M.Sc. Project Proposal Written Description

Project title:

Harnessing Wind Energy for Sustainable Heating in Cold Regions: A Comparative Study of Direct Wind-Powered Heating, Heat Pump Systems, and Hybrid Solutions for Icelandic Communities

Student:

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Course:

T899-MEIS 30 ECTS

Introduction / Background:

The project explores innovative heating solutions for rural regions, focusing on integrating wind energy with thermal storage and heat pump systems. With increasing global emphasis on renewable energy and energy autonomy, this work addresses the challenge of providing efficient, cost-effective heating in areas lacking geothermal resources, such as Þórshöfn, Iceland. The project is highly relevant at both academic and industry levels, as it bridges advancements in wind energy, thermal storage, and heat pump technologies, while tackling practical challenges like energy conversion losses, system integration, and economic feasibility.

Specifically, the investigation centers on comparing three heating options: (1) direct coupling of wind turbines with water heating elements, (2) wind-powered heat pumps using shallow boreholes, and (3) a hybrid system combining heat pumps with vertical borehole heat exchangers and wind-powered water heating.

By evaluating technical and economic feasibility, the project aims to identify the most efficient and sustainable solution for localized heating, contributing to energy independence and reduced reliance on fossil fuels in rural communities. This work aligns with global decarbonization goals and offers scalable insights for other regions.

Review of the current state of knowledge:

Cold and rural regions like Þórshöfn face unique heating challenges due to the absence of geothermal resources. Current heating solutions in such areas often involve fossil fuels or electric resistive heating, which may not be sustainable or cost-effective.

According to a report by Byggðarstofnun [1]. Regions that cannot rely on geothermal heat rely either on direct resistive heating (e.g Þórshöfn, Kirkjubæjarklaustur), or a distribution system of water that's heated, either with electricity or by burning oil (kynt hitaveita), (e.g Kópasker, Ísafjörður). The price of heating a reference home with direct electrical resistive heating in regions without access to a geothermal resource in 2023 was 197 thousand ISK, but it could reach 99 thousand ISK when using a heat pump, which is near the average price for heating a reference home with geothermal heat.

Heat pump systems are widely recognized for their efficiency in extracting geothermal heat. Pairing heat pumps with windmills in rural regions without geothermal access would increase energy autonomy by decreasing their reliance on access to the grid, which is sometimes unreliable in the winter, when heating is needed the most. Heat demand is also seasonally correlated with windmill power output.

The proposed project builds on these advancements by exploring tailored solutions for Icelandic communities lacking geothermal resources. It addresses gaps in knowledge by comparing direct wind-powered heating, heat pump systems, and hybrid approaches, while incorporating thermal storage and economic analysis.

Goal, research question, aim/objectives:

1. Can coupling a wind turbine with a water heating element (with/without battery storage) provide a cost-effective heating solution in cold regions?
2. How does a wind-energy-based heating system compare to water-to-water heat pump systems in terms of energy efficiency and practicality?
3. What are the efficiency and cost benefits of combining heat pumps with vertical borehole heat exchangers and wind-powered water heating during peak cold periods?
4. What are the operational and economic trade-offs of direct wind-powered water heating versus hybrid systems using heat pumps?

Research Objective:

The main research objective of this project is: *To identify the most efficient, sustainable, and cost-effective heating solution for cold regions by means of comparing three systems—direct wind-powered water heating, wind-powered heat pumps, and hybrid systems combining heat pumps with wind-powered water heating—through technical simulations, economic analysis, and integration with local energy infrastructure.* This will enable communities like Þórshöfn to achieve energy autonomy and reduce reliance on fossil fuels.

Methods:

The project is grounded in renewable energy systems theory, focusing on wind energy conversion, thermal storage, and heat pump efficiency. Key literature includes studies on decarbonizing rural heating systems [2], heat pump performance in cold climates [3], and thermal energy storage [4]. The work will also draw on simulation and optimization frameworks for energy systems design. A simulation model will be developed using software like MATLAB or Simulink to analyze system performance under varying conditions.

Citations/References:

[1] Byggðastofnun, "Samanburður á orkukostnaði heimila árið 2023", 2024, available: https://www.byggdastofnun.is/static/files/Orkukostnadur/2023/orkukostnadur-heimila-arid-2023.pdf

[2] F. Padovani, N. Sommerfeldt, F. Longobardi, and J. M. Pearce, "Decarbonizing rural residential buildings in cold climates: A techno-economic analysis of heating electrification," *Energy and Buildings*, vol. 250, p. 111284, 2021, doi: 10.1016/j.enbuild.2021.111284.

[3] S. J. Self, B. V. Reddy, and M. A. Rosen, "Geothermal heat pump systems: Status review and comparison with other heating options," *Applied Energy*, vol. 101, pp. 341–348, 2013, doi: 10.1016/j.apenergy.2012.01.048.

[4] I. Dincer and M. Rosen, *Thermal Energy Storage: Systems and Applications*, 2nd ed. Wiley, 2010, pp. i–xix. doi: 10.1002/9780470970751.

Schedule:

What are the specific milestones of the project?
Look at the logistics of carrying out the work, develop the intended outcome, and incorporate it into a work schedule, possibly through a Gantt chart or Integrated Master Plan/Integrated Master Schedule.

Milestone 1: Project initiation and planning

- Finalize project scope, objectives, and research questions.
- Develop a detailed project plan, including timelines.

Outcome: A clear roadmap for the project, including a work schedule.

Milestone 2: Data collection, and definition of simulation parameters

- Collect data on wind energy potential in Þórshöfn.
- Collect data on heating demand in Þórshöfn.
- Identify key variables for the simulation model (e.g., energy demand, wind speed variability, tank sizing, heat pump efficiency).

Outcome: Simulation framework and parameter list.

Milestone 3: Develop simulation model.

- Create a simulation model to optimize system dimensions and evaluate energy storage and distribution options.
- Test scenarios for water heating elements, heat pumps, and hybrid systems.

Outcome: Functional simulation model.

Milestone 4: Evaluate Energy Conversion and Storage Options

- Analyze energy conversion losses for water heating elements and heat pumps.
- Compare insulated water tanks (thermal storage) vs. battery storage solutions.

Outcome: Technical feasibility report.

Milestone 4: Economic feasibility analysis

- Estimate installation, operational, and maintenance costs for each heating system option.
- Compare long-term cost-effectiveness of wind-powered heating systems vs. conventional district heating.

Outcome: Economic feasibility report.

Communication Plan:

Meetings with Ármann every Wednesday at 12:00 at his office in RU.
Meetings with Hafsteinn when he's free on Microsoft Teams.

Signature of Student:

Arnar Gylfi 2025/2/1

Approval: Signature of Supervisor:

Full name & date (email approval is accepted)