Case study 2023-2024

Work Plan

Matching residential cooling demand with rooftop PV

Andrej Bernhard

Hannah Livingston

Lukas Schmidt-Engelbertz

Clara Tillous Oliva

Fiona Turner-Hehlen

Coach

Simen Kjørstad

Industry Partner

Filippo Tani (BKW)

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1 Introduction

The escalating threat of climate change, characterized by rising temperatures and therefore an increased cooling demand, has intensified the global search for sustainable energy solutions. This urgency is underscored by the need to reduce dependence on traditional energy sources. In this context, the intersection of cooling demand and photovoltaic (PV) generation is emerging as a critical linkage for achieving energy efficiency and environmental sustainability. Europe, as a diverse and dynamic continent, offers a unique landscape for assessing the potential of combining PV and cooling systems, considering variations in climate, building structures, and energy consumption patterns.

BKW, a world leader in the development of energy solutions for buildings and networks, wants to assess the future demand for cooling and the extent to which it could be met by installing PV cells at a residential level. This assessment involves a multi-faceted approach, including the development of a bottom-up physical model to estimate time-resolved cooling demand in residential buildings. At the same time, a detailed time-resolved PV generation model is constructed, integrating outdoor irradiance and geographical factors. The calibration of constant factors for both models and the projection of these models into the future up to 2050 with time-dependent parameters further contribute to the comprehensive nature of the study.

This work plan outlines the process required to successfully carry out this analysis. Section 2 sets out the goals and non-goals of the project, clearly stating what the boundaries of our study should be. This is followed in Section 3 by the project deliverables, which lead to our previously stated objectives. Breaking this down to even smaller levels, the work breakdown and deliverables in Section 4 clearly state each step that needs to be taken. Section 5 briefly enumerates the resources we have available to develop the analysis and addresses the constraints that need to be considered. Finally, Section 6 summarises the previously developed plan into a detailed schedule, indicating who is responsible for each task.

2 Project Goals and Non-Goals

2.1 Project Goals

Our main goal is to model both cooling demand and photovoltaic capacity of individual average Swiss dwellings. The types of dwellings will be modelled by three distinct categories: apartment buildings, multi-family houses and single-family houses. In a second step, these models shall be scaled up to encompass total Swiss cooling demand and PV capacity. Other countries shall be modelled in a similar fashion. For this, a time-resolved physical model of buildings portraying temperature dynamics based on weather and building parameters will be developed, and coupled with a time resolved output of PV production from a rooftop PV system. From this we want achieve the following goals:

1. To gain a better understanding of the ability of a household PV system to meet household electrical cooling demand on an individual level.

2. To scale our findings to Switzerland and to extend the model to the entire ENTSO-E region.

3. To analyse how the increase of hotter days will impact the correlation between PV and cooling demand.

4. If time allows, to estimate the impact of other technologies coupled to the system (heat pump, energy storage, among others).

2.2 Project Non-Goals

Project non-goals were defined in order to avoid confusion and to clearly identify the intended output of the project. The project non-goals are the following:

1. To model the cooling demand of commercial or industrial buildings.

2. To perform an economic analysis or provide a business case for BKW.

3. To model the possible interactions between buildings and the power market.

3 Project Objectives

To achieve our goals they are divided into smaller objectives. In a first sequence, the relevant data has to be acquired and cleaned up to make data processing easier. Secondly, a valid cooling model and a valid PV model are to be coded. Data is then fed into the model to test its reliability upon studying the results and comparing them to reliable third party sources. Finally, the two models are combined to analyse how well cooling demand can be covered by PV generation.

1. Create a physical model of three types of residential buildings with rooftop PV installations to measure electrical cooling demand based on time-resolved temperature and irradiance data compared with the output of the PV-array to determine how much of the cooling demand could be supplied by PV.

2. Use the model with region specific parameters to generate data regarding the ability of PV generation to match cooling demand in different countries in the ENTSO-E region throughout the year.

3. Use the model to project how total cooling demand and grid electricity consumption will increase based on increased temperatures due to climate change until 2050.

4. Analyse how adding local storage could increase the ability of rooftop PV to match cooling demand for a single home throughout the day and year. Data will include predictions as temperatures rise further with climate change, and how the addition of local energy storage can improve the synergy.

5. Use the building energy model to determine the amount of energy needed to heat the buildings and discuss how heat pumps could help to accomplish this.

4 Work Breakdown and Deliverables

4.1 Work Breakdown

1. **Determine and assemble, based on best modelling practices from literature, what data will be fed into the models**

    - Gather relevant meteorological data: Hourly temperature and solar irradiance data from the MERRA-2 reanalysis data set.

- Estimate average parameters (size of rooftop, degree of thermal insulation, etc.) of Swiss and European residential buildings as inputs into PV and cooling model
  - Gather data on these parameters for three types of residential buildings in Switzerland.
  - Gather data for a typical residential building in each ENTSO-E member country
  - Estimate how these parameters may change until 2050

2. **Develop a Cooling Demand model that outputs the amount of energy required to cool a residential building for each hour of the day for 1 year.**
   - Design a model framework based on cooling models discussed in the literature review and those currently used by BKW, which incorporates specific building parameters such as degree of insulation and thermal inertia.
   - Use R to implement the model's framework. The model will take a time series of temperature and irradiance data and will output an hourly time series of the power required to maintain a comfortable temperature for occupants, based on the building parameters and the coefficient of performance of the cooling system.

3. **Develop a model that outputs the amount of electrical energy that a rooftop PV system generates every hour of the day for 1 year.**
   - Become familiar with the SolaR program, which will be used to model a sample PV array
   - Based on literature, determine an average PV array size and region specific parameters such as inclination angle that will be used as inputs into the SolaR model.
   - Use SolaR to output an hourly time series of PV production from a rooftop array for a residential building.

4. **Integrate the Cooling Demand and SolaR models to determine the number of hours per year that the PV generation can fully match cooling demand, percentage of total hourly demand that can be matched by PV.**
   - In R, compare the time series of electricity supply to demand, subtract the output of the PV array from the cooling demand model to determine the percentage of the time that the cooling demand is able to be satisfied by PV production.
   - Visualize the data in the form of plots to gain a better understanding of the correlation.

5. **Using the robust models generated, rerun the simulation with the following parameters to gain further insight on the synergy of PV generation and cooling.**
   - Change building parameters to model additional types of residential building ie. apartment, single family house.
   - Using data from other countries, simulate output for other countries in the ENTSO-E region.

- Using average predicted temperature data, generate an output that will model the behaviour until 2050.
- Adapt the model to add the ability to store excess generated PV energy to meet cooling demand in a later hour. Run the model to determine how much this affects the outcome.
- Use the model to determine the total amount of electricity needed to heat or cool the building hourly over the course of the year to analyse how heat pumps may interact with PV generation.

6. **Present the model and findings of this study to BKW as an analysis tool to determine the present and future benefit of using rooftop PV systems to meet rising cooling demands of residential buildings.**

4.2 Deliverables

1. Integrated PV and cooling model coded in R
2. Written report describing findings and analysis
3. Final Presentation to industry partner

5 Resources and Constraints

In this section we look at our main resources and also at the main constraints that need to be taken into account for the project.

5.1 Resources

Our resources include extensive temperature and solar irradiance data over the last decade, validated building cooling and photovoltaic generation models accessible via R and R libraries, and specific R libraries provided by BKW itself that add to our toolkit. Alongside these assets, team discussions will be a key resource in the successful implementation of the project. The collaboration, insight and diverse perspectives fostered within our team serve as the cornerstone for innovative problem solving and effective execution throughout our project. Finally, we benefit from BKW's invaluable industry expertise, which enriches our insights and solutions in this area.

5.2 Constraints

Our main constraints include the limited availability of future temperature and solar irradiance data up to 2050, which requires the use of average estimates that can significantly affect the accuracy of the results. In addition, the accurate determination and setting of numerous parameters for both PV generation and cooling demand are critical, as their correct configuration has a significant impact on model accuracy. Here, a range of parameter settings can be expected in the relevant literature, making it very difficult to assume the real average that best represents the locations analysed in our study.

6 Project Schedule

Task	Duration	Start Date	End Date	Leader
1. Gather important data and develop cooling demand and PV generation model.				
1.1 Develop the bottom-up physical model of 3 types of residential buildings to estimate time-resolved cooling demand. Paying special attention to buildings' inertia and outdoor temperature levels.	4 Weeks	19.02.2024	18.03.2024	Lukas
1.2 Develop time-resolved PV generation model which takes outdoor irradiance and geographical factors into account.	4 Weeks	19.02.2024	18.03.2024	Hannah
1.3 Gather relevant data (1) to calibrate constant factors of PV generation and cooling demand model and (2) to project models into the future up to 2050 with time-dependent parameters.	4 Weeks	19.02.2024	18.03.2024	Clara
1.4 Join both models to compare PV generation and electricity cooling demand on a simple residential level. Subsequently, scale up the size of the problem to represent cities and countries.	1 Week	11.03.2024	18.03.2024	Fiona
2. Make improvements to the model and run with test cases.				
2.1 Meet with BKW and receive first feedback on model.	1 Day	18.03.2024	25.03.2024	Clara
2.2 Run the model for various test cases. Predominantly changing two type of settings: country and year.	3 Weeks	18.03.2024	15.04.2024	Lukas
2.3 Validate the results by comparing to real-world data and other results stated in related literature.	3 Weeks	18.03.2024	15.04.2024	Andrej
3. Gather results and prepare final deliverables.				
3.1 Write the final report. Summarize the results of the bottom-up residential cooling/PV model. What implications does this have? What could be the next steps to improve the model?	3 Weeks	15.04.2024	06.05.2024	All
3.2 Prepare final presentation.	2 Weeks	22.04.2024	06.05.2024	All
3.3 Practice final presentation. Make last changes on the report.	1 Week	06.05.2024	13.05.2024	All

Table 1: Project schedule

Calendar Week	8	9	10	11	12	13	14	15	16	17	18	19	20
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Table 2: Gantt chart of project schedule