The Effect of Climate and Orientation on the Energy Performance of a Prefab House in Norway

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Abstract

Norway has a wide range of climatic conditions throughout the country. The climate varies from coastal to inland areas. Geographic latitude and longitude, as well as the gulf stream oceanic flow, account for this phenomenon. Different climate types can certainly affect residential building heating energy demands and make overheating more likely. On the other hand, a building's orientation has an impact on its heating energy requirements. A building's orientation affects how much solar gain it receives and how much wind it receives over the course of the year. Employing DesignBuilder® software, This study examines how different orientations affect the energy performance of a pre-designed house with and without solar photovoltaic panels in typical Norwegian climates. The results confirm that in different locations, the optimal situation is South-East and the lowest energy consumption without and with photovoltaic panels belongs to Bergen with 83305 Wh/m^2 and Oslo with 29442 Wh/m^2 respectively. This comparative study will be helpful to stakeholders in the building ecosystem (municipalities, engineers, and designers, building companies, suppliers, and residents) in making more informed decisions.

1. Introduction

Norwegian households used 48 TWh of energy, or 22 percent of the total energy consumed (Statistics Norway, 2021). The non-residential sector contributes almost 18% of total energy which implies that almost 40 percent of the final energy consumption in Norway comes from the building stock (Sartori et al., 2009). Generally, these statistics apply to western countries as well (*EU Energy and Transport in Figures*, 2009). Efforts are being made by the Norwegian authorities to reduce the energy demand for buildings (Korsnes et al., 2013). Recent revisions to the technical building regulations (TEK17, 2017) require greater insulation, heat recovery, and airtightness than earlier versions.

In the household as well as in the service sector, electricity is the most widely used energy carrier (Fig. 1). Electricity has been increasing in the energy mix, reaching 83% in 2017 and this confirms the importance of the possibility of generating electricity from the house itself via solar panels. The second largest portion of household energy is derived from biofuels. About 5.8 TWh of energy was generated by biofuels in 2017. Fuelwood constitutes the majority of this energy, but pellets and bio-oils are also used by households. (“Energy use by sector”)

Often referred to as prefab or modular homes, prefabricated houses are manufactured off-site and then transported to the building site for final assembly. Assembling prefabricated houses involves precutting and prefabricating building components, such as walls, roofs, floors, and doors, in a controlled environment before they are transported to the building site. In general, predesigned and prefabricated homes offer several advantages, including lower costs, energy efficiency, and versatility, making them an increasingly popular choice in many countries. Due to these factors, Scandinavia and Norway have a long history of using prefabricated houses.

There can be a significant impact on the amount of energy required to heat and cool a house based on the local climate. In cooler climates, for instance, homes require more energy to stay warm in the winter, while in warmer climates, homes require more energy to stay cool in the summer. On the other hand, a house's orientation can also affect its energy efficiency. It is possible to reduce the amount of energy required for heating a residence with large windows facing the south during the winter months by utilizing natural solar heat gain. South-facing windows, however, can increase heat absorption by the home in hotter climates, which increases cooling energy requirements. In addition to influencing the amount of natural light that enters a home, the orientation can also have a significant impact on the energy consumption of the home by reducing the need for artificial light.

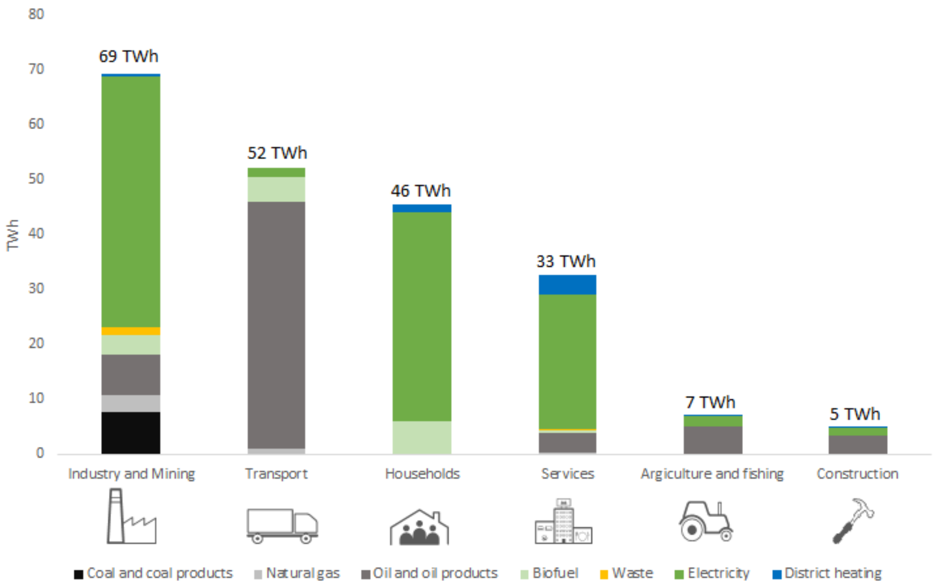

Figure 1: Norway's final energy consumption by energy carrier in 2020 (adapted from ("Energy use by sector"))

In the present study, a pre-designed house in five different typical Norwegian climates was tested to answer the following: 1) In different climates, how does a house's orientation affect its energy efficiency? 2) What is the optimal orientation for the house in the selected location? 3) What is the effect of climate on energy consumption? 4) What is the effect of solar photovoltaic panels on the energy consumption of a house in different climates? A bioclimatic paradigm was used to assess the operational energy and daylight performance of this type of building in various climates.

2. Literature Review

Nordic countries' cold climate and abundance of natural resources have created unique challenges and opportunities in the field of energy efficiency. This has resulted in a significant amount of research being conducted on the energy performance of these countries (Abrahamsen et al., 2023; Carpino et al., 2020, 2020; Cohen et al., 2007; Liu et al., 2015; Mahapatra & Olsson, 2015; Molin et al., 2011; Tommerup et al., 2007).

Many factors can affect the energy efficiency of a house, including the climate (Cronin et al., 2018; Li et al., 2021) and its orientation (Abanda & Byers, 2016; Albatayneh et al., 2018; Elghamry & Azmy, 2017; Lahmar et al., 2022). There have been numerous studies that examine the effects of climate, building orientation, location, etc. on a building's energy performance. In particular, the orientation of the façade has a significant impact on the performance of building integrated photo voltaic (BIPV) on façades (Akbarinejad et al., 2022). As a consequence of the relatively symmetrical sun path throughout the day, it is difficult to determine the of a building located in a warm-humid climate. Nicoletti et al. (2022) employed EnergyPlus to evaluate the energy and visual performance of a building with photochromic glazings in southern Italy. By considering five climatic locations in Saudi Arabia, Alyami et al. (2022) examined the effects of location and insulation material on the energy efficiency of residential buildings. By observing and conducting experiments on four existing buildings, Khaliq and Mansoor (2022) determined the effectiveness of energy consumption, as well as developing a model based on different contributing parameters, including orientation, construction materials, construction type, etc. Morsali et al. (2021) investigated the effects of building direction and roofs on the energy consumption of residential buildings through simulations using Building Information Models. Abdul Mujeebu and Ashraf (2020) examined the impact of location and range of thermostat set points for cooling and heating on nano gel glazing energy performance and economics in a multistory office building, considering 26 climatic regions across Saudi Arabia. Various climate regions, Lapsia (2019) investigated the effect of its geometric shape and orientation on its energy performance. Fela et al. (2019) evaluated the impact of climate on daylight performance in a reference office in which there is only one glazed opening, and on which a range of window-to-wall ratios are measured on one of the short façades facing a variety of orientations. Tab. 1 summarizes the results from the literature review. optimal façade orientation for tropical cities in terms of maximum energy yield and daylight performance. On tropical building façades, Mangkuto et al. (2023) determined the optimum orientation for BIPV. Karthick et al. (2023) examined the effects of building orientation, window glazing, and shading techniques on the energy efficiency and comfort.

Table 1: Summary of literature review

References	Main Parameter	Climate	Software	Location
(Mangkuto et al., 2023)	Building Orientation	Tropical		Indonasia
(Karthick et al., 2023)	Building Orientation, Window Glazing, and Shading Techniques	Warm-Humid	DesignBuilder, EnergyPlus	
(Nicoletti et al., 2022)	Building Location, Window Glazing		EnergyPlus	Southern Italy
(Alyami et al., 2022)	Building Location and Insulation Material	Hot-Humid	IES-VE	Saudi Arabia
(Khaliq & Mansoor, 2022)	Orientation, construction materials, type of construction			Pakistan
(Morsali et al., 2021)	Roof shapes and building orientation		REVIT	
(Abdul Mujeebu & Ashraf, 2020)	Location and deadband	Hot-Humid	Ecotect	Saudi Arabia
(Baruah & Sahoo, 2020)	Orientations, location types of roof surfaces, walls and fenestrations	Sub-tropical humid climate with dry winter conditions	eQUEST	Himalayan terrain of India
(Lapisa, 2019)	Different climates, geometric shapes, and orientation		TRNSYS, CONTAM	Jakarta, Marseille, and Poitiers
(Hammad et al., 2018)	Location and design of windows		Green Building Studio	The middle east and north africa (MENA)
(Dobosi et al., 2019)	Various locations		EnergyPlus in Sketchup	Romania
(Fela et al., 2019)	Orientation, window size, and lighting control	Tropical area	Radiance and Daysim	Indonesia
(Košir et al., 2018)	Location’s climatic specifics		EnergyPlus in OpenStudio	
(Elhadad et al., 2018)	Building orientation		IDA ICE 4.7	Egypt
(Khan & Asif, 2017)	Green roof and building orientation	Hot-Humid	Ecotect	Saudi Arabia
(Poddar et al., 2017)	Building orientations and seasonal variations		DesignBuilder, EnergyPlus	South Korea
(Diaz & Osmond, 2017)	Various locations	Hot-Humid Tropics	WUFI Plus	Location

3. Simulation Setup

A pre-designed two-story Norwegian house (Fig. 2) was designed in accordance with the spaces and areas specified in Tab. 2.

To meet the requirements of the Norwegian regulations, the materials used in this house have been selected so as to meet the requirements of the TEK 17 standard (*Byggteknisk Forskrift (TEK17) Med Veiledning*, 2017), which has been adopted by the Norwegian government. A summary of the requirements for external walls, roofs, floors, and windows prescribed by TEK 17 can be found in Tab. 3.

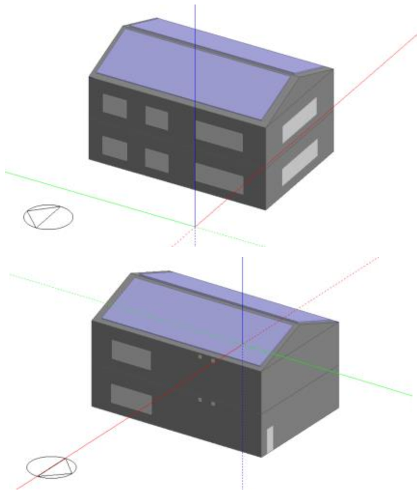

Figure 2: The overview of the building

Table 2: Names and areas of the building spaces

	Name of Areas	**Area (m^2)**
First story	Living Room	85.825
	Kitchen	10.954
	Toilet-Bathroom	5.995
	Bedroom 1	20.289
	Bedroom 2	17.351
	Hallway	10.144
Second story	Living Room	85.825
	Kitchen	10.954
	Toilet-Bathroom	5.995
	Bedroom 1	20.289
	Bedroom 2	17.351
	Hallway	10.144
	Total Area of Each Story	**150.558**
	Total Area of the Building	**301.116**

Table 3: Comparison of standard requirements and used values for the simulations

Small house (150 m^2)	**Requirement of TEK 17**	**Used**
U-value outer walls [W/(m^2 K)]	≤ 0.18	0.176
U-value roof [W/(m^2 K)]	≤ 0.13	0.127
U-value floors [W/(m^2 K)]	≤ 0.10	0.094
U-value windows and doors [W/(m^2 K)]	≤ 0.80	0.78
Proportion of window and door areas of heated gross internal area	≤ 25%	≤ 25%

The heating system of the house is ground heating fed by a hot water boiler which uses electricity from the grid to heat the water and has a coefficient of performance (CoP) equal to 0.65 (the default CoP specified in the software's library for this system). Due to the climate characteristics, no cooling system is considered for the house.

Noteworthy to indicate is that the ventilation rate has been set to 0.5 air change per hour (the minimum permitted amount) (Dimitroulopoulou, 2012) and the air infiltration rate has been set to 0.3 air change per hour as it must be under 0.6 (Bunkholt et al., 2021).

Moreover, to check the possibility and the amount of electricity generation by solar energy in each city, the pitched roof of the building is covered with solar photovoltaic (PV) panels with characteristics such as area of the PV panel equal to 128 m^2, efficiency of 0.15, and fraction of surface with active solar cells equal to 0.9.

Similar to many other studies and simulations, our study has also limitations. There are other parameters to be set based on the DesignBuilder® software requirements which have been set as the default value of the software itself. Moreover, as mentioned above, there are some critical parameters such as CoP, air infiltration and ventilation rates which the results are sensitive to them, so they are worthy to be studied in the future.

From another point of view, as seen in the next section, only eight main orientations have been considered in the simulations. And necessarily the optimum orientation is not among these. In addition, the shading effect of other buildings has not been considered in this study and the slope of the PV cells has been set as the slope of the roof which is not necessarily optimum.

4. Results and Discussion

As a result of setting up all the above parameters in the DesighnBuilder® software, five Norwegian cities with differing climates were selected as the locations for the house, namely Oslo, Trondheim, Tromsø, Kristiansand, and Bergen. Throughout each city, one simulation has been performed for each direction (south, south-east, east, north-east, north, north-west, west, south-west). To calculate the energy consumption and energy generation of PV panels during the year, as well as the percentage of energy consumption reduction with generation during the year, the house was rotated in the eight directions listed above. As a result, the data referred to above were exported and are shown in Appendix A.

The simulations show that the lowest energy consumption in each city can be reached in the facing into the direction of south-east with the amount of 87715, 102530, 135250, 87759, 83305

[Wh/m^2] per year for Oslo, Trondheim, Tromsø, Kristiansand, and Bergen respectively (Fig. 3).

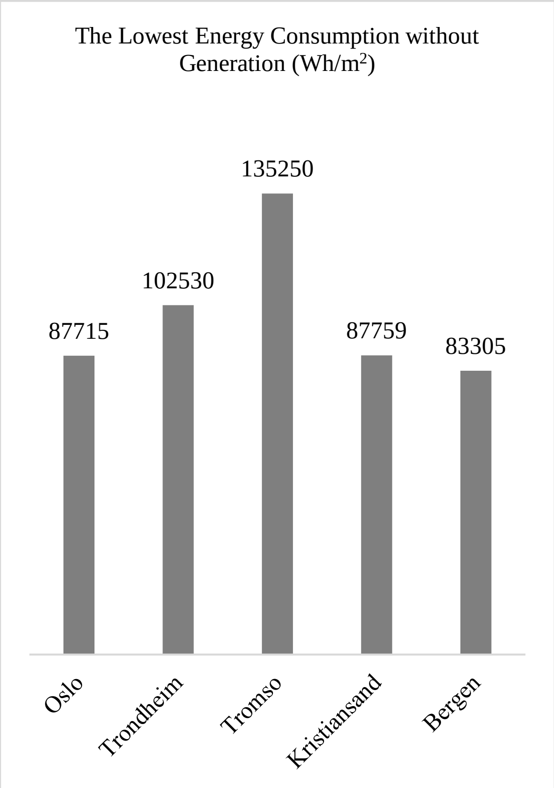

Figure 3: The lowest energy consumption in the cities among all orientations

Furthermore and as it could also be expected, Tromsø and Trondheim have the highest yearly energy consumption, which is the result of their geographical location and climate.

Interestingly, the highest energy generation with the PV panels is available in a different facing in comparison to the facing with the lowest energy consumption in each city. The PV panels are able to produce the highest amount of energy in the facing into the West with the amount of 58366, 58920, 49770, 58366, and 49073 [Wh/m^2] per year for Oslo, Trondheim, Tromsø, Kristiansand, and Bergen respectively (Fig. 4). It is expected that the performance of the PV panels are highly affected negatively in cloudy weathers such as Bergen and Tromsø.

Although it is not surprising that the second lowest amount of energy generation by PV panels is in Tromsø because of the angle of the sun light due to the altitude of the city and because of the long periods of darkness, it is absolutely surprising that Bergen has the first lowest amount of energy generation while it has considerably lower altitude and also has shorter periods of darkness comparing to Tromsø.

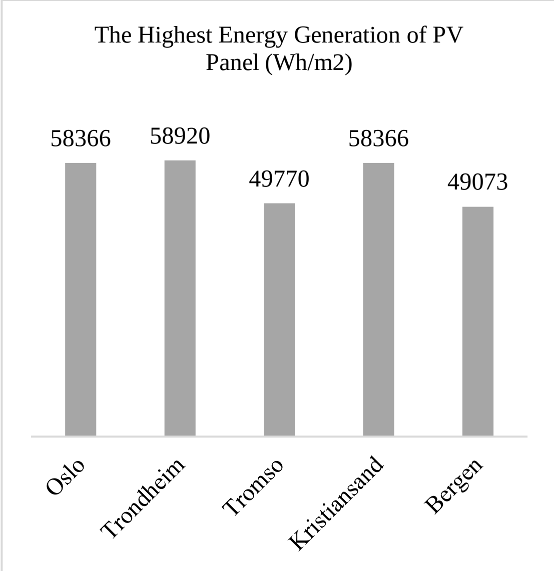

Figure 4: The highest energy generation with the PV panels in the cities among all orientations

By combining the yearly energy consumption with and without energy generation by PV panels, it can be concluded that by adding PV panels to this building, the maximum energy reduction can be achieved in the south-east facing by 66.43, 57.42, 36.7, 66.4, and 58.85 percent for Oslo, Trondheim, Tromsø, Kristiansand, and Bergen respectively (Fig. 5).

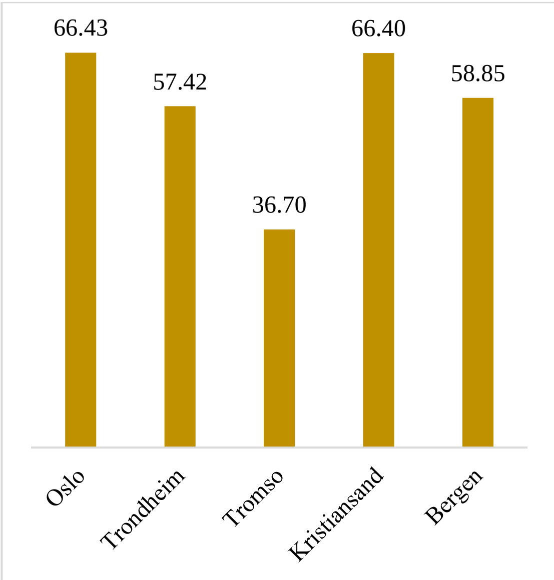

Figure 5: The highest energy consumption reduction using PV panel (%) in each city among all arientations

Finally, although the highest energy generation is achieved in Trondheim (58920 Wh/m^2), the highest percentage of energy consumption reduction with generation is achieved in Oslo and Kristiansand with a negligible difference, 66.43 and 66.4 percent respectively (Fig. 6).

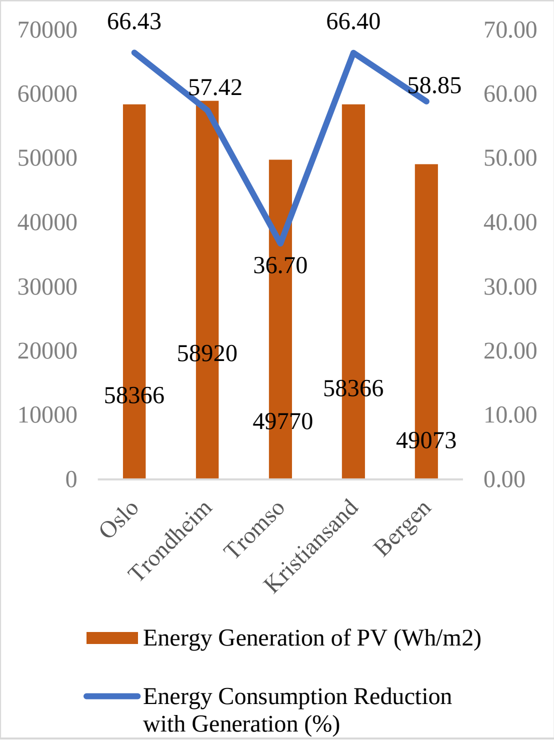

Figure 6: The highest energy generation and energy consumption reduction in the cities among all orientations

5. Conclusion

The findings of the study highlighted the significance of considering climate variations and building orientation when assessing residential building heating energy demands and the likelihood of overheating. The geographic latitude and longitude, along with the influence of the Gulf Stream oceanic flow, were identified as contributing factors to the diverse climate types across Norway.

Through the analysis, it was determined that the optimal orientation for energy efficiency differed across locations, with the South-East direction emerging as the most favorable in the examined scenarios. The study also investigated the impact of incorporating solar photovoltaic panels into the house design, noting that different locations demonstrated varying energy consumption levels. The city of Bergen showed the lowest energy consumption without photovoltaic panels, recording 83,305 Wh/m^2, while Oslo exhibited the lowest consumption with photovoltaic panels, at 29,442 Wh/m^2.

By shedding light on these energy performance variations, this study provides valuable guidance for stakeholders involved in the design and construction of residential buildings in Norway.

Appendix A: The extracted data from simulations

City	Facing	Energy consumption without generation (Wh/m^2)	Energy consumption difference according to minimum amount (%)	Energy generation of PV (Wh/m^2)	Energy consumption with generation (Wh/m^2)	Energy consumption reduction with generation (%)
Oslo	S	89343	1.86	58221	31122	65.17
	SE	87715	0.00	58273	29442	66.43
	E	88242	0.60	58333	29909	66.11
	NE	92290	5.22	58225	34065	63.09
	N	95970	9.41	58222	37748	60.67
	NW	95260	8.60	58297	36963	61.20
	W	92760	5.75	58366	34394	62.92
	SW	90810	3.53	58248	32562	64.14
Trondheim	S	104210	1.64	58890	45320	56.51
	SE	102530	0.00	58870	43660	57.42
	E	103260	0.71	58880	44380	57.02
	NE	107650	4.99	58850	48800	54.67
	N	111690	8.93	58890	52800	52.73
	NW	111410	8.66	58900	52510	52.87
	W	108570	5.89	58920	49650	54.27
	SW	106100	3.48	58880	47220	55.49

Tromsø	S	136980	1.28	49540	87440	36.17
	SE	135250	0.00	49640	85610	36.70
	E	135990	0.55	49740	86250	36.58
	NE	140730	4.05	49600	91130	35.24
	N	144640	6.94	49540	95100	34.25
	NW	144050	6.51	49670	94380	34.48
	W	141160	4.37	49770	91390	35.26
	SW	138890	2.69	49620	89270	35.73
Kristiansand	S	89395	1.86	58221	31174	65.13
	SE	87759	0.00	58273	29486	66.40
	E	88285	0.60	58333	29952	66.07
	NE	92370	5.25	58225	34145	63.03
	N	96030	9.42	58222	37808	60.63
	NW	95320	8.62	58297	37023	61.16
	W	92780	5.72	58366	34414	62.91
	SW	90860	3.53	58248	32612	64.11
Bergen	S	84359	1.27	49040	35319	58.13
	SE	83305	0.00	49023	34282	58.85
	E	83555	0.30	49051	34504	58.71
	NE	86045	3.29	49034	37011	56.99
	N	88497	6.23	49040	39457	55.41
	NW	88300	6.00	49039	39261	55.54
	W	86681	4.05	49073	37608	56.61
	SW	85362	2.47	49049	36313	57.46

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