
Refrigerant	GWP	675

5.6.4. HVAC system with Variable Refrigerant Volume (VRV) heat pump

The VRV Heat Pump (see Figure 10) offers a solution for both comfort and low energy consumption. Reduced CO2 equivalent is achieved using lower GWP R-32 refrigerant and a lower refrigerant charge. Utilizing a single-component refrigerant simplifies reuse and recycling. The system boasts market-leading real-life seasonal efficiency, ensuring the greatest sustainability throughout its lifecycle. The technology enables efficient operation in small rooms without requiring additional measures. Specially designed indoor units for R-32 deliver low sound levels and maximum efficiency. Installation flexibility mirrors R-410A systems, with piping lengths up to 165 meters and a total length of 1,000 meters. Sound pressure can be as low as 40 dB(A) thanks to 5 low sound steps, while ESP reaches up to 78 Pa to facilitate ducting. The operating range extends from +46°C in cooling to -20°C in heating. The VRV 5 incorporates key VRV standards and technologies, including Variable Refrigerant Temperature, continuous heating, a 7-segment display, full inverter compressors, a 4-side heat exchanger, and refrigerant-cooled PCBs.

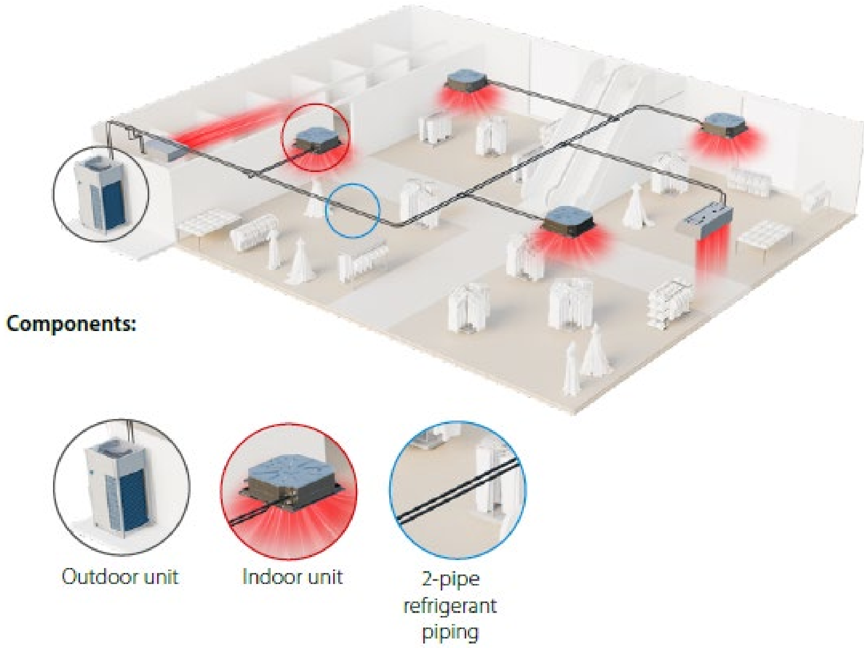

Figure 10 – VRV heat pump system [7]

For a better understanding and comparison with VRV heat recovery system in Table 4 are provided technical specifications of a VRV heat pump system of the outdoor unit.

Table 4 - Technical specifications of the VRV heat pump model RXYA8A by Daikin

Technical data	Unit of measure	Value
Capacity range	HP	20
Cooling capacity	kW	55.9
Heating capacity	kW	62.5
SEER	-	7.16
SCOP	-	4.38
Sound pressure level	dBA	56.3
Refrigerant	GWP	675

A comparison of the VRV heat recovery data from Table 3 with the VRV heat pump data from Table 4 reveals a high degree of similarity in most performance metrics. The primary difference observed is a 1.5% lower SEER value for the heat pump system.

This analysis demonstrates that while the VRV heat pump system exhibits slightly lower seasonal energy efficiency compared to its heat recovery counterpart, the overall performance characteristics of both systems are remarkably similar. The choice between these two VRV technologies will likely depend on specific project requirements and considerations such as the need for simultaneous heating and cooling, available space constraints, and the desired level of energy efficiency.

5.6.5. Ground to water heat pump

Heat pumps are a versatile and increasingly popular subsystem within HVAC systems. They operate on the principle of transferring heat rather than generating it, making them highly energy efficient.

The heat from the ground (Figure 11) is taken up via a closed brine system in which a mixture of water and antifreeze circulates. In the heat pump evaporator, the brine (water mixed with anti-freeze, glycol or ethanol) releases its energy to the refrigerant, which is vaporized to be compressed in the compressor. The refrigerant, of which the temperature has now been raised, is passed to the condenser where it gives off its energy to the heating medium circuit and, if necessary, to any docked water heater.

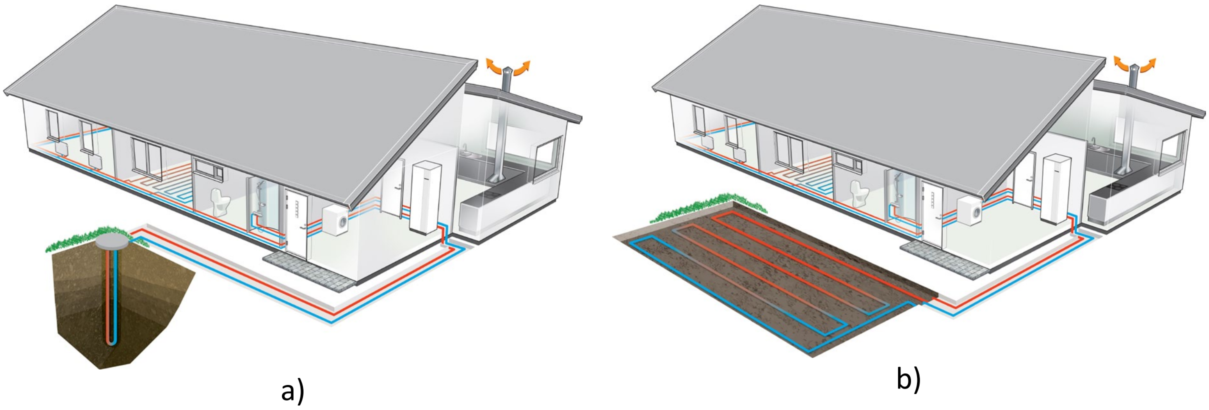

Figure 11 – Ground source heat pumps: a) borehole collectors; b) horizontal ground collectors

Table 5 presents the Coefficient of Performance (COP) data for a Viessmann Vitocal 350-G Pro 352.A114 (B0/W35 114,2 kW) [8] ground-source heat pump, utilizing R134a as the refrigerant. The COP values are displayed as a function of varying ground source temperatures, providing valuable insights into the heat pump's efficiency across different operating conditions.

Table 5 – COP of ground to water heat pump as function of ground temperatures

Ground temperatures	Water temperatures					
	35 [^{0}C]	**45 [^{0}C]**	**50 [^{0}C]**	**55 [^{0}C]**	**65 [^{0}C]**	**73 [^{0}C]**
	COP					
-5	3.9	3.26	2.99	2.75	2.32	2.02
0	4.41	3.61	3.29	3.01	2.53	2.2
5	4.92	3.99	3.63	3.3	2.76	2.39
10	5.41	4.46	4.02	3.64	3	2.59
15	6.42	5.01	4.48	4.04	3.29	2.82
20	7.32	5.67	5.04	4.5	3.65	3.1
25	8	6.49	5.56	4.9	4	3.4

To gain a deeper understanding of the COP values presented in the preceding table, Figure 12 illustrates the variation of the COP as a function of source temperature. This graphical representation provides valuable insights into the performance trends of the system across a range of operating conditions.

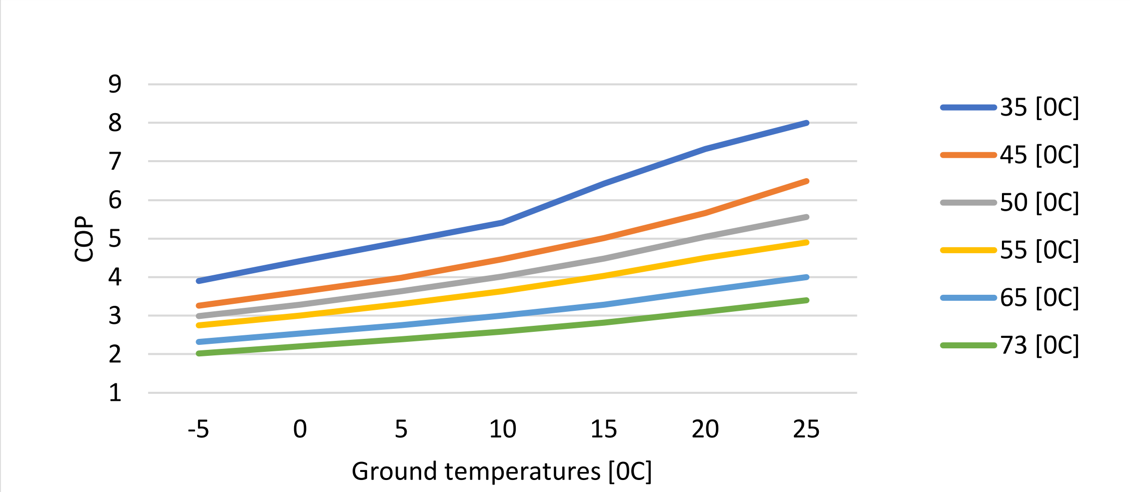

Figure 12 – COP variation with the ground temperature

An analysis of Figure 12 reveals a clear trend: the COP of the ground source heat pump system exhibits its highest values under conditions where the ground source temperature is elevated, and the temperature of the heated (brine) is significantly lower. This observation aligns with the fundamental principles of heat pump operation, where a smaller temperature differential between the heat source (ground) and the heat water (brine) generally results in more efficient heat transfer.

The same phenomenon occurs when we refer to the heating capacity of the heat pump (see Table 6).

Table 6 – Heating capacity of the ground to water heat pump as function of ground temperatures

Ground temperatures	Water temperatures					
	35 [^{0}C]	**45 [^{0}C]**	**50 [^{0}C]**	**55 [^{0}C]**	**65 [^{0}C]**	**73 [^{0}C]**
	Heating capacity					
-5	90.5	81.5	76.5	71.5	61	52.6
0	114.2	101.6	96	90.2	78.1	68.3
5	136.1	124.6	118.3	111.7	98	86.6
10	158	151.2	144.1	136.5	120.8	107.6
15	196.1	181.3	173.3	164.8	146.7	131.5
20	228.2	215.7	206.8	197.2	177.3	160.1
25	254.5	241	239	221	201	191.9

5.6.6. Water to water heat pump

The working principle of a water-to-water heat pump closely resembles that of a ground-source heat pump. Both operate by transferring thermal energy using a refrigerant. However, a key distinction lies in the heat source. While a ground-source heat pump extracts heat from the ground through a buried loop of pipes, a water-to-water heat pump (Figure 13) directly sources thermal energy from a body of water, such as a lake, river, or a well. This direct water interaction allows for efficient heat exchange, making water-to-water heat pumps a viable option for heating and cooling applications in various settings.

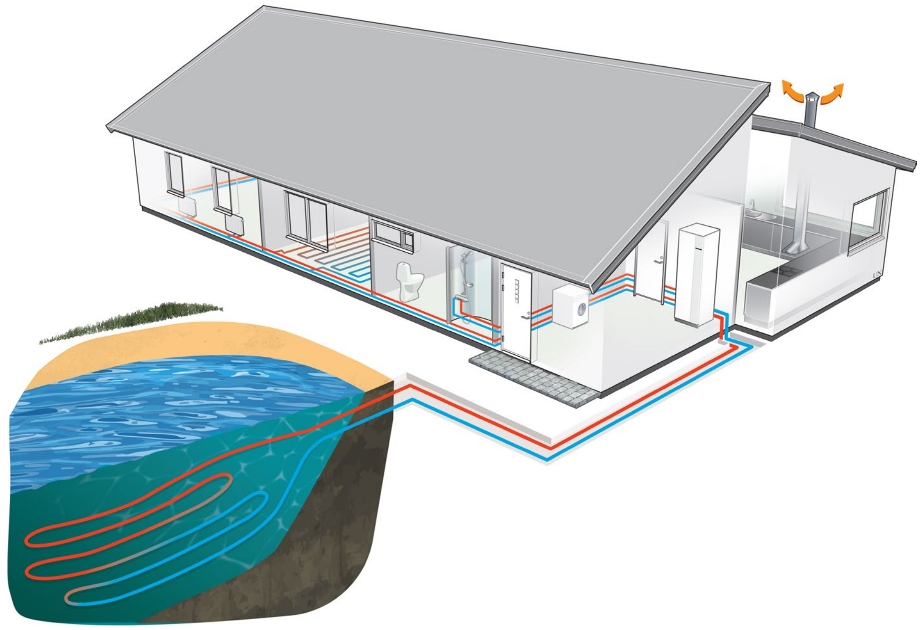

Figure 13 – Water source heat pump

To facilitate a straightforward comparison between the two distinct heat pump types, Table 7 presents the Coefficient of Performance (COP) values for the Vitocal 350-G Pro 352.A076 model (W10/W35 106kW) [8] alongside a similarly capable alternative. This comparative analysis highlights the superior energy efficiency of the Vitocal 350-G Pro, demonstrating a notable increase in COP compared to the ground to water model.

Table 7 – COP of the water-to-water heat pump as function of water temperatures

Water temperatures	Water temperatures (indoor)					
	35 [^{0}C]	**45 [^{0}C]**	**50 [^{0}C]**	**55 [^{0}C]**	**65 [^{0}C]**	**73 [^{0}C]**
	COP					
10	5.44	4.52	4.07	3.689	3.03	2.61
15	6.5	5.09	4.56	4.09	3.34	2.85
20	7.53	5.78	5.13	4.58	3.71	3.15
25	8.2	6.1	5.4	4.9	4.11	3.47

5.6.7. Air to water heat pump

Air-to-water heat pumps function by extracting heat from the surrounding air, like other heat pump types, and transferring it to a water-based heating system through a refrigerant cycle. This makes them a readily accessible and cost-effective solution for many applications.

Key features of air-to-water heat pumps include their ability to extract heat from the ambient air, providing both heating and cooling, and generally being less expensive to install compared to geothermal systems. Their accessibility stems from their widespread availability and suitability for a wide range of applications.

To facilitate a comprehensive comparative analysis of different heat pump technologies, Table 8 and 9 presents the technical specifications of an air-to-water heat pump from the same Viessman manufacturer: the Vitocal 300-A 302.B60 [8] equipped with two compressors.

This inclusion of an air-to-water heat pump alongside ground-source and water-source heat pumps allows for a direct evaluation of key performance characteristics, including COP and heating capacity. By examining these specifications, distinct advantages and disadvantages of each technology can be readily identified, enabling informed decision-making when selecting the most appropriate heat pump system for specific project requirements.

Table 8 – COP of the air-to-water heat pump as function of outdoor temperatures

Outdoor temperatures	Water temperatures		
	35 [^{0}C]	**45 [^{0}C]**	**55 [^{0}C]**
	COP		
-22	1.8	1.6	-
-15	2.3	2.1	1.7
-7	2.9	2.6	2.3
2	3.6	3	2.6
7	4	3	3
10	4.4	3.7	3.2
12	4.5	3.8	3.3
20	4.9	4.2	3.5
25	5.2	4.3	3.7
30	5.4	4.5	3.8
35	5.7	4.7	3.9

Table 9 – Heating capacity of the air-to-water heat pump as function of outdoor temperatures

	Water temperatures

Outdoor temperatures	35 [^{0}C]	45 [^{0}C]	55 [^{0}C]
	Heating capacity		
-22	44	39.6	-
-15	59	55.4	51
-7	76.2	73.4	70.4
2	94.4	90.2	86
7	111.6	112.2	112.8
10	122.8	121.2	120.6
12	128.8	127.2	125.8
20	145.2	139.8	134.6
25	154.4	147.8	140.8
30	164.6	155.8	147.2
35	174	163.8	153.4

It’s important to note that the air-to-water heat pump’s efficiency can fluctuate due to significant variations in outdoor air temperature, particularly in colder climates. Additionally, outdoor units can generate noise, which may be a concern for some installations.

The choice of heat pump technology – ground-source, water-source, or air-source – significantly impacts system performance, installation complexity, and overall cost. Water-source heat pumps and ground-source heat pumps generally exhibit the highest efficiency due to the stable temperature over the year, but they require available water sources and extensive ground loop installation, while air-source heat pumps provide a more accessible and cost-effective solution with a wider range of applications.

Ultimately, the optimal choice depends on various factors, including climate conditions, site-specific considerations, available resources, and individual project requirements. A thorough evaluation of these factors, coupled with a comprehensive analysis of technical specifications and performance data for each system, is crucial to ensure the selection of the most suitable and cost-effective heat pump solution for a given application.

References

[1] ANSI/AHRI 210/240-2008: 2008 Standard for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment". Air Conditioning, Heating and Refrigeration Institute. 2008.
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[6] https://www.daikinmea.com/en_us/product-group/chillers.html (accessed January 14, 2025).

[7] https://www.daikinmea.com/en_us/product-group/air-handling-units.html (accessed January 14, 2025).

[8] https://www.viessmann.ro/ro/cunostinte/tehnologie-sistem/pompe-caldura.html (accessed January 15, 2025).

6 - Deliverables

To evaluate the success of the tutorial, we suggest that students answers an online questionnaire.

7- What we have learned

Different scales on how to evaluate Building Energy Efficiency.

The scientific metrics of HVAC systems.

Strategies to optimize HVAC systems.

Building Automation Systems.

What renewable sources can be integrated in HVAC systems.

Statistic data and forecasts in terms of renewable heat consumption.

Differences in scientific metrics between different types of HVAC systems.