Report

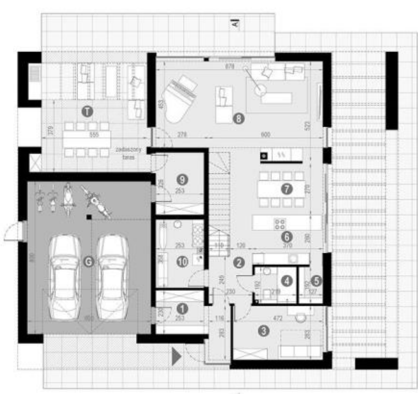
a) Description of the problem – location and assumed energy demand

The modernization plan for a detached house in Denmark near the coast to leverage the region's abundant wind resources encompasses a strategy for enhanced energy efficiency. The transition from a gas boiler to a high-efficiency heat pump aligns with European regulations. This approach is complemented by targeted energy-saving measures and optimized heating distribution systems, contributing to an integrated and environmentally responsible heating system. Given Denmark's coastal location, the modernization plan strategically integrates renewable electricity sources. The potential for a small wind turbine is explored, capitalizing on the region's wind-rich environment.

Financial considerations are vital, with investment costs calculated for acquiring and installing the heat pump and wind turbines. Income streams, including feed-in tariffs and anticipated energy savings, are assessed to offset these costs and ensure long-term financial viability. Furthermore, a comprehensive analysis evaluates the change in primary energy consumption, providing insights into the project's impact on overall energy usage assumption. This thorough and integrated approach ensures that the modernization plan meets regulatory requirements and maximizes energy efficiency, harnessing wind resources of the coastal location for environmental and economic benefit.

<u>*Assumption*</u>

- House design



  - House with 15*15 m^2 of w*l, Area = 225 m^2
  - Height from floor to ceiling 3 m
  - Total exterior area = 4*15*3 = 180 m^2
  - Window
    - Area (20%) = 0.2*180 = 36 m^2
    - Clear with reflective film glass: SHGC = 0.25 to minimize thermal loss regarding EU regulation

Type of window glazing	Shading coefficient	Solar heat gain coefficient	Visible light transmittance
Single-pane 6 mm glazing			
- Clear glass (base case)	1.00	0.86	90%
- Clear with tinted film	0.50	0.43	48%
- Clear with reflective film	0.29	0.25	15%
- Clear with spectrally selective film	0.51	0.44	69%

- Electrical energy demand (Reference in Excel file: hourly_power_usage)
  - Electric demand of a household in Denmark is about 5.6 MWh

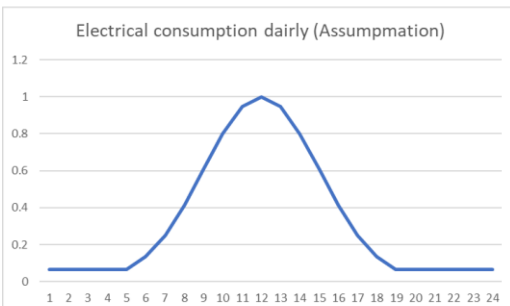
Electricity	total/year	Denmark per capita
Own consumption	33.08 bn kWh	5,604.06 kWh

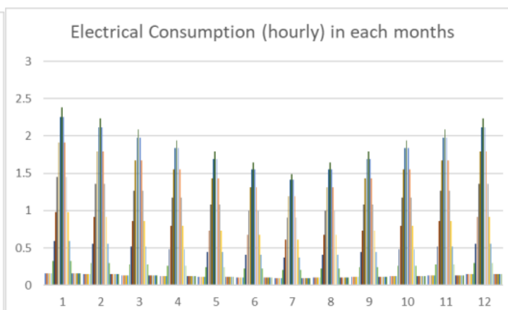
Source: [Energy consumption in Denmark (worlddata.info)]

- Electric demand per month
  - Winter (December – February): Highest percentage due to electrical consumption from heating and indoor lighting for the longer night. Demand is at its peak in January.
  - Summer (June to August): The lowest percentage is due to reduced electrical consumption from heating, and there is no need for cooling during summer since the highest temperature is approximately 26°C. Demand is at the bottom in July.
  - Assume the percentage for each month

0.57	0.54	0.50	0.47	0.43	0.39	0.36	0.39	0.43	0.47	0.50	0.54	5.6
10.3	9.6	9.0	8.3	7.7	7.1	6.4	7.1	7.7	8.3	9.0	9.6	%

- Electric demand per hour
  - Assume that each day in a month, demand is the same and each month has 30 days
  - Apply normal distribution to each day by assuming that the demand reaches the peak at noon and low during the night

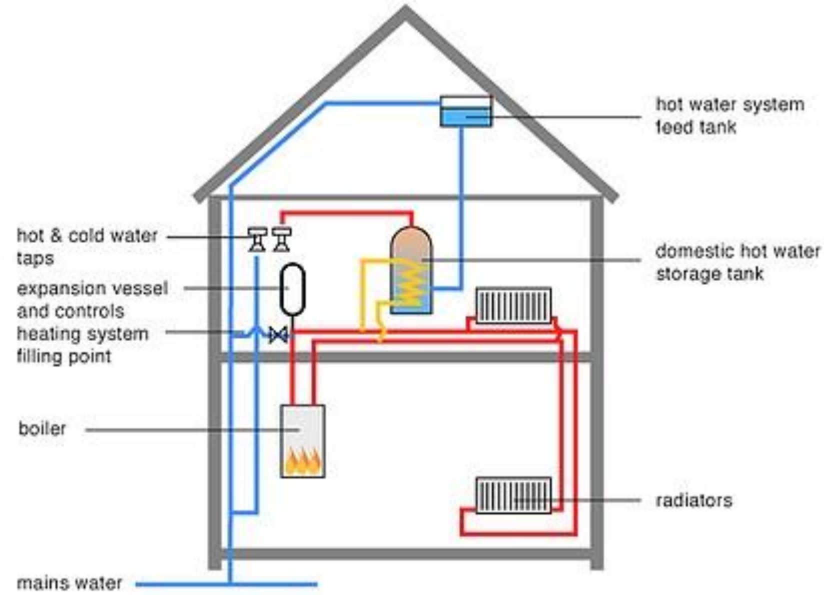




h/M	1	2	3	4	5	6	7	8	9	10	11	12
1	0.1568859	0.147081	0.137275	0.12747	0.117664	0.107859	0.098054	0.107859	0.117664	0.12747	0.137275	0.147081
2	0.1568859	0.147081	0.137275	0.12747	0.117664	0.107859	0.098054	0.107859	0.117664	0.12747	0.137275	0.147081
3	0.1568859	0.147081	0.137275	0.12747	0.117664	0.107859	0.098054	0.107859	0.117664	0.12747	0.137275	0.147081
4	0.1568859	0.147081	0.137275	0.12747	0.117664	0.107859	0.098054	0.107859	0.117664	0.12747	0.137275	0.147081
5	0.1568859	0.147081	0.137275	0.12747	0.117664	0.107859	0.098054	0.107859	0.117664	0.12747	0.137275	0.147081
6	0.3230286	0.302839	0.28265	0.262461	0.242271	0.222082	0.201893	0.222082	0.242271	0.262461	0.28265	0.302839
7	0.5951729	0.557975	0.520776	0.483578	0.44638	0.409181	0.371983	0.409181	0.44638	0.483578	0.520776	0.557975
8	0.9812742	0.919945	0.858615	0.797285	0.735956	0.674626	0.613296	0.674626	0.735956	0.797285	0.858615	0.919945
9	1.4477137	1.357232	1.26675	1.176267	1.085785	0.995303	0.904821	0.995303	1.085785	1.176267	1.26675	1.357232
10	1.9112612	1.791807	1.672354	1.5529	1.433446	1.313992	1.194538	1.313992	1.433446	1.5529	1.672354	1.791807
11	2.2578884	2.11677	1.975652	1.834534	1.693416	1.552298	1.41118	1.552298	1.693416	1.834534	1.975652	2.11677
12	2.3868764	2.237697	2.088517	1.939337	1.790157	1.640978	1.491798	1.640978	1.790157	1.939337	2.088517	2.237697
13	2.2578884	2.11677	1.975652	1.834534	1.693416	1.552298	1.41118	1.552298	1.693416	1.834534	1.975652	2.11677
14	1.9112612	1.791807	1.672354	1.5529	1.433446	1.313992	1.194538	1.313992	1.433446	1.5529	1.672354	1.791807
15	1.4477137	1.357232	1.26675	1.176267	1.085785	0.995303	0.904821	0.995303	1.085785	1.176267	1.26675	1.357232
16	0.9812742	0.919945	0.858615	0.797285	0.735956	0.674626	0.613296	0.674626	0.735956	0.797285	0.858615	0.919945
17	0.5951729	0.557975	0.520776	0.483578	0.44638	0.409181	0.371983	0.409181	0.44638	0.483578	0.520776	0.557975
18	0.3230286	0.302839	0.28265	0.262461	0.242271	0.222082	0.201893	0.222082	0.242271	0.262461	0.28265	0.302839
19	0.1568859	0.147081	0.137275	0.12747	0.117664	0.107859	0.098054	0.107859	0.117664	0.12747	0.137275	0.147081
20	0.1568859	0.147081	0.137275	0.12747	0.117664	0.107859	0.098054	0.107859	0.117664	0.12747	0.137275	0.147081
21	0.1568859	0.147081	0.137275	0.12747	0.117664	0.107859	0.098054	0.107859	0.117664	0.12747	0.137275	0.147081
22	0.1568859	0.147081	0.137275	0.12747	0.117664	0.107859	0.098054	0.107859	0.117664	0.12747	0.137275	0.147081
23	0.1568859	0.147081	0.137275	0.12747	0.117664	0.107859	0.098054	0.107859	0.117664	0.12747	0.137275	0.147081
24	0.1568859	0.147081	0.137275	0.12747	0.117664	0.107859	0.098054	0.107859	0.117664	0.12747	0.137275	0.147081

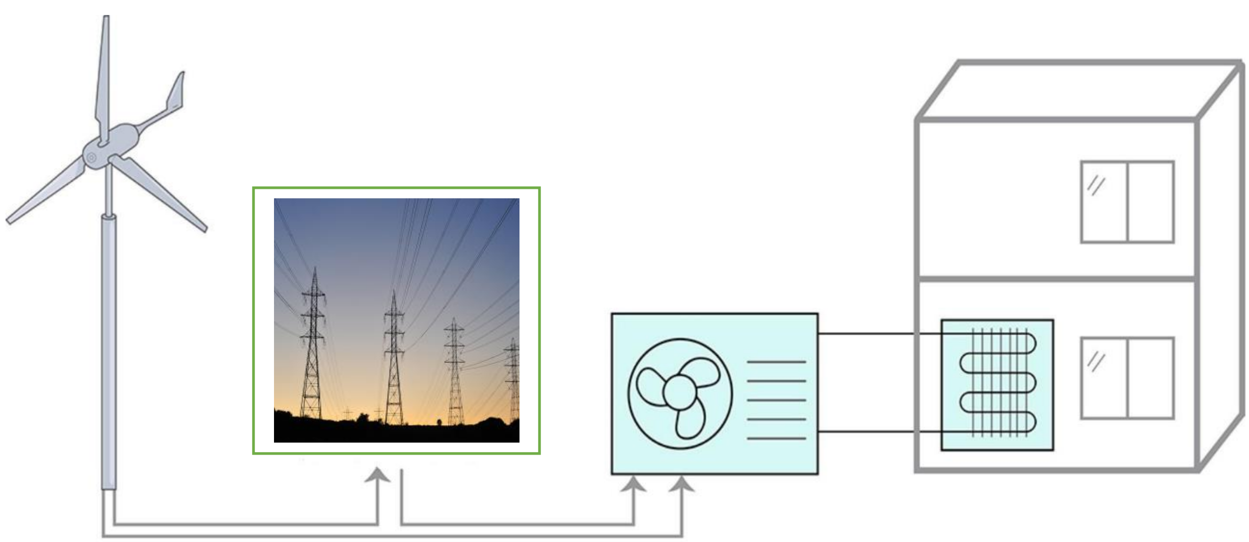
b) Scheme and system description:

In the beginning, a gas boiler was used as a heating source.



A new system was designed, and a new heating source was used.

A scheme illustrating the new system:



The house features an integrated and sustainable energy system that replaces the traditional gas boiler with a heat pump for efficient heating and cooling. A wind turbine is installed on the property, generating electricity by harnessing wind energy. The house remains connected to the electrical grid, acting as a reliable backup and allowing excess electricity from the wind turbine to be fed back into the grid. The integrated energy distribution system, equipped with smart controls and a thermostat, optimizes the use of renewable sources, adjusting settings based on occupancy and weather conditions. Safety features, including brakes and a yaw system for the wind turbine, ensure efficient and secure operation in varying conditions. This overall approach emphasizes energy efficiency and sustainability, reducing reliance on non-renewable resources like natural gas and providing a reliable, eco-friendly solution for heating and powering the house.

c) Real components with technical data

- According to the assumption of electrical demand each hour and the power needed for the heat pump, overall electrical consumption does not exceed 3 kW/h. After considering the wind-enriched location of the house, a wind turbine, a **3.5 kW** Wind Turbine System (Raum Energy), is selected with the expectation of operating at high capacity.

raum ENERGY

a revolution in wind energy

3.5 kW Wind Turbine System
Specification Sheet

Wind is a naturally occurring and abundant resource and is one of the cleanest ways to produce electricity. Very little processing needs to be done to convert it into clean, free energy. Operation of our wind turbines produces no pollution with no emissions, excessive noise or waste heat by-products. Wind can be harvested with minimal impact on the environment, a very important factor in meeting our increasing energy needs.

Synergy
- Solar
- Biomass
- Diesel Generator
- Hydroelectric
- Geothermal

Applications
- Commercial and Industrial
- Residential and Resort
- Agricultural
- Remote Communities
- Off-Grid Power
- Institutional and Public

Key Benefits
- Energy cost savings from wind generated power
- No scheduled maintenance
- Designed to reliably operate in harsh cold & hot climates
- Operation creates virtually no environmental impact
- Cost-effective and financially viable
- 5-Year Warranty

Turbine

Rated Power Output	3.5 kW
Energy Production*	500 kWh/month
Type	5 blades, downwind
Generator	Gearless, brushless, permanent magnet
Swept Area	12.6 m^2 (135 ft^2)
Blade Length	2 m (77 5/8")
Blade Material	Fibreglass reinforced plastic
Total Turbine Mass	81 kg (178 lb)
Voltage/Phase @ Rated Power	120 Vac peak
Current/Phase @ Rated Power	12 Aac peak
Generator NEMA Rating	Class F, 5 HP
Life Expectancy	> 20 years

*5.0 m/s (18 km/h) average wind speed, Rayleigh Distribution, Sea Level elevation

Operational Data

Rated Wind Speed	11 m/s (40 km/h or 24.4 mph)
Start-up Wind Speed	3.2 m/s (12 km/h or 7.5 mph)
No-Export Shutdown Wind Speed	25 m/s (92 km/h or 56 mph)
Furling Method	Active Braking System (ABS)
RPM at Rated Power	315 RPM
Survival Wind Speed	50 m/s (180 km/h or 112 mph)
Survival RPM	1,000 RPM

- **Heat Pump: (Air/water heat pump VITOCAL 200-a)**

An air/water heat pump extracts heat from the outdoor air through an evaporator containing a refrigerant with a low boiling point. The refrigerant absorbs heat as the air is drawn over the evaporator coils, causing it to evaporate. The vaporized refrigerant is then compressed by a compressor, increasing its temperature and pressure. The hot, pressurized refrigerant is directed to a condenser inside the building, transferring heat to a water-based heating system. The heated water can be used for space heating or providing hot water. The cycle continues with the refrigerant passing through an expansion valve, reducing its pressure, and returning to the evaporator. The system's efficiency extends to cold weather, making it suitable for year-round operation, and it can also operate in reverse for cooling. Advantages include high energy efficiency and environmental friendliness compared to traditional combustion-based heating systems.

Vitocal 200-A	**Type**	**AWO-M / AWO-M-E-AC**					
		201.A04	**201.A06**	**201.A08**	**201.A010**	**201.A13**	**201.A16**
Voltage	V	230	230	230	230	230	230
Heat performance data after EN 14511							
A2/W35	kW	2.6	3.1	4.0	5.0	6.92	6.47
Coefficient of performance (COP)		3.6	3.8	4.0	4.0	4.0	3.6
Output	kW	2.3 – 4.2	3.0 – 5.7	3.5 – 7.0	4.0 – 9.5	4.5 – 10.3	5.0 – 11.8
Heat performance data after EN 14511							
A7/W35, spread 5 K	kW	4.0	4.8	5.6	7.0	7.85	8.64
Coefficient of performance (COP)		4.6	4.7	4.7	4.7	4.7	4.5
Output	kW	3.2 – 5.7	3.8 – 6.6	4.6 – 8.5	5.0 – 12.6	5.0 – 13.7	5.5 – 14.3
Heat performance data after EN 14511							
A–7/W35, spread 5 K	kW	3.8	5.6	6.7	8.7	9.5	11.3
Coefficient of performance (COP)		2.9	2.7	2.9	3.1	3.1	2.8
Cooling performance data after EN 14511							
A35/W18							
Rated cooling capacity	kW	4.5	4.9	5.4	6.0	7.4	9.5
Energy efficiency ratio (EER)		3.4	3.6	3.8	3.6	3.7	3.3
Outdoor unit dimensions							
Length (depth)	mm	546	546	546	546	546	546
Width	mm	1109	1109	1109	1109	1109	1109
Height	mm	753	753	753	1377	1377	1377
Indoor unit dimensions							
Length (depth) x Width x Height	mm	370 x 450 x 880					
Weight							
Outdoor unit	kg	102	102	103	145	145	145
Internal unit type AWO-M, AWO	kg	40	40	40	40	40	40
Internal unit type AWO-M-E-AC, AWO-E-AC	kg	41	41	41	41	41	41
Cold circuit refrigerant		R410A	R410A	R410A	R410A	R410A	R410A
– Capacity	kg	1.4	1.4	1.4	2.4	2.4	2.4
– Global Warming Potential (GWP)		2088	2088	2088	2088	2088	2088
– CO_2-Equivalent	t	2.9	2.9	2.9	5.0	5.0	5.0
Energy Efficiency Class							
According to EU regulation Nr. 811/2013							
– Low Temperature Application (W35)		A++	A++	A++	A++	A++	A++
– Medium Temperature Application (W55)		A++	A++	A++	A++	A++	A++

d) Analysis of the working system (energy consumption)

- Heat energy consumption

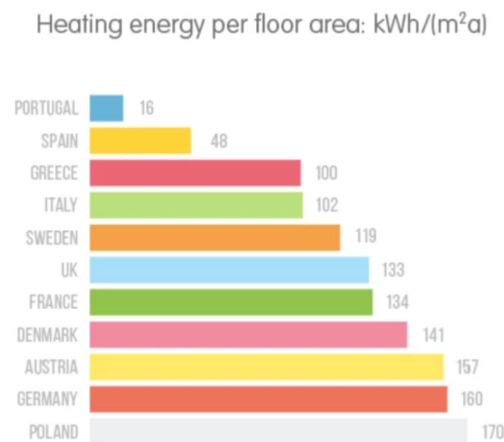
  According to:

$$\dot{Q} = \dot{Q}_{gained} + \dot{Q}_{losses}$$

$$\dot{Q}_{gained} = \dot{Q}_{solar} + \dot{Q}_{extra}$$

$$\dot{Q}_{losses} = H(T_{ambient} - T_{inner})$$

  - $\dot{Q}_{losses}$: Heat loss can be calculated by the product of temperature difference between room and ambient and the value "H". H value can be estimated by the assumption of "Heating Ratio", which is different depending on location and room component. In this project, the heating ratio is assumed as 140 kWh/m^2/year according to:



Source: https://www.ovoenergy.com/guides/energy-guides/how-much-heating-energy-do-you-use

Then, use the trial-error method to define the H value to achieve a heating ratio of approximately 440.

After modernization, assume that efficiency of heat pump is about 4 times to gas boiler. Therefore, the new heating ration is around 35 kWh/m^2/year. After trial-error, H value is around 160.

- $\dot{Q}_{extra}$: Heat dissipates from occupants and appliance
  - 2 Occupants in the house and heat gain from human is around 60W/person

Human Heat Gain		
Typical Application	**Sensible Heat (btu/hr) (W)**	**Latent Heat (btu/hr) (W)**
Theater-Matinee, Auditorium,	200 58.6	130 38.1
Theater-Evening, School	215 63	135 39.6
Offices, Hotels, Apartments	215 63	185 54.2
Retail & Department Stores	220 64.5	230 67.4

Source: Human Heat Gain (engineeringtoolbox.com)

  - List of appliances in the house, hours of usage, and heat dissipation

Appliance	t (h)	H (W)	H total (Wh)
Heater	8	300	2400
Refrig	24	200	4800
Oven	1	1000	1000
Microwave	1	800	800
Lighting (N=10)	8	50	400
Television	4	600	2400
		Total	11800

Total heat dissipation per day is 11800 W and 491.67 W an hour

  - $\dot{Q}_{extra} = 491.67 + 120 = \mathbf{611.67\ W}$
- $\dot{Q}_{solar}$: Heat radiation from the Sun, which can be obtained from:

$$\dot{Q}_{solar} = A_{window} * Transparency * G(i)$$

Where G(i) is Global irradiance on the inclined plane (plane of the array) (W/m2)

- Heat Pump Energy Supply (kWh) = COP × Electricity Consumed (kWh).

From MATLAB calculations, it indicates that:

Energy demand: $8.15*10^3$ kWh.

Heat pump energy supply: $4.48*10^4$ kWh.

e) Change in primary energy consumption

According to the calculation of the heat demand from MATLAB, which is equal to $3.14*10^4$ kWh, the estimated gas usage of a gas boiler with 95% efficiency is approximately 3133 cubic meters from the assumption that the gas is natural gas and use the following conversion ratio for simplification:

$$1\ m^3 = 10.55\ kWh$$

The assumption of the electrical demand of a household in Denmark is 5.6 MWh per year. After installing renewable energy sources, wind turbines can provide electricity for a total of

9.88 MW. However, after adding a heat pump, its power consumption has to be considered, which results in a total electricity demand of 8.07 MW annually. Moreover, the energy from wind turbines of 5.4 MW can be fed back to the grid, and the energy demand from the grid is reduced to 3.59 MW.

f) Investment cost and potential savings/incomes

- Investment
  - Wind turbine

    According to the research, the estimated cost of wind turbines includes turbine components, balance of plant, and installation
    - Turbine component: Including nacelle, rotor, and tower, which is around $1200/kw
    - Balance of plant: Including cables, foundation, and grid connecting components, which are around $760/kw
    - Installation: Until foundation installation and wind turbine commissioning is around $830/kw

Source: Wind farm costs – Guide to an offshore wind farm

List	$ for 1kW	$ for 3.5kW
Turbine component	1200	4200
Balance of plant	760	2660
Installation	830	3255
	Total	10115

  - Heat Pump

An air heat pump is selected, and investment costs include unit cost (around $4000) and installation cost (around $1500), which is approximately **$5500** in total.

Source: How Much Does A Heat Pump Cost? (2023 Guide) (thisoldhouse.com)

- Savings/incomes

All the sources of electricity in the primary system are from the grid. After changing the heat source from a gas boiler to an air heat pump and adding a wind turbine as a renewable source of power generation, it can be concluded that the system does not require natural gas for the gas boiler, and there is an additional source of electrical power supply when needed (considered as potential saving). Moreover, the excess power can feed to the grid and generate income for sell electricity. The following information illustrates energy prices, electricity and natural gas, and tariffs for selling electricity.

Energy prices

Prices of electricity for households with normal consumption	Prices of natural gas for households with normal consumption
2.8 DKK per kWh	**15.0** DKK per m3
First half of 2023	First half of 2023

Source: [Energy prices - Statistics Denmark (dst.dk)]

ENERGINETS ELTARIFFER I 2024	
FORBRUGERE BETALER	
Nettarif (energitarif)	7,4 øre/kWh
Systemtarif (energitarif)	5,1 øre/kWh
For andelen af forbrug over 100 GWh/år	0,51 øre/kWh
Systemabonnement (pr. forbrugsmålepunkt)	180 kr./år
PRODUCENTER BETALER	
Indfødningstarif i forbrugsdominerede områder	0,3 øre/kWh
Indfødningstarif i produktionsoverskudsområder	0,9 øre/kWh
Balancetarif for produktion	0,24 øre/kWh
BALANCEANSVARLIGE AKTØRER BETALER	
Gebyr for balancekraft	0,1 øre/kWh
Ugentligt gebyr	30 EUR/uge

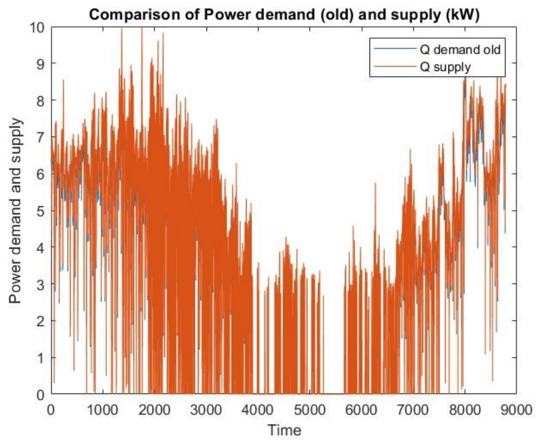
Source: [Aktuelle tariffer (energinet.dk)]

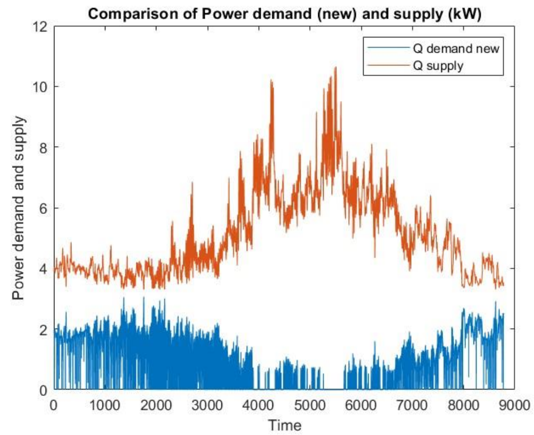
After calculating electrical savings (converting Danish Krone to US Dollar), before and after installation, wind turbines result in less electrical consumption from the grid before and after installation. The system can save **$3,898 per year**. The excess power can generate an income of about **$4,859 per year**. Lastly, it can save **$6,579** a year from natural gas supply.

In summary, the total investment in wind turbines and heat pumps is **$15,615**, while the net gain, which includes electrical and gas-saving and electrical supply to the grid, is about **$15,335 per year**. The payback period is around **2 years**, which means the system can generate income of around **$4,900 per year** (not including savings) in the following year.

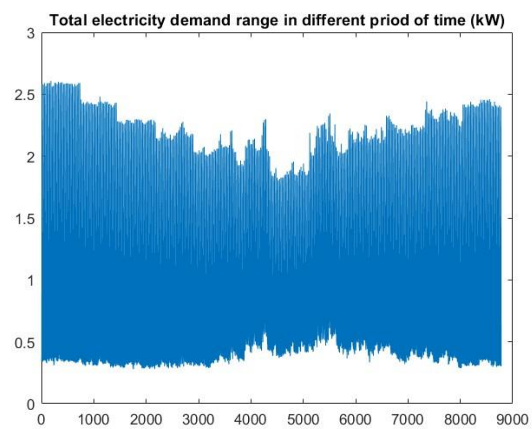
g) Visualization of the results (graphs)

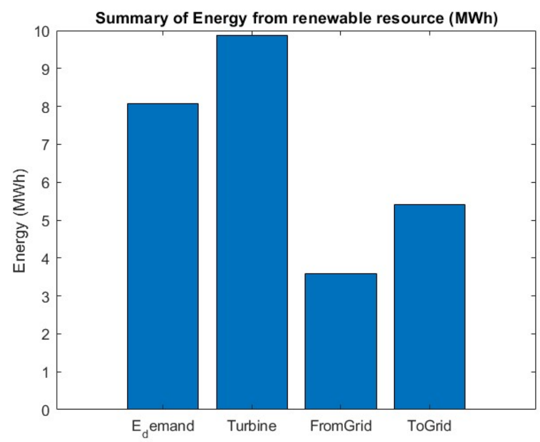
- Heat demand and supply for old and new system



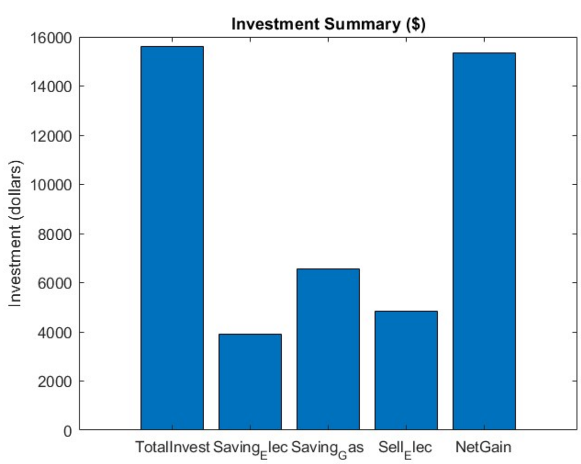


- Electricity demand and renewable resource





- Investment



h) conclusions

The modernization plan for a coastal detached house in Denmark emphasizes leveraging abundant wind resources for enhanced energy efficiency. The transition from the gas boiler to a high-efficiency heat pump aligns with European regulations, complemented by targeted energy-saving measures and optimized heating distribution systems. It can supply heat about 4.48×10^4 kWh/year and an electricity demand of 8.07 MW annually (including a power supply to the heat pump). The plan integrates renewable electricity sources, exploring the potential of a small wind turbine in a wind-rich environment, which can produce energy in a total of 9.88 MW per year. Financial considerations, including investment costs, $10,115 for a wind turbine and $5,500 for a heat pump. The system provides income streams from feed-in tariffs, $4,859 in total, and energy savings, $6,579 for gas savings, and $3,898 for electrical savings, which are carefully assessed for long-term viability. The payback period is approximately 2 years after considering a total investment of $15,615 and the sum of income-generating and energy-saving, a total of $15,335. Additional elements like electrical power consumption, changes in power from the grid after installing the wind turbine, system investment, energy savings, income from selling energy, and the payback period are considered in a comprehensive analysis. This holistic approach ensures regulatory compliance, maximizes energy efficiency, and harnesses coastal wind resources for environmental and economic benefits.