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Model for Load Analysis at Granåsen

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MASTER THESIS

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Preface

This thesis is submitted as the final stage of the Master's program at Department of Electrical Power Engineering at the Norwegian university of Science and Technology (NTNU). The master thesis has been written during spring 2018, under the supervision of associate professor Eivind Solvang, in collaboration with Research centre for Sports centers and technology (SIAT).

The motivation for conducting this master thesis origins from SIAT's participation in the recently finalized conceptual investigation of energy solutions for the planned development in Granåsen, Trondheim. This work is meant as a preparatory work, in order to be able to determine to which extent Granåsen can be self sufficient with energy.

Firstly, I would like to thank SIAT, especially Bjørn Aas and Snorre Nordbo Olsen, for providing me an interesting and topical problem description. Also for great help along the way, and for letting me participate in *Enovaprosjektet* at Granåsen. It has been truly inspiring. I would like to thank all the participants from *Enovaprosjektet* who have helped me, and a special thanks to Sindre Solberg at Siemens. Also thanks to all who have contributed with providing data for the work.

Additionally, special thanks to my supporting family, and to my friends for unbelievable times during these five years as a student at NTNU.

Finally, I would like to express gratitude to my supervisor Eivind Solvang, for guidance and encouragement throughout the work with this master thesis.

Trondheim, 2018-06-20

Maren Haugland Hansen

Abstract

Granåsen ski arena had in 2017 a total energy consumption of 1036.4 MWh, and a maximum power peak of 986 kW. During the next years, Granåsen is facing a comprehensive expansion, which will lead to increased energy and power demand. The purpose of this thesis is to ensure Granåsen to be a sustainable facility, with respect to eventual energy self sufficiency. This work includes analyzis of current load profiles, load modelling and assessment of solar cells.

A bottom up approach to load modelling is used in order to construct load prognoses, involving both engineering and statistical methods. Retrieval of data is therefore emphasized. The system boundaries have been chosen to encompass four central loads of a Granåsen: Lights, snow production, elevator and buildings. The energy consumption prognoses for the buildings are based on reference data from buildings in Norway with similar functions. A constructed scenario where events, weather, and temperatures are the determining variables, provides an annual energy consumption which corresponds to approximately the double of the current consumption. It is, however difficult to compare the results due to different system boundaries and great uncertainties. It has therefore become evident that the approach performed in this work is more relevant than the numerical results.

PV production potential is found to be 652790 kWh/year when all future available roof is utilized for PV modules. That furthermore corresponds to a 750. 8kW$_p$ plant. A 30 °tilt provides the highest annual output, while a 90°tilt leads to a higher yield during the winter. PV can, with respect to a 30°tilt, contribute to decrease the forecasted load profiles by 35%. With no energy storage, however, 69,442 kWh excess energy would go to waste during the summer months. PV can also, with no energy storage implemented, to a small extent remove power peaks.

Energy storage together with PV can be very relevant to implement in a sports facility as Granåsen, especially to function as a peak shaving unit. A battery with capacity 720 kWh suggested for this purpose can work as a peak shaving unit for 250 kW during two hours. However, just below 100 batteries are required in order to store all the excess energy for the installed PV and given load scenario. Mobile Energy storage, which works as peak shaving units other places on a daily basis, but collected at Granåsen for special events could be a relevant execution model to get a smoother load profile during the year.

Sammendrag

Granåsen skianlegg hadde i 2017 et totalt energiforbruk på 1036.4 MWh, og en maksimal effekttopp på 986 kW. I løpet av de neste årene står Granåsen ovenfor en omfattende utbygging, som vil lede til økt energi og effektbehov. Formålet med dette arbeidet er å bidra til å sikre Granåsen til å bli et bærekraftig anlegg med hensyn på mulig selvforsyning av energi. Dette arbeidet inkluderer analyse av nåværende lastprofiler, modellering av lastprognoser og vurdering av solceller.

En opp-ned type tilnærming er brukt for å konstruere lastprognoser, hvor både teknologiske og statistiske metoder er involvert. Datainnhentning er derfor vektlagt. Systemgrensene er valgt til å omfatte fire typer sentrale laster i Granåsen: Lys, snøproduksjon, heis og bygninger. Forbruksprognosene for bygningene er basert på referansedata fra bygninger i Norge med lignende funksjoner. Et konstruert scenario hvor arrangement, vær og temperatur er de avgjørende variablene, gir et årlig energiforbruk som tilsvarer omtrent det dobbelte av det nåværende forbruket. Det er derimot vanskelig å sammenligne resultatene grunnet forskjellige systemgrenser og store usikkerheter knyttet til variablene.

Potensiale for PV produksjon er funnet til å være 652790 kWh/år når all tak i fremtidig bygningsmasse er utnyttet for PV moduler, som videre tilsvarer et anlegg på 750,8 kW_p. En 30°helningsvinkel gir høyest årlig utbytte, mens en helningsvinkel på 90°fører til et høyere utbytte om vinteren. PV kan, under forutsetning om en 30°helningsvinkel, bidra til å redusere den estimerte last prognosen med 35%. Likevel, uten energilagring implementert, vil 69442 kWh gå til spille i løpet av sommeren. Uten lagring, kan PV kan også i liten bidra til å redusere effekttopper.

Energilagring i samspill med PV kan være veldig aktuelt å implementere i et idrettsanlegg som Granåsen, særlig med tanke på effektutjevning. Et batteri med kapasitet på 720 kWh foreslått for dette formålet kan fungere som effektutjevner for 250 kW i to timer. Det trengs på den andre siden sett i underkant av 100 batterier for å lagre all overskuddsenergien for den gitte last prognosen i samspill med installert PV. Mobile batterikontainere, som fungerer som effektutjevnende enheter andre steder på daglig basis, men innhentet i Granåsen for spesielle arrangement, kan være en gunstig gjennomføringsmodell for å få en flatere lastprofil i løpet av året.

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Acronyms

AB Arena Building

AC Alternating Current

BIPV Building Integrated Photo Voltaic

BS Bruce Springsteen

BTA Brutto Areal (Gross Area)

CC Cross country

CIGRE International Council on Large Electric Systems

COC Continental Cup

DC Direct Current

EJ Exersice Jump

ES Energy Storage

EV Electric Vehicle

FIS The International Ski Federation

GHG Greenhouse Gases

HIT Tubular Metal Halide-Single Ended

HVAC Heating Ventilation and Air Conditioning

IEA International Energy Agency

LED Light Emitting Diodes

NC Norway Cup

NOK Norske kroner

NS Norsk Standard

NVE Norges Vassdrag- og Energidirektorat

PCU Power Conditioning Unit

POC Point of Coupling

PV Photo Voltaic

RES Renewable Energy Sources

RW Robbie Williams

SP Snow Production

SH ShoothinG Hall

TAM Daily Mean Temperature

TEK Byggteknisk forskrift

WC World Cup

ZEN Zero Emission Neighbourhood

Nomenclature

Greek Letters

α	Elevation angle	[°]
$\eta_{armature}$	Armature efficiency	[%]
η_{pv}	Efficiency of PV modules	[%]
η_{sys}	Efficiency of PV system, derating factor	[%]
ω	Hour angle	[°]
Φ	luminous flux	[lm]
ϕ	Latitude angle	[°]
δ	Declination angle	[°]

Roman Letters

A_{module}	Area of solar module	[m^2]
I_{sc}	Short circuit current	[A]
P	Rated Power	[W]
P_{load}	Gross electricity demand	[kW]
P_{net}	Net electricity demand	[kW]
P_{nom}	Nominal battery capacity	[kWh]

P_{prod}	Local production of electricity	[kW]
P_{rated}	Rated battery power	[kW]
$S_{M,t}$	Solar radiation perpendicular on a tilted panel	[kWh/m^2]

Chapter 1

Introduction

Sports facilities have a utility model which often cause significant power peaks, especially during extensive events. A world cup (WC) event in ski jumping will draw 3-5 MW during a few hours and a concert can for example draw 2-3 MW during 2-3 hours. [26] Operation of event venues can hence be expensive. Sports arenas can in fact have a daily electricity cost of more than $3,000.[32] One of the challenges with sports facilities is that the energy use is not directly comparable with any other consumers as houses or offices. The timetable of the sports facilities, different seasons, public attendances and sport activity and level are factors which affect the energy consumption. [17]

Another challenge related to sports arenas and event venues, is the strict requirement to energy supply. During world cup Falun 2015, the international ski federation (FIS) demanded to use diesel generators as main supply and the grid as a back up. Temporary solutions in the event sector, linked to energy supply in particular are trends that are desirable to change.

As sports arenas and hence the modern society are dependent on a secure energy supply, the global energy consumption is increasing. 80% of the global energy supply origins from fossil energy sources, which in turn contributes to global warming and extreme weather. [65]

Increased power consumption is traditionally met with grid expansion or upgrades. The current power grids are not designed for the increased use of electricity.[60] However, distributed production provides new opportunities for the power producing companies, grid operators and customers. New technology enables optional approaches to grid investments to be more profitable. Customers can contribute with local flexibility on the consumer and production side.

[47]

Norway has, due to the renewable directive of EU, committed to increase the share of renewable energy consumption to 67.5% within 2020.[19] In Norway, hydro power stands for 97% of the power production, and out phasing of current power production is thus unlikely to happen. An increase in renewable power production in Norway will therefore contribute to cover growth in energy and power consumption and lead to increased net export to other countries. [62]

1.1 Background

Granåsen ski facility is facing a comprehensive expansion during the next years. Granåsen aims to develop towards an everyday activity centre which includes cross country skiing, biathlon, ski jump, cultural events and outdoor life. The development is planned in four phases, tentatively described in Tab. 1.1:

Phase	Period	Development
1	2018-2019	Crosscountry facilities
2	2019-2020	Ski Jumps
3	2020-2021	Shooting hall
4	2021-2023	Other

Table 1.1: A provisional description of the development in Granåsen[26]

For the energy sector, it is a paramount objective that the direct emissions related to energy production should equal zero within 2030. In pursuance of this, *Klimasats* has allocated Trondheim kommune 450 000 NOK in order to enhance the environmental work related to this project, by defining Granåsen as a zero emission neighbourhood (ZEN).*Klimasats* aim to develop requirement specifications for Granåsen as a ZEN by defining emission factors and analyzing the practical and geographical boundaries. Trondheim kommune has, as a result of the expansion in Granåsen, set an objective not to increase the total energy consumption, compared to today's facility. It is therefore necessary to implement smart energy solutions. One and all added building stock must satisfy passive house standards. For Granåsen as a ZEN, it is furthermore an objective to establish a micro grid with markets for electrical energy and local production. [26]

Problem Formulation

The expansion of Granåsen will lead to an increased rate of activity, which in turn will require additional power installed.

While everyday use will lead to increased base load, larger events may lead to increased power peaks. Hence, the facility has to be dimensioned to withstand the largest power peaks that will occur.

This thesis will be a part of the work to ensure Granåsen to be a sustainable facility, with respect to eventual energy self sufficiency. This includes load modelling, assessment of energy supply (PV) and Granåsen as a micro grid.

1.2 Objectives

The main objectives of this Master's project are

1. Literature studies related to the scope of the exercise

2. Analysis of current load profiles

3. Estimation of possible future load scenarios

4. Investigate the effect of integration of PV .

5. Proposal of further work

1.3 Approach

The objectives described in 1.2 is approached as follows.

As a starting point a literature study have been performed, and relevant topics for this work are described in Chapter 2 and 3.

It has been put sufficient effort in to collecting data from several actors. This has been done both to get an overview over the current situation in Granåsen, analyzing current load profiles, and to use it as input when possible future load profiles and PV production potential have been modelled. It has also been information which has not been possible to obtain, and it has hence been necessary to conduct suitable assumptions. A full contact scheme is attached in App.H. It is mainly the program Matlab which has been used in this work. As a starting point, to collect and analyze current load profiles, and secondly to create prognoses for the future. The complete code is attached in Appendix. The scripts depend largely on external data, but they provide an idea of what has been done, and how the load profiles are calculated.

Additionally, participation in *Enovaprosjektet*, a conceptual study of Granåsen, has led to an increased understanding of the scope of the development and challenges in Granåsen. The meetings has consisted of an association of several parties, all of which have had a lot to contribute with.[27]

1.4 Limitations

This thesis depends on a huge amount of external data which has been challenging to obtain, as the information about the loads and operation times in Granåsen is distributed beyond many different actors. Lack of network topology in Granåsen has also contributed to limit the overview that has been pursued to obtain.

The development project in Granåsen is still a conceptual study, and there are hence significant uncertainties associated with the project, concerning the regulation plan and loads. It has therefore been necessary to make several assumptions, which will be closer described subsequently.

1.5 Thesis structure

Chapter 2 describes relevant concepts for this context. Chapter 3 explains load modelling and describes general methodologies . Aspects with energy consumption in buildings are also reviewed, and some exemplary energy efficiency measures in sport facilities are provided. Chapter 4 describes the current situation in Granåsen ski centre which is based on collected data from several parties, and various reports. Chapter 5 illustrates the methodologies that have been applied in order to obtain the prognoses for PV production and load profiles, presented in chapter 6 and 7, respectively. A discussion of the results is performed in chapter 8, and the main conclusion is outlined in chapter 9, together with recommendations for future work.

Chapter 2

Context concepts and definitions

This chapter describes the following concepts:

1. Zero Emission Neighbourhood

2. Power peaks

3. Microgrid

   PV systems and solar energy

   Energy storage

Parts of section 2.3.1 are collected from the specialization project *stand alone PV systems in rural areas*[33].

2.1 Zero Emission Neighbourhood

A zero emission society is a future vision of zero net emissions of greenhouse gases. [65]

ZEN Research Centre defines a neighbourhood as a class of interconnected buildings with associated infrastructure[1], located within a defined geographical area. FME ZEN includes the following in the definition of ZEN:

" *A zero emission neighbourhood aims to reduce its direct and indirect greenhouse gas (GHG) emissions towards zero over the analysis period, in line with a chosen ambition level with respect*

[1] Infrastructure includes grids and technologies for exchange, generation and storage of electricity and heat. Infrastructure may also include grids and technologies for water, sewage, waste, mobility and ICT.

to which life cycle modules, building and infrastructure elements to include. The neighbourhood should focus the following, where the first four points have direct consequences for energy and emissions:

- *Plan, design and operate buildings and associated infrastructure components towards zero life cycle GHG emissions.*
- *Become highly energy efficient and powered by a high share of new renewable energy in the neighbourhood energy supply system.*
- *Manage energy flows (within and between buildings) and exchanges with the surrounding energy system in a smart and flexible way.*
  ... " [23]

2.2 Power

In the energy sector, the focus has gradually moved from being directed at the energy consumption towards being directed at the power consumption.

Power is a concept which describes how quickly a work is performed. [61] When a quantity of energy is consumed simultaneously, so called power peaks occur. Generally, this can for example happen if a sufficient number of electrical vehicles are charged concurrently, or in conjunctions with large events as for example concerts or sports events, which require sufficient lighting, media and other loads at the same time.

The power grid has to be dimensioned to meet the demand of the highest instantaneous power. In *Kraftsystemutredninger 2016*, NVE predicts Norwegian power grid investments for the next ten years to exceed 140 billion NOK, which among other things is due to increased consumption and power peaks. Such an expansion will have a major impact on natural environment and in turn lead to emissions of greenhouse gases. The main motivation linked to reduction of power peaks is hence to reduce the need of expansion of the grid.

2.2.1 Peak Shaving

Peak Shaving is a term used when the intention is to decrease peak demand. The concept is illustrated in fig. 2.1. Through peak shaving, installation of new capacity can be avoided in order to cover the energy demand of a variable load. Peak shaving can be achieved by implementing energy storage, which has the advantage of being emission free during operation.

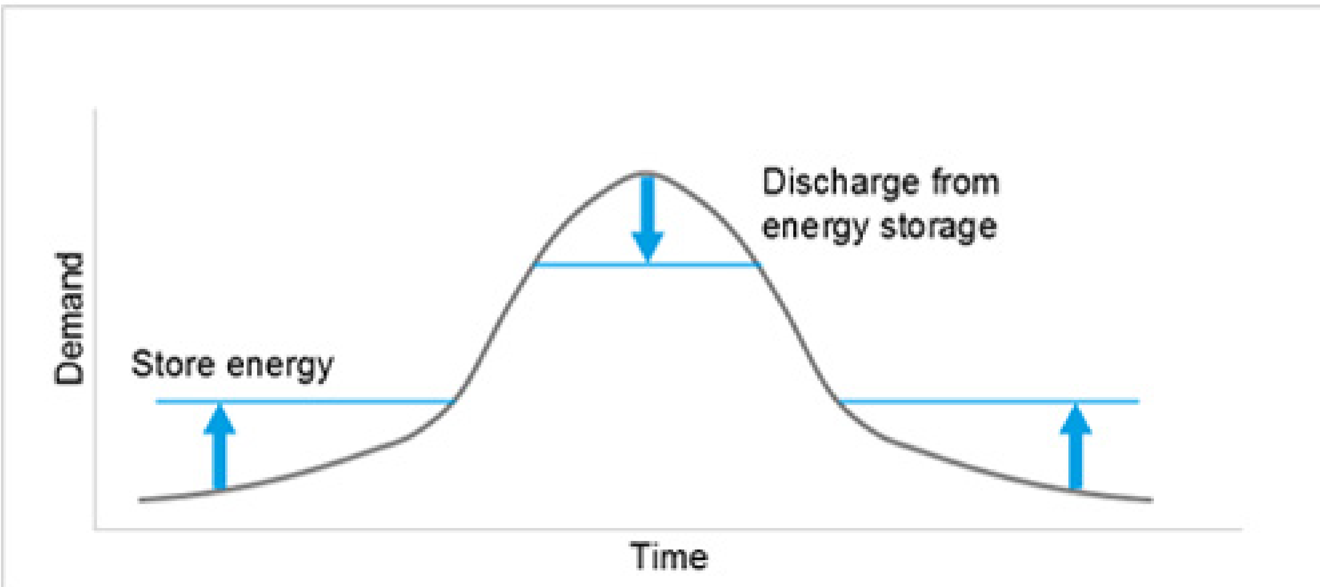


Figure 2.1: Peak shaving of electrical loads as energy is stored during times with low energy demand. [20]

Such installations don't necessarily have to be owned by the grid operators. Advantages of peak shaving are:

- The electricity bill can be reduced for both commercial and industrial customers, as the peak demand decreases
- The operational costs are reduced for the utility when generating power during periods of peak.
- Flattening of the load delays new investments in infrastructure.

[14]

2.3 The Microgrid Concept

CIGRE defines microgrid as follows: *Microgrids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded.* [36]

A distinction is made between microgrids which are connected to the power grid, and microgrids which are not, i.e. isolated microgrids. The former is connected to the power system through a main switch, i.e. point of coupling (POC). In case of faults, the microgrid can be operated in island mode.

The utility distribution system can, when operated in grid-mode function as a balancing unit, i.e. supply or absorb potential discrepancy in the power generated by the microgrid. It is desirable to keep the difference between production and demand to a minimum.

A micro grid can cover a house, or an entire circuit of transformers. The size of micro grids can thus vary greatly. [35]

Energy sources in a microgrid can be renewable or fossil. By utilitizing on-site production, the energy demand of a building or other loads can be significantly changed, seen from the grid's perspective. *Prosumer* is a neologism that refers to an electricity consumer that produces electricity in order to support self consumption. [52] As there can be both import and export of electricity to the power grid, the net electric load P_{NET} is: [40]

$$P_{NET} = P_{load} - P_{prod} \tag{2.1}$$

where P_{load} is the total electric demand and P_{prod} is the local production of electricity.

2.3.1 Renewable Energy Sources (RES)

Well developed technologies within RES are summarized in Tab. 2.2. This thesis will focus on photo voltaic (PV) technology, and a more detailed description will follow in section 2.3.1.

Energy based technology type	Primary energy	Output type	Module power (kW)	Electrical efficiency (%)	Overall efficiency (%)	Advantages	Disadvantages
Wind	Wind	AC	0.2–3000	–[a]	~50–80	✓ Day and night power generation ✓ One of the most developed renewable energy technology	✗ Still expensive ✗ Storage mechanisms required
Photovoltaic systems	Sun	DC	0.02–1000	–[a]	~40–45	✓ Emission free ✓ Useful in a variety of applications	✗ Storage mechanisms required ✗ High up-front cost
Biomass gasification	Biomass	AC	100–20,000	15–25	~60–75	✓ Minimal environmental impact ✓ Available throughout the world ✓ Alcohols and other fuels produced by biomass are efficient, viable, and relatively clean burning	✗ Still expensive ✗ A net loss of energy in small scale
Small hydro power	Water	AC	5–100,000	–[a]	~90–98	✓ Economic and environmentally friendly ✓ Relatively low up-front investment costs and maintenance ✓ Useful for providing peak power and spinning reserves	✗ Suitable site characteristics required ✗ Difficult energy expansion ✗ Environmental impact
Geothermal	Hot water	AC	5000–100,000	10–32	~35–50	✓ Extremely environmentally friendly ✓ Low running costs	✗ Non-availability of geothermal spots in the land of interest
Ocean energy	Ocean wave	AC	10–1000	–[a]	–[a]	✓ High power density ✓ More predictable than solar or wind	✗ Lack of commercial projects ✗ Unknown operations and maintenance costs
Solar thermal	Sun and water	AC	1000–80,000	30–40	~50–75	✓ Simple, low maintenance ✓ Operating costs nearly zero ✓ Mature technology	✗ Unknown operations and maintenance costs ✗ Low energy density ✗ Limited scalability

[a] No data available.

Figure 2.2: Well developed technologies of renewable energy sources in a microgrid [51]

Solar Energy

Today, various energy systems take direct advantage of the enormous amount of energy that the sun delivers. Solar energy is, with respect to other renewable energy sources, leading within availability, cost effectiveness, capacity and efficiency and can be seen as an eminent opportunity to meet prospective energy demands. The entire energy demand of the earth could in theory be met by solar energy. The sun is the most enduring, noiseless and non-contaminating energy source. Taking manufacturing, installation, operation and maintenance into account, solar power generation has very small GHG emissions, compared to convenient energy resources. [37, 24, 41]

PV Technology PV technology has gone through a sufficient increase in efficiency, and the prices have fallen the recent years. From 2011 to 2014, the costs of a PV module decreased by 60%, and the declination is expected to continue in the future. [37]

A PV cell is a device which utilizes the photo voltaic effect to convert a flow of photons into a flow of electrons. The photo voltaic effect can be described as the generation of voltage or electric current in a material when it is exposed to light. Solar cells form the basis of the PV generator, which furthermore produces direct current (DC) power. [33]

There are two overall categories when it comes to PV systems: Grid connected PV systems and stand-alone PV systems.

For both matter, the PV array may be mounted on a pole, constitute an integral part of a building (BIPV) or be connected separately to a roof. [42]

In a grid connected system, the PV panels provide DC power to a power conditioning unit (PCU), which is an inverter that convert DC to AC and makes sure the power is suitable for the loads. An energy meter is able to keep track of the power flows, and how much energy that is either produced or received from the grid. Such a system generally replaces power which would have been bought from the grid otherwise. Surplus energy can either be exported to the distribution grid or stored in a battery.[31] Energy storage implemented in PV systems is mostly widespread in stand alone systems, but can constitute advantages in grid connected systems as they additionally can work as a peak shaving unit as described in section 2.2.1.

Solar radiation When assessing the potential for utilization of solar energy, incoming solar radiation is an important parameter.

Not all of the radiation that the sun emits reaches the surface of the earth, some is scattered in the atmosphere. A further explanation is shown in App.B, fig. B.1. For a particular site, radiation data are most commonly provided as global irradiation on a horizontal surface. [41]

It is mainly the latitude that determines the intensity of the incoming radiation, but factors as seasonal variation, local weather conditions as temperature, wind, snow, clouds, etc, are also essential. Additionally, plant specific factors as e.g. orientation, vegetation and technology will affect the amount of energy produced. [48]

Norway is located at a high latitude which means that the solar radiation received on a horizontal surface is varying throughout the year.

Implementation of PV panels in Norway has, however, several advantages, as the temperature coefficient of the voltage of a PV panel is negative. [41] That means that the efficiency is higher in low temperatures. Power supplied from a solar module in March can therefore be significant.

As it can be seen from fig.B.1, radiation can also hit the solar panels due to reflection, and snow can hence contribute to increase the radiation during the winter.

The annual average radiation measured in different cities in Norway is listed in Tab.2.3.[48]

Site	Solar radiation on a horizontal surface [kWh/m^2 year]	Produced energy - PV cells [kWh/m^2 year]		Produced energy - Solar collector [kWh/m^2 year]	
		Inclination 30°	Inclination 90°	Inclination 30°	Inclination 90°
Oslo	875	140	110	450	315
Kristiansand	965	150	115	500	350
Bergen	790	110	80	390	273
Trondheim	800	130	100	400	280
Tromsø	700	110	80	350	245

Figure 2.3: Annual solar radiation and production potential in different cities in Norway. [48]

In order to maximize the output of a PV panel, the module surface should be perpendicular to the sun. It is possible to utilize tracking systems, so that the solar panel can follow the movement of the sun in order to increase direct radiation. This is, however, more costly. If the solar panels are fixed, the optimal inclination angle will depend on which time of the year it is most desirable to maximize the performance of the solar panels. The optimal module inclination angle for Trondheim, i.e. the angle that maximizes the output over a year, is tested by Multiconsult and found to be 45 °. The average inclination on Norwegian roofs is 27 °, however, and angles between 20 ° and 45 ° provide a quite similiar output. [44]

The annual production from a PV system can in simplified manners be calculated from (2.2)

$$\sum_{t=1}^{8760} S_{M,t} * A_{module} * \eta_{sys}\eta_{PV} \tag{2.2}$$

where $S_{M,t}$ is the solar radiation perpendicular on a tilted panel ° in hour t [kWh/m^2], η_{sys} is the efficiency of the power electronics, losses in cables and diodes, and η_{PV} is the efficiency of the PV panel. A default value for η_{sys} is in the PV performance online calculator PV WATTS set to 0.77, and will further be used in subsequent calculations.[42]

2.3.2 Energy Storage

The demand for battery storage in EV's has over the last years contributed to become a driver for development within energy storage.

Market segments as power markets can benefit from energy storage as it can directly provide energy to a wide system, support energy distribution, or function as ancillary systems for businesses or households at individual levels. Several ownership models can also be deployed as customer level, utility and third party, with a combination of business and financing models to advocate improvement.[54] An overview of different energy storage technologies can be seen in fig. 2.4.

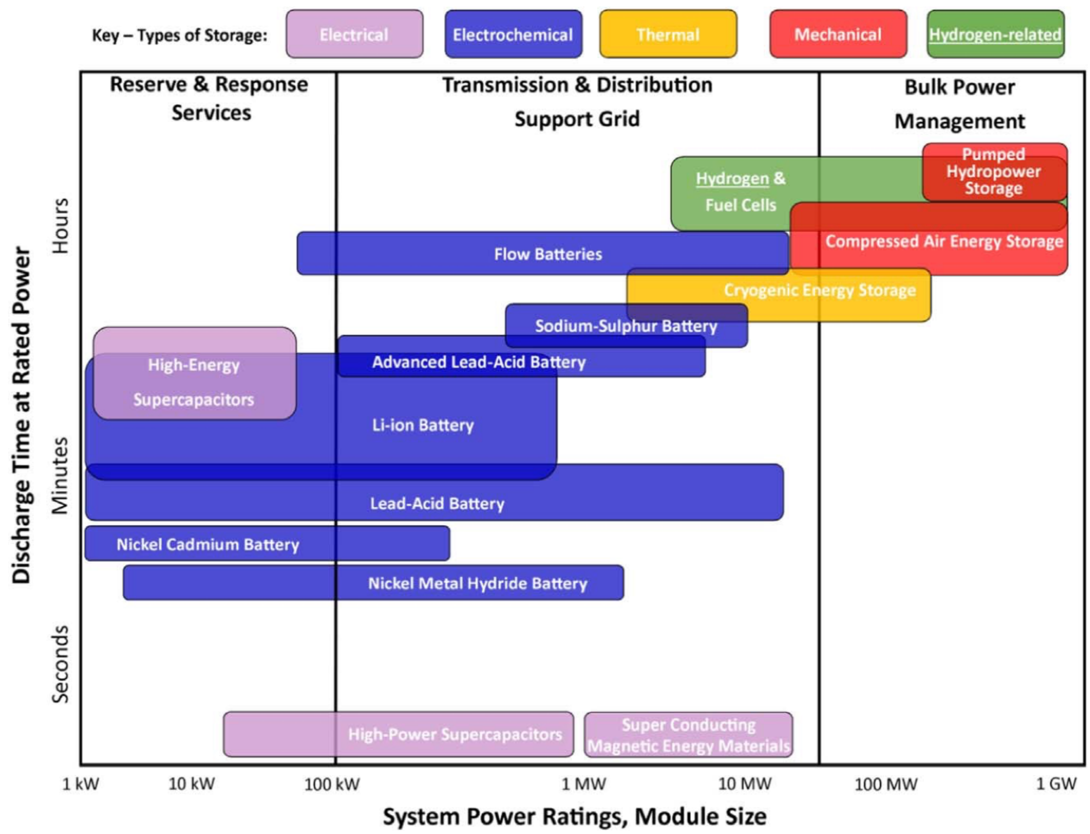


Figure 2.4: An overview of various energy storage technologies[45]

This section will focus on batteries.

Battery Storage

A battery can turn chemical energy directly to electrical energy through a redox reaction. In order to handle power peaks and increased integration of renewable energy, flexibility in the power system is important. Batteries can contribute to flexibility through load relocation, changes in consumption profiles , smoothing of price fluctuations and storage of locally produced energy, as described in 2.2.1.

Batteries are as for today not very widespread for this purpose, but the growth in battery implementation is especially expected to come in connection with electric vehicles and buildings with PV plants in the future. For households and non-residential buildings, it will currently not be economically beneficial to invest in batteries only for the purpose of relocating the loads. A price variation in power for different times of the day would have to exceed 50 øre/kWh, for such an installation to be profitable, according to a report published by NVE.[34]

Battery capacity connected to PV A PV battery system will normally imply that the energy only is stored during daytime when the production is larger tha n demand. That means that the capacity available for load relocation will be dependent on the production of the PV plant.

Battery capacity connected to EV Batteries in EVs can be exploited for storage when the vehicle is not in use. This can be a measure to ease the electrical grid. Storage can be gained through either utilitizing the battery while it is still in the vehicle, or outmoded EV batteries can be implemented as a battery bank on site. The first concept presupposses a mature technology which can transfer power between the battery and the grid. This type of technology has limited availability today, but it is constantly being developed.

The second concept may be applicable only in several years, as the lifetime of today's batteries are often assumed to be 15 years, and EVs has primarily been sold to a greater extent in the recent years. [34]

Mobile energy storage Transportable energy storage systems (TESS) can be batteries identified by a grid scale capacity. They are mounted in a mobile truck. Integrated in the mobile storage system are also power controllers and converters. Benefits with TESS are mobility, flexibility, and power supply can be provided during special conditions. [66]

Commercial battery Lithium-ion batteries have high energy density and are considered as state of the art batteries. [21] The nominal capacity of a battery (kWh) and the rated power (kW) are parameters that describe the ability of the battery to store a certain amount of energy, and maximum power, where latter is relevant for peak shaving purposes. Other parameters to consider when implementing batteries are lifetime, loss performance and dimensions. An example of a commercial battery is given int Tab.2.1

P_{rated}	250kW
P_{nom}	720kWh
I_{sc}	850 A
Lifetime	10 years
Loss performance	4-6%

Table 2.1: Example of characteristics of a commercial battery

Chapter 3

Load Modelling and Energy Consumption

When planning and designing microgrids, a crucial aspect is to understand the load requirements of the location of interest. Both underestimating and overestimating the energy consumption can lead to either unmet load or oversized facilities. Estimates or forecasts of energy and power demand for various purposes involve load models.

This chapter will review aspects of load modelling, load flexibility and energy use in buildings, with particular emphasis on passive buildings and corresponding requirements. The end of the chapter provides two examples of energy efficiency measures in sports arenas.

3.1 Load modelling

Load modelling may be explained as spatial, individual energy demands assembled and specified in time. This can imply to settle load profiles for different categories with comparable demand.[57]

A load profile can be described as the graphical representation of a variation of any loads, either observed or expected, as a function of time.[43] Fig. 3.1 illustrates essential characteristics of a load profile.

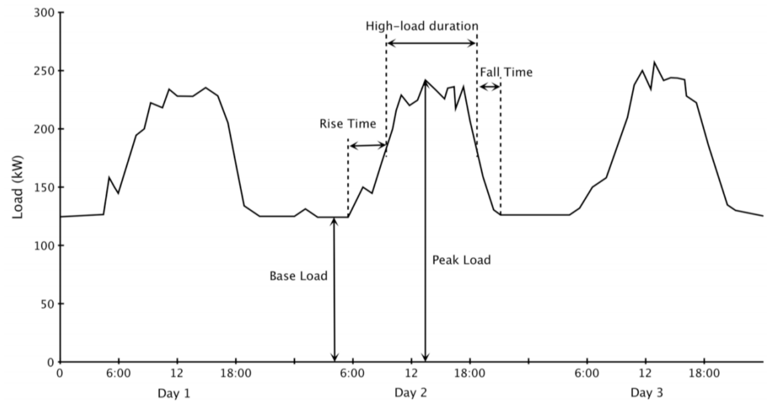


Figure 3.1: Characteristics of a load profile. [43]

Models for energy consumption can be categorized into top-down models and bottom-up models. There are also models which take advantages of techniques from both. [63]

Top-down load models Top-down models are mostly based on statistics and economic theory, and the input variables required are often easily obtained. [38] Top-down models handle a whole sector as an energy sink, and adjust for factors that influence consumption. [63]

Bottom-up models Bottom-up models aggregate consumption over an entire building stock, after the individual energy consumption of a building or appliances are calculated. All models that utilize input data from a hierarchical level lower than at sector level are encompassed as bottom-up models. [63] Furthermore, bottom-up models can be categorized into statistical and engineering models. Generally, historic data of energy consumption and additional descriptive variables constitute the fundamental of statistical load models.

Load profiles developed using engineering models are based on data about fundamental load components as households or individual appliances. Information about e.g. building physics, occupancy patterns and number of different appliances are incorporated into the model. [38]

The availability of elemental consumption details determines the preciseness of this modelling approach. This is a common limitation for bottom-up models as detailed data about consumer behaviour can be difficult to obtain. [49]

3.1.1 Load Flexibility

Electrical loads can, based on consumption characteristics, be split into three kinds. These are summarized in table 5.2.

Load Type	**Slack Characteristics**	**Examples**
On demand	Must remain available	Lights, Interactive computing
Deferrable	Exploits delays in time	Washers, Batch computing, Dishwashers
Flexible	Takes advantage of ES	HVAC, EVs,Refrigerators

Table 3.1: Three categories of loads and their characteristics [64]

In order to adjust a load profile of a load, the load has to carry some slack. Slack is a term which is used to describe to what degree the load can be delayed without affecting outcomes or operations which occur earlier or later. *On demand* loads present zero slack in operation and must be supplied when they are requested. They are typically related to consumer action. *Deferrable* loads are usually actions which run to finalization when started, and they allow the energy consuming action to be scheduled to some extent. Furthermore, *Flexible* loads allow for a more elastic consumption. Those three classes are all present in the traditional electricity grid, but as the grid evolves from industrial to a more information aged grid, the opportunity to utilize slack characteristics becomes more important.

Four mechanisms, of which three are depicted in fig.3.2, illustrate the flexibility of a load:

- Load shifting: The consumption is moved to another time
- Load shaving: described in section 2.2.1
- Valley filling: New load is turned on to rise the electricity use
- Load reduction

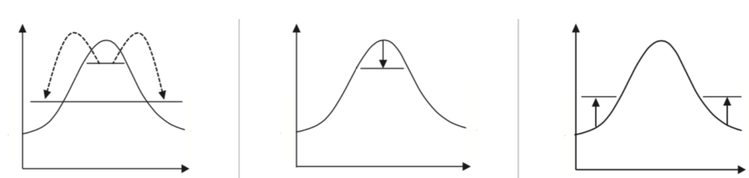


Figure 3.2: Load shifting, load shaving and valley filling . [40]

3.2 Energy use in buildings

Generally, evaluation of consumption trends connected to energy is performed according to different fuels and types of consumers. Those can primarily be divided into various sectors of the economy: industry, transport, residential, services, agriculture and others.[25]

In Norway, 40% of the total domestic energy use is due to energy use in buildings, hereof 40% from non-residential buildings.[40]

The energy use in buildings are primary influenced by factors that can be divided into two categories. Technical and physical factors, and human influenced factors as illustrated in fig. 3.3.

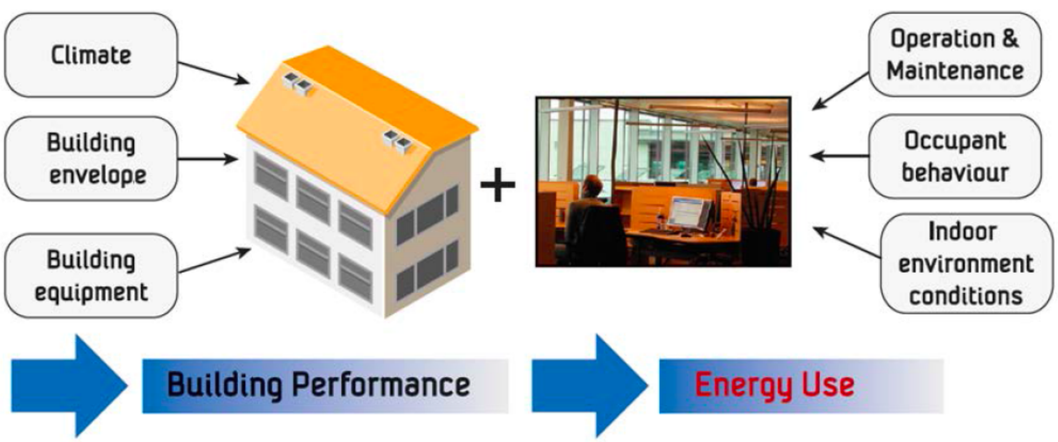


Figure 3.3: Factors that affect energy use in buildings. [46]

Upon entry of new buildings in Norway, the building code TEK, controls the minimum requirement for quality. The code includes isolation, density, ventilation, etc. Tightening of these requirements leads to ever less energy consumption in Norwegian buildings.

3.2.1 Energy Consumption by Building Category

It can be seen from figure 3.4 that there is a decrease in specific energy consumption for most building categories in Norway, except for sports buildings and industrial. However, those categories consist of non-homogenic buildings which are complicated to compare. [29]

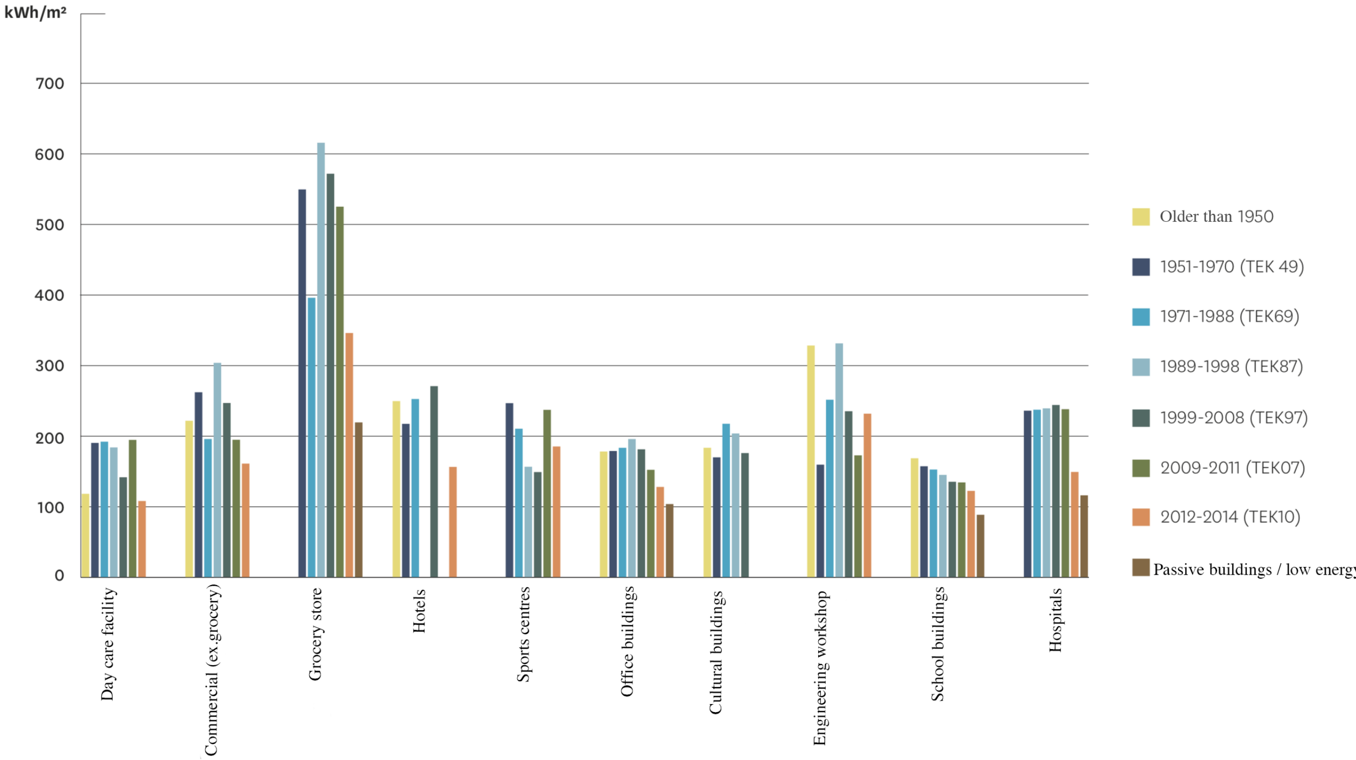


Figure 3.4: Trends in energy consumption by building category [29]

NVE has divided energy use in buildings by functions, within different building categories, which can be seen in fig. 3.5. Annual specific energy consumption for different building categories are listed in Tab.3.2

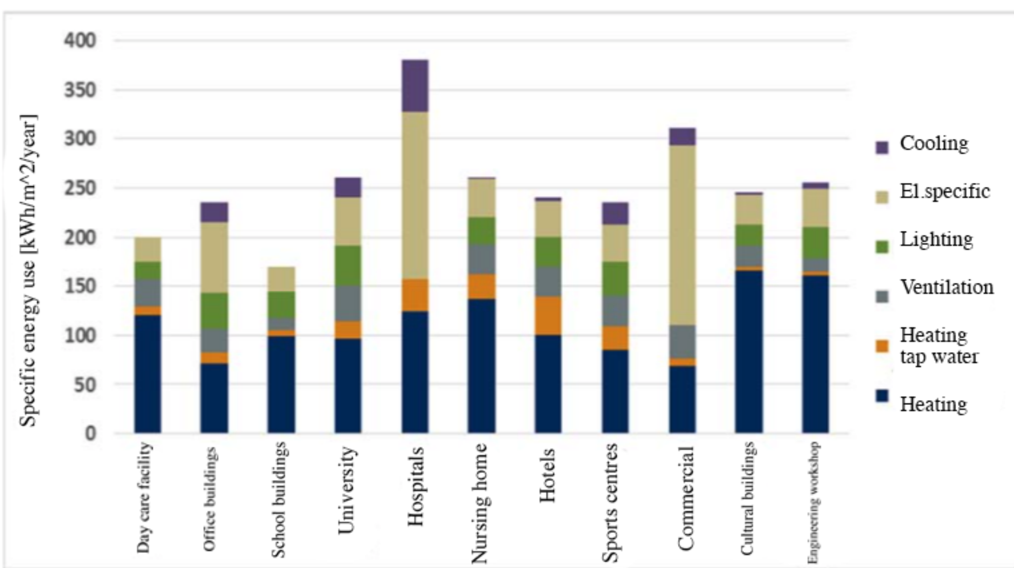


Figure 3.5: Specific energy consumption in buildings divided by purpose. [39]

Building category	Specific energy consumption [kWh/m^2/year]
Hotel	240
Day care facility	200
Office	235
School	170

Table 3.2: Annual specific energy consumption for a selection of building categories in Norway. [39]

Sports facilities For sports centres in Norway, a representative consumption is 235 kWh/m^2 /year.[39] Sports facilities are very complex and the report shows that there can be a sufficient variation in energy use among the different sports centres. The timetable of the sports facilities, different seasons, public attendances and sport activity and level are factors which affect the energy consumption. [17] Based on measurements for five different sports centres, a representative consumption divided by purpose is presented in figure 3.6.

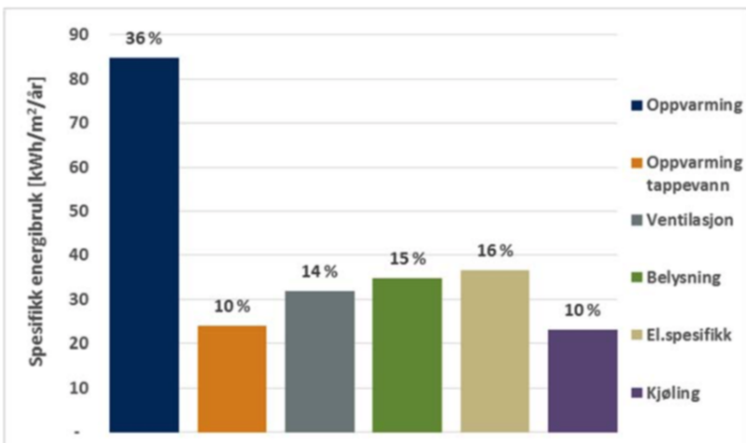


Figure 3.6: Purpose divided energy use in sports facilities. [39]

3.2.2 Passive Buildings

The passive house standard is a development towards more sustainable buildings, i.e. more energy efficient and environmental friendly than buildings following the convenient building code TEK 17. Passive houses are isolated well, use minimal energy for heating purposes, and they mainly utilize renewable energy. The term *passive* origins from the utilization of passive actions to reduce the energy demand.

The Norwegian passive house standards NS 3700 and NS 3701 address criteria for residential and industrial buildings respectively.

NS3701 contains five central requirements, including heating loss, heating demand, cooling demand, energy demand for lighting purposes, and minimum requirements for various building components. Additionally, the standards set requirements for leakage numbers, measurement techniques and reporting of the energy performance upon completion. [12] [56]

The specific requirements of passive buildings depend on representative climatic data, type of building and area. Procedures for determination of requirements for energy demands concerning heating and cooling are based on formulas presented in fig.3.7 and Tab.3.3, and the corresponding coefficients and the requirements for energy demand for lights are listed in Tab. 3.4.

Annual mean temperature θ_{ym}	Maximum calculated net specific energy demand for heating kWh/(m^2 year)	
	Building where $A_{fl} < 1\,000\ m^2$	Building where $A_{fl} \geq 1\,000\ m^2$
$\geq 6,3\ ^{\circ}C$	$EP_{H,0} + X\frac{(1000 - A_{fl})}{100}$	$EP_{H,0}$
$< 6,3\ ^{\circ}C$	$EP_{H,0} + X\frac{(1000 - A_{fl})}{100} + \left(K_1 + K_2\frac{(1000 - A_{fl})}{100}\right)(6,3 - \theta_{ym})$	$EP_{H,0} + K_1(6,3 - \theta_{ym})$

Figure 3.7: Requirements for net heating demand for passive buildings [59]

DOT_S	Max calculated net specific energy demand for cooling kWh/(m^2 year)
> 20 ° C	β(20-DOT_S)
< 20 ° C	0

Table 3.3: Requirements for maximum calculated net specific energy demand for cooling[59]

Building category	**EP**$_{H,0}$	**X**	**K**$_1$	**K**$_2$	β	**LENI**[1] kWh/(m^{2}year)
Sports centre	20	0.8	3.8	0.10	0.9	14.5
School	20	1.30	3.5	0.15	0.75	9.9
Office	20	0.85	3.6	0.10	1.4	12.5
Hotel	25	1.40	4.0	0.10	1.5	17.5

Table 3.4: Values for determination of passive house requirements for specific energy demand[59]

Net total annual energy demand for passive buildings typically varies between 65 kWh/m^2-80 kWh/m^2.[56]

Load profiles of passive buildings

This subsection will be based on findings from *Impact of Zero Energy Buildings on the Power System*[40]. A regression method has been used in order to evaluate the energy consumption of non residential buildings, in terms of gaps between average existing buildings and energy efficient passive buildings.

For heat consumption, the results implied that passive buildings have lower temperature dependency than the average buildings. That is, the gradient for consumption linked to heating purposes is less for passive buildings when the ambient temperature is decreased. As it can be seen in figure 3.8, the heat consumption in existing buildings is almost double compared to passive buildings.

[1] Lighting Energy Numeric Indicator is an index that is used to assess the energy efficiency of the lighting.[30]

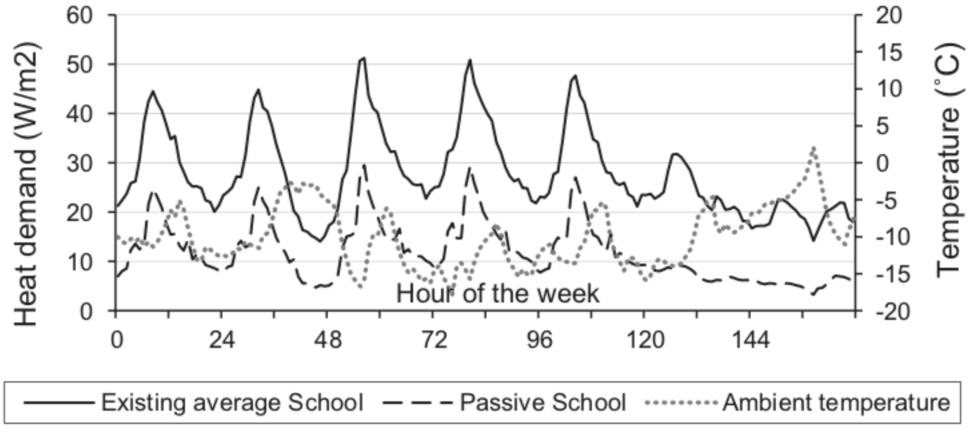


Figure 3.8: Heat consumption profile prognosis of existing and passive school buildings for a cold week during the winter. [40]

Concerning electric specific demand, findings indicate that when buildings become more energy efficient, electricity demand is less affected than heating demand. However, the temperature dependency is approximately 30% less for passive office buildings compared to convenient office buildings. The peak load is decreased by 12-13%, but the consumption profiles have the similar characteristic bell shape as shown in fig. 3.9.

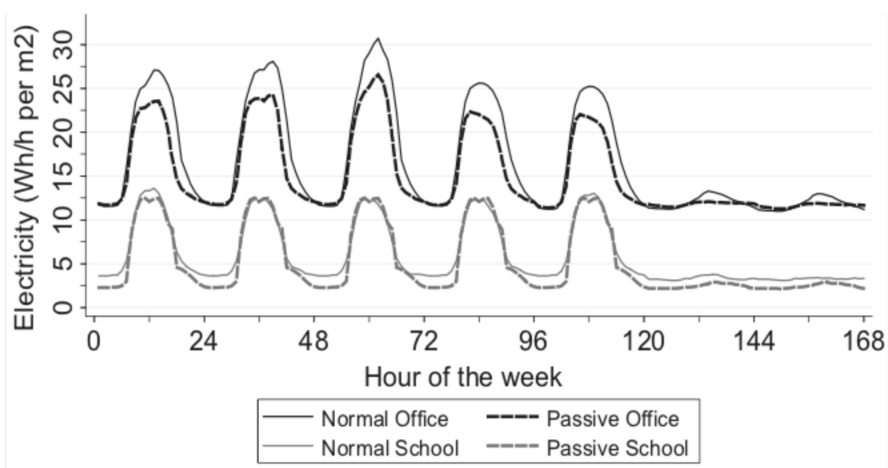


Figure 3.9: Specific el. consumption profile prognosis of existing and passive school and office buildings for a cold week during the winter. [40]

When convenient buildings are compared to passive offices and schools, the total energy demand is respectively 27% and 55% lower for passive buildings.

3.3 Energy Efficiency at Sports Arenas

Integration of LED lights in sports world Sport stadiums and arenas have through the ages utilized metal halide lights (HIT) for illumination. HIT lighting is energy intensive, and it also raises environmental concerns, as mercury is present in metal halides. LED lights are more energy efficient and do furthermore posess environmental advantages compared to HIT lights. Previously, high costs and issues with lighting requirements linked to media and broadcasting made implementation of LED-lights problematic. Technological advances on both lighting and broadcast sides, as well as decreasing costs, have made LED lighting systems highly appropriate at venue arenas. [22]

Integration of PV modules at sports arenas Partners including Skagerak Energi and the Norwegian football club Odd aim to establish local production and storing of electrical energy at Skagerak Arena. PV cells in combination with batteries are according to the plan going to constitute a part of the local energy system. In conjunction to football matches, the consumption of the arena is tenfolded in relation to normal conditions. The power output normally lasts for 2-3 hours before the floodlights are off. The energy storage system is therefore planned in order to handle the power peaks, and to store the surplus production of the PV plant. The aim is to install a plant consisting of 3230 PV modules which will annually produce 660 MWh. [28]

Chapter 4

Granåsen Ski Facility

This chapter will be based on information obtained from *Energnotat for helhetsplan Granåsen*[26], on-site inspection and contact with different participants[1], and aims to describe Granåsen ski facility, including:

- Annual events in Granåsen
- Existing building stock
- Loads and energy distribution
- Development plans

4.1 Description of Granåsen

Granåsen Ski Centre is today the most important facility in Mid-Norway for Nordic skiing. The facility functions as a competition and exercise facility, and is also popular for everyday use for residents of Trondheim. In recent years, the facility has also served as a concert arena for great artists as Robbie Williams and Bruce Springsteen. [27]

4.1.1 Annual Events at Granåsen

Events that regularly take place every year are listed in Tab 4.1. [3]

[1] A full contact form is provided in Appendix H

Event	Description
WC	Week 11 (Monday - Thursday)
NC	3 weekends[2] during one season.
Granåsen Cup	6 Tuesdays (17:00-20:00) during one season
COC continental cup	One weekend in the autumn every third year

Table 4.1: Events that take place in Granåsen every year

4.1.2 Building Stock

Today's building stock is operated by the city operation of Trondheim (Trondheim bydrift) and is summarized in Tab. 4.2.

Building	BTA (m^2)	NTA (m^2)
Granåsen skicentre, 3 floors	838.7	776.8
Granåsen skicentre jump, 1 floor	529.4	459.3
Commenting box crosscountry,	104.4	90.7
judges tower jump, 5 floors	231.3	203.5
Commenting box jump, 2 floors	266.1	228.8
Total		**1900 m^2**

Table 4.2: Overview of today's building areas

Additionally, *Toppidrettssenteret* (TIS) at 3300 m^2, was finalized in 2013 . NTNU research centre for elite sport is localized here, in addition to fitness centre, gymnastic hall, medical centre and physiotherapy clinic.

4.2 Present Energy distribution

The information about the topology of the power system in Granåsen is restricted, but mail correspondences with Trønder Energi [6] make it reasonable to assume that the following infor-

[2] Weekend includes Saturday and Sunday

mation is correct: There are six transformers at Granåsen as shown in fig.4.1. [10] They have a total capacity of 5.1 kVA.

Transformer 1 and 2 were put up in conjunction with a Bruce Springsteen (BS) concert in 2016. However, the transformers were not used as BS had diesel generators. The transformers were used during the concert of Robbie Williams in 2017. Transformer 220/1574 does not belong to Trondheim kommune, and measurement data has not been available. [6]

Granåsen - overview, transformers
2011.09.23 - based on information from Geir Arne Haugen
2018.02.28 - Revised

○ **Transformer / Measurepoint**
△ **Cabinet**

Measure ID (EAN)	Measure ID	Location, measurer
707057500068449538	228004091	Kongsvegen 214
707057500068449569	229983134	Kongsvegen 214
68449545	229975323	Granåsen - Skianlegg - Kongsvegen 214
68449552	229983146	Granåsen - Skianlegg - Kongsvegen 214
707057500068874293	12108514	Kongsvegen 214, Tribuneanlegg
7070575000 68882557	73500490 87611731	Kongsvegen 214, snøproduksjon Granåsen
68838509		Kongsvegen 214 - Brakke

Figure 4.1: Overview of transformers at Granåsen

4.2.1 Description of Loads

In addition to buildings, installations with energy demand in Granåsen include: [26]

- Flood lights
- Snow production
- Lift
- Charging points for EV
- Construction machinery, track machines, etc.

Fig. 4.1 provides available information about which transformers the different loads receive power from.

Buildings

There are no separate meters installed in the buildings, and except for TIS, the buildings only have electrical heating. [26] The heating demand in TIS is covered by heating pumps and the annual energy consumption is currently about 140 000 kWh for ventilation, heating and lights. [26] TIS is operated by AHA eiendom and will hence be further excluded from the analysis, as information about energy consumption has not been provided.

Snow production

Production of snow is characterized by short time of operation and does furthermore cause tall power peaks in periods where the energy demand is high due to heating purposes. The total energy consumption from snow production is not necessarily significant, but the power peaks may lead to power prices up against 8 NOK/kWh. [27] This is due to monthly power rates from the power suppliers. The power demand in conjunction to snow production at Granåsen ski centre can be up to 1 MW. The production of snow origins from fan guns or lances, and the seasonal requirement to supply is in excess of 20 000 m^3.

Lift

The cable car is a Doppelmayr and is used to carry the ski jumpers to the top of the hill during ski jump events. The cable car is old and the rated power tag has worn away. The power ratings have not been possible to obtain from the operations department in Granåsen.[7]

Lights

Lights serve for the following purposes in Granåsen:

- Floodlit trail
- Stadium Jump
- Stadium CC
- Parking lot

An overview of the lights in conjunction to the jump stadium can be seen in fig. 4.2. Documentation is attached in App.A.1. Light poles and lights close to the tribune shown in fig.4.2 do in this report lack documentation. The available power ratings are presented in Tab. 4.3

Purpose	**Rated Power (W)**	**Type**	**Supplier**	**Quantity**	**Max(kW)**
Floodlit trail[5]	52	LED	Siteco	55	3.3
Stadium CC[5]	2x600	HIT	Siteco	17	20.4
Stadium Jump	2000	HIT	Siteco[3]	106[4]	212
Total					**235.7**

Table 4.3: Power ratings for lights at Granåsen

Floodlit track The track is 2.3 km, and during the season[5] lights are turned on between 8:00 and sunrise, and between sunset and 23:00. [10]

[3] See App.A.1for technical specifications
[4] This number is counted by inspection and may differ.
[5] Season is considered to be approximately between 01.10 - 01.04

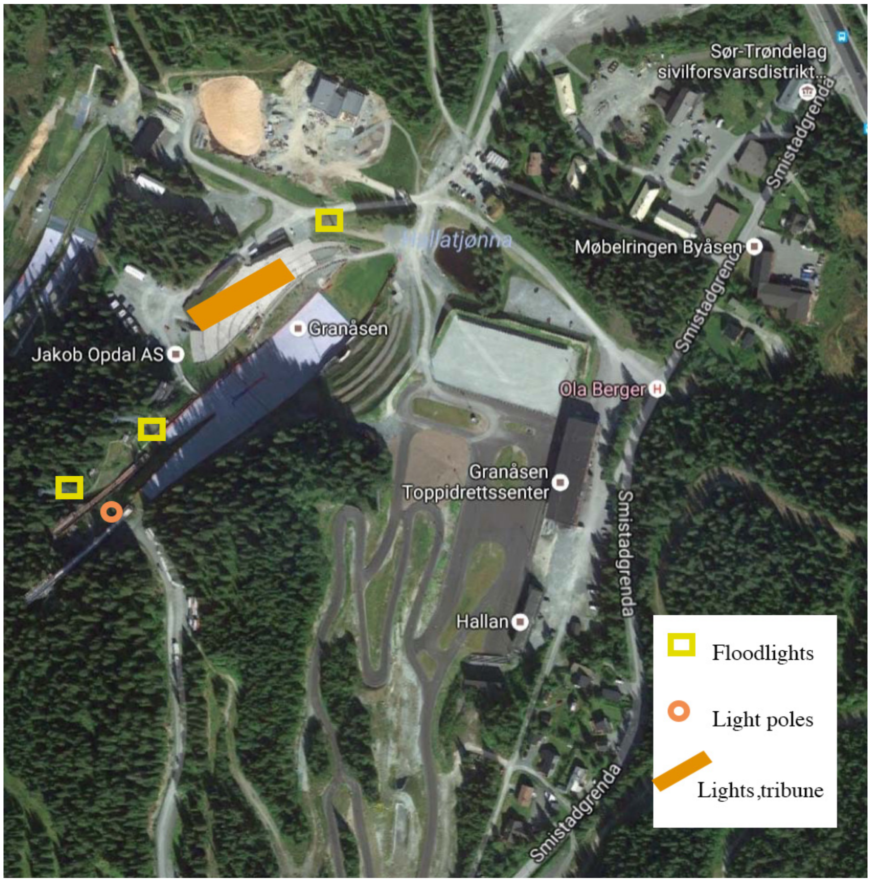


Figure 4.2: Overview of current lights at the Jump stadium, Granåsen

Stadium Cross country The CC stadium lights are on in line with the track lighting during the evening. There are two light sources in each armatures, in which one is on for exercise purposes, i.e. daily within the season, and both are on during competitions. [5] However most of the competitions take place during daytime and have little need for competition lighting. For local competitions during the evening, exercise lights are sufficient. [3] At the two concerts that have been held, the floodlights have been turned on during dismantling.

Flood lights jump The stadium flood lights jump are operated manually, and turned on if needed. That is, for exercises or competitions. The lights are on at full capacity during competitions and half during exercises. Earlier, exercises were held during the evening twice a week, but currently most of the exercises happen during daytime. However, sometimes lights are required during the day as well, depending on the weather and the lighting conditions. If the light is "flat", full lighting capacity may be required. If the weather is uncertain, half capacity may be sufficient.

4.2.2 Consumption Profiles

Load data from 2016 and 2017 have been provided from the municipality of Trondheim, and meters were set up by Trønder Energi during this year's Raw Air. Annual load profiles divided into weeks are presented in fig.4.3 and fig. 4.4, and events that coincide with the different power peaks are listed in Tab. 4.4. Total energy consumption and maximum power are shown in Tab. 4.5. This section then sequentially presents load profiles for:

1. Total energy consumption 2017, hourly resolution
2. Snow production for 2016 and 2017, hourly resolution
3. A selection of two different weeks, daily resolution
4. A day snow production apparently is run on full capacity
5. Comparison of equal events in 2016 and 2017

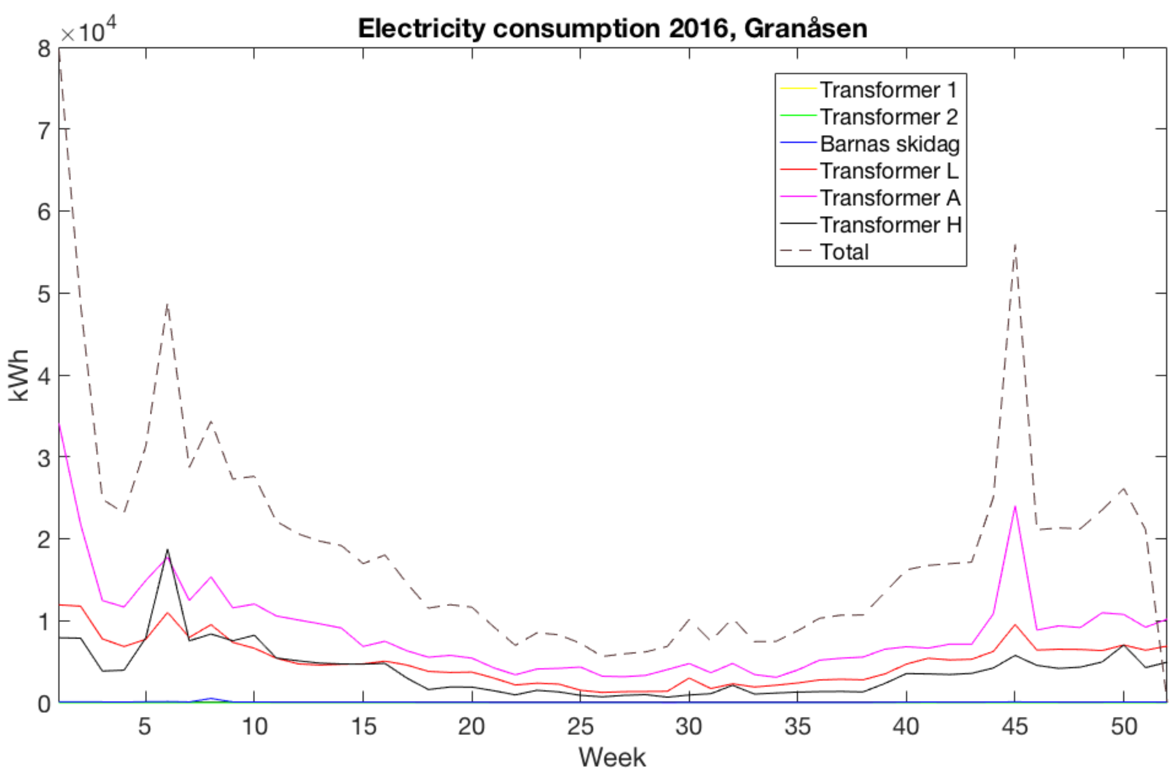


Figure 4.3: Energy consumption in Granåsen, 2016

Week	Date	Event
	2016	
6	9.-10. February	Youth Cup +WC
9	6.march	*Barnas Skidag*
10	11-13. March	Junior NM, jump
30	26.July	BS Concert
	2017	
3	21.-22. January	NC combined
4	25.January	NM jump
9	5. March	*Barnas Skidag*
11	14.-15. March	Youth cup
11	15.-16.March	Raw Air
12	24-25.March	NC combined
31	31.July	Concert,RW
31	5-6.August	NC combined

Table 4.4: Major events of 2016 and 2017

	2016	2017
Total (kWh/year)	984670	1036400
Maximum Power (kW)	936.69	985.00

Table 4.5: Total energy and maximum power in 2016 and 2017

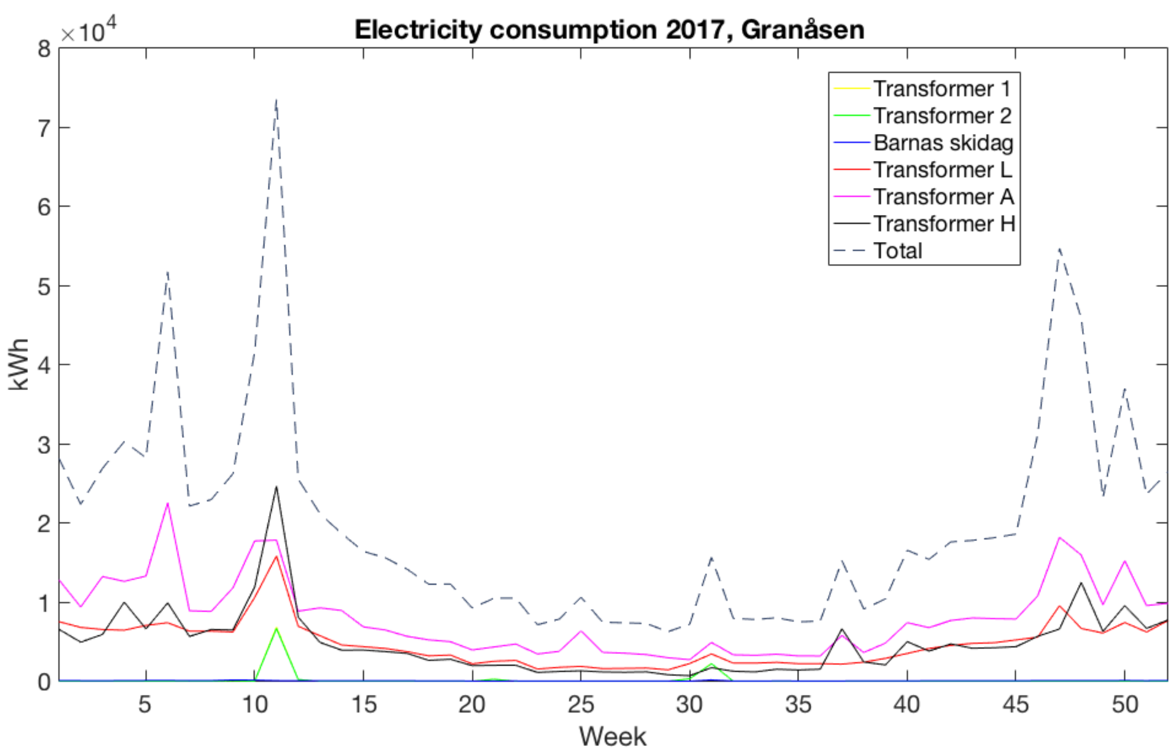


Figure 4.4: Annual load profile 2017

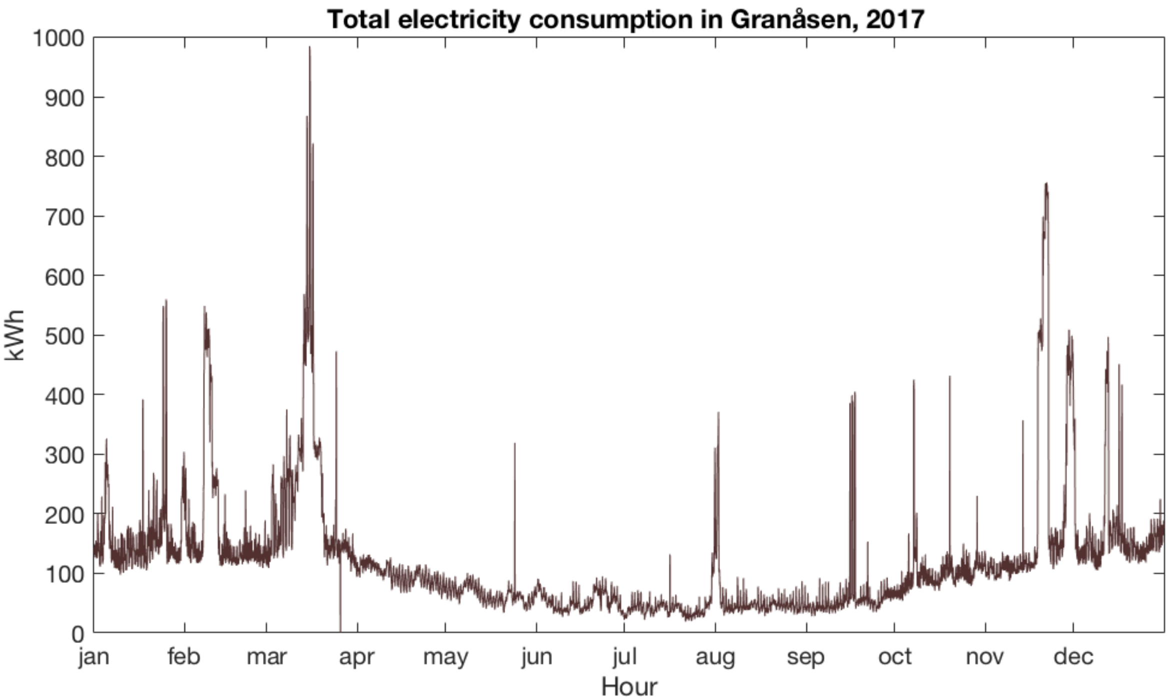


Figure 4.5: Total energy consumption 2017, hourly resolution

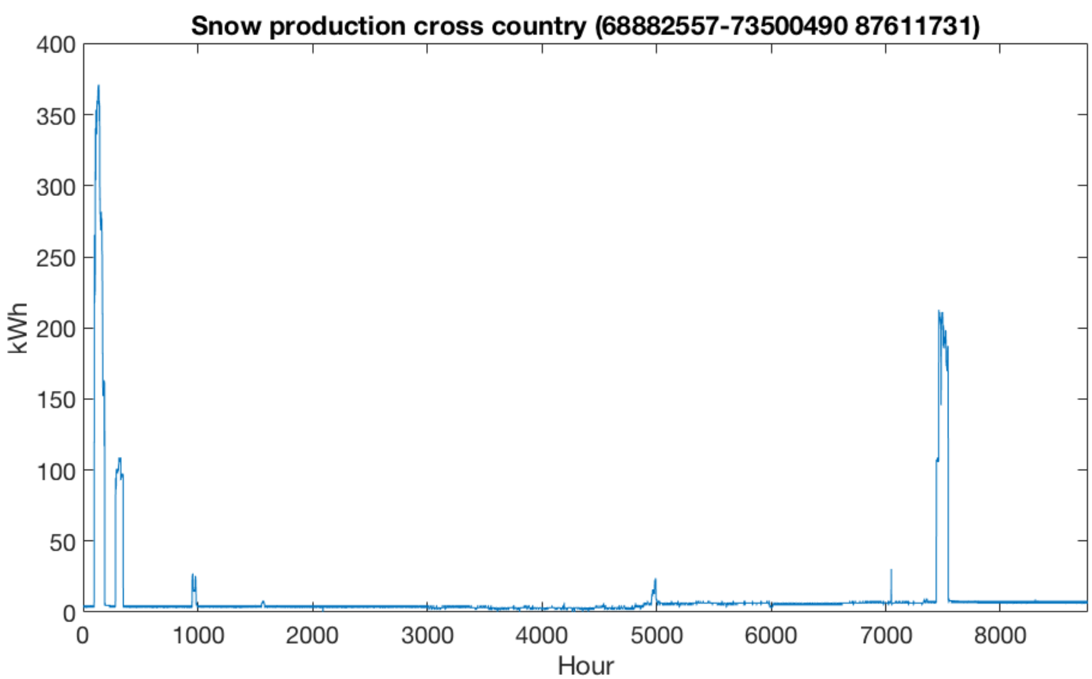


Figure 4.6: Annual consumption profile for measure point snow production,2016

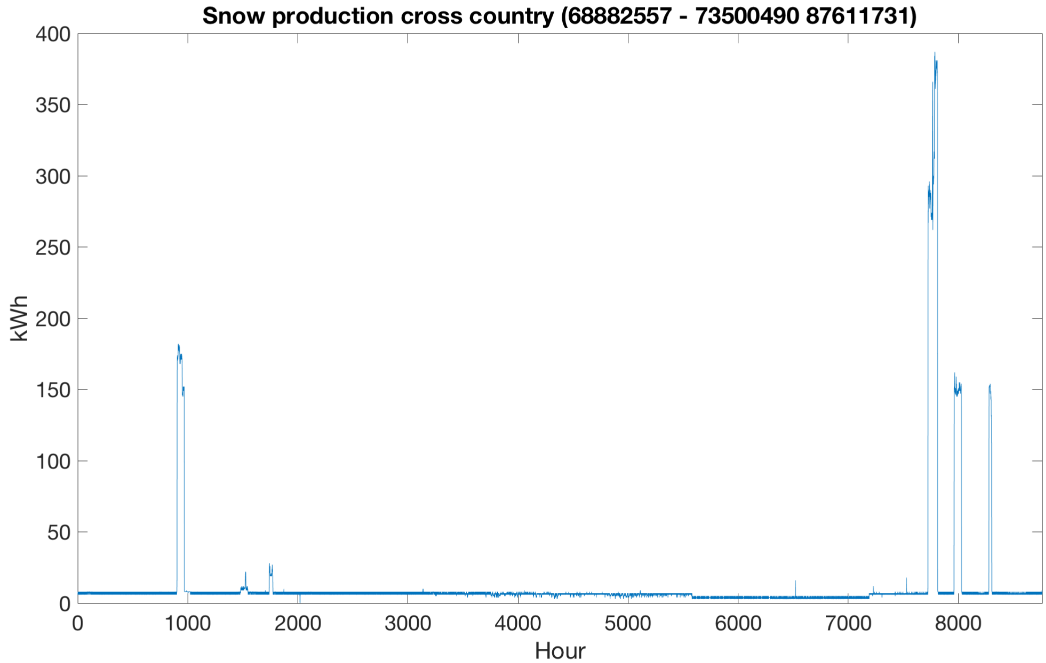


Figure 4.7: Annual consumption profile for measure point snow production,2017

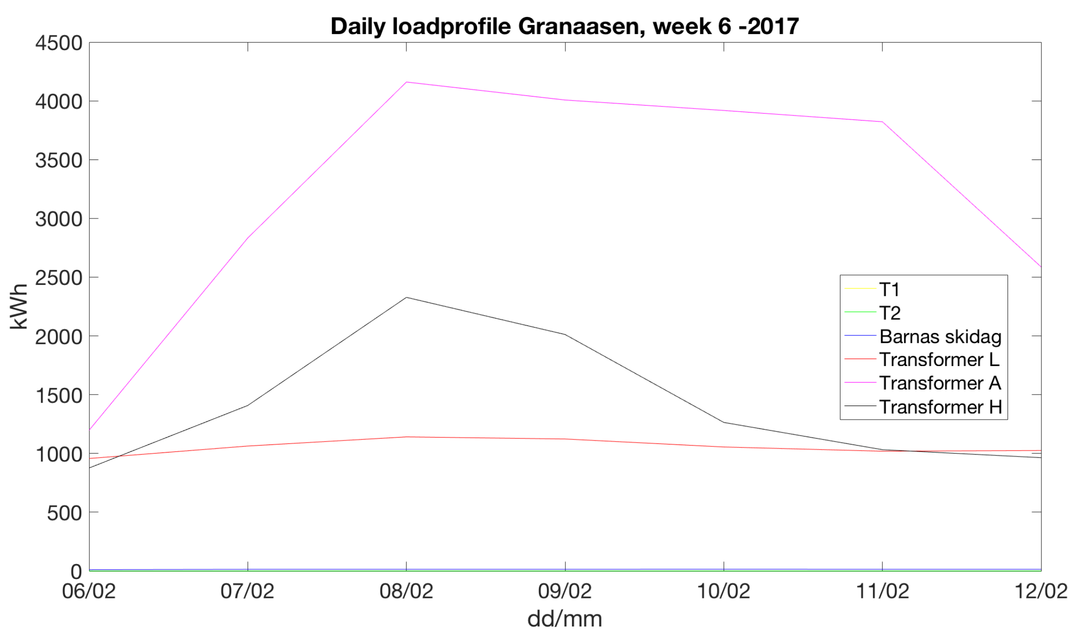


Figure 4.8: Electricity consumption in Granåsen, 2017 - Week 6

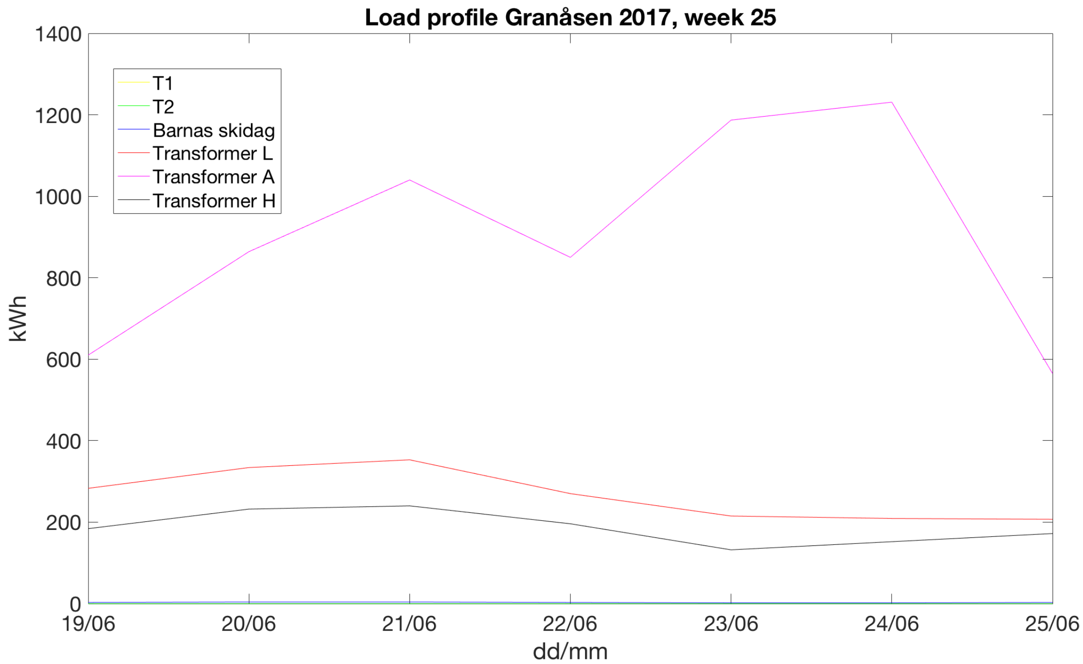


Figure 4.9: Electricity consumption in Granåsen, 2017 - Week 25

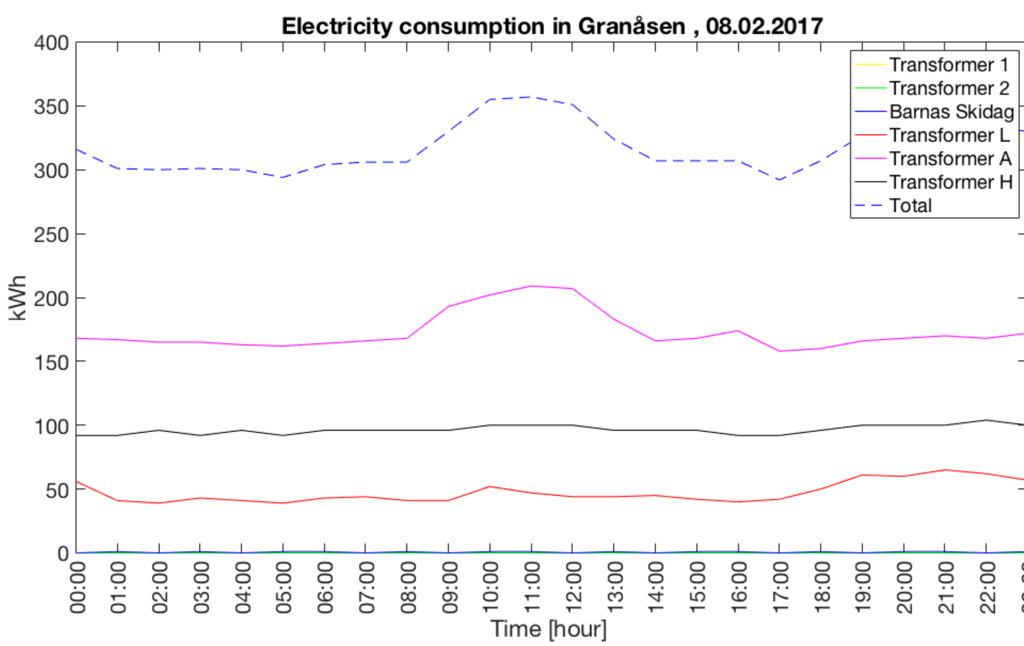
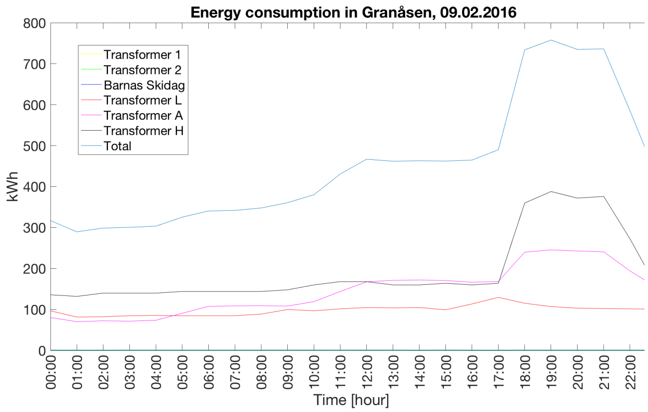
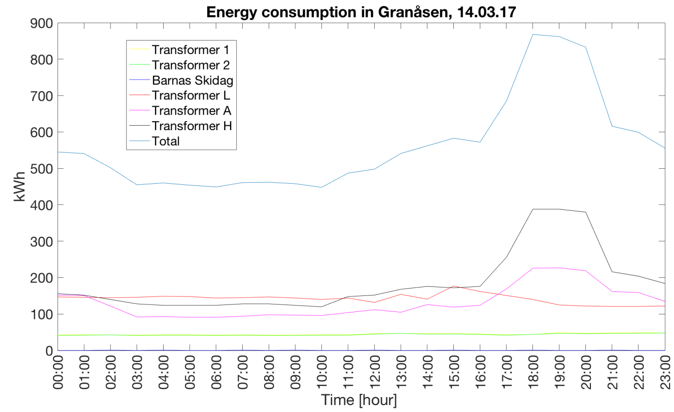


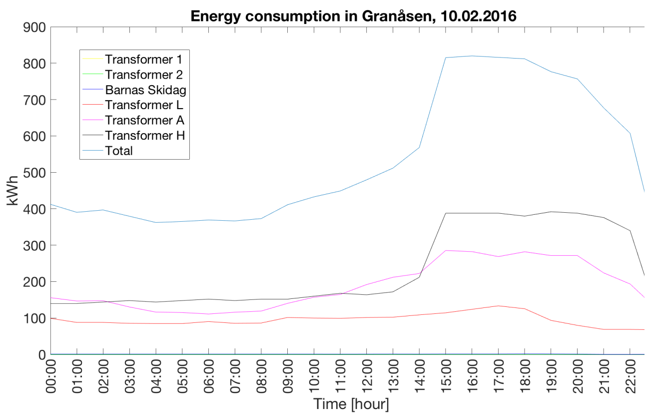
Figure 4.10: Snow production at Granåsen 08.02.17, hourly resolution

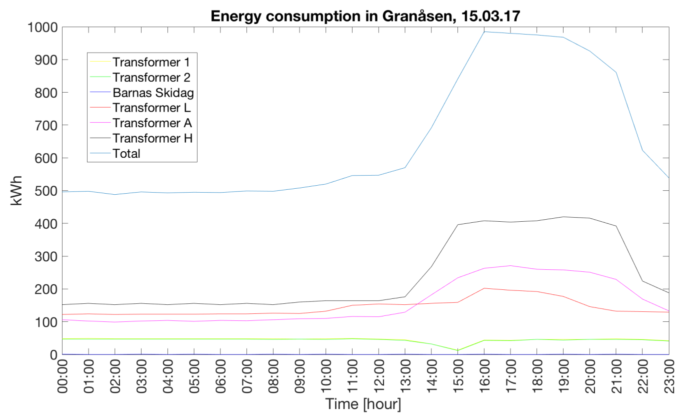
2016	2017

Youth Cup

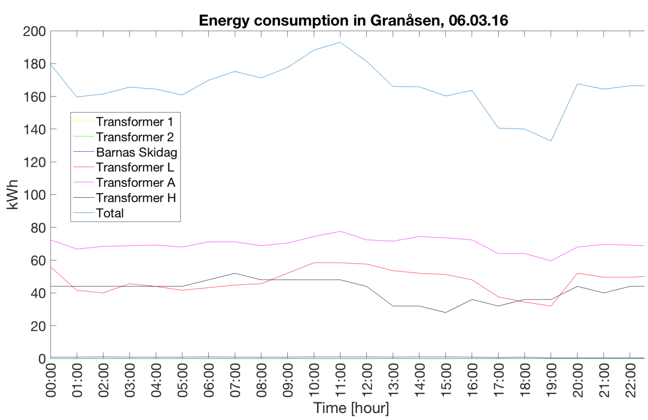








Barnas Skidag



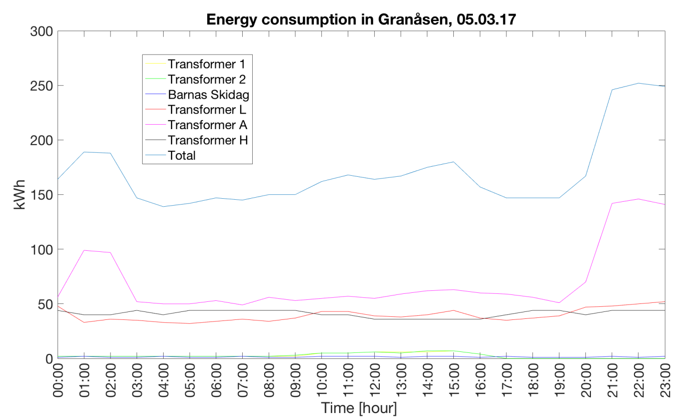
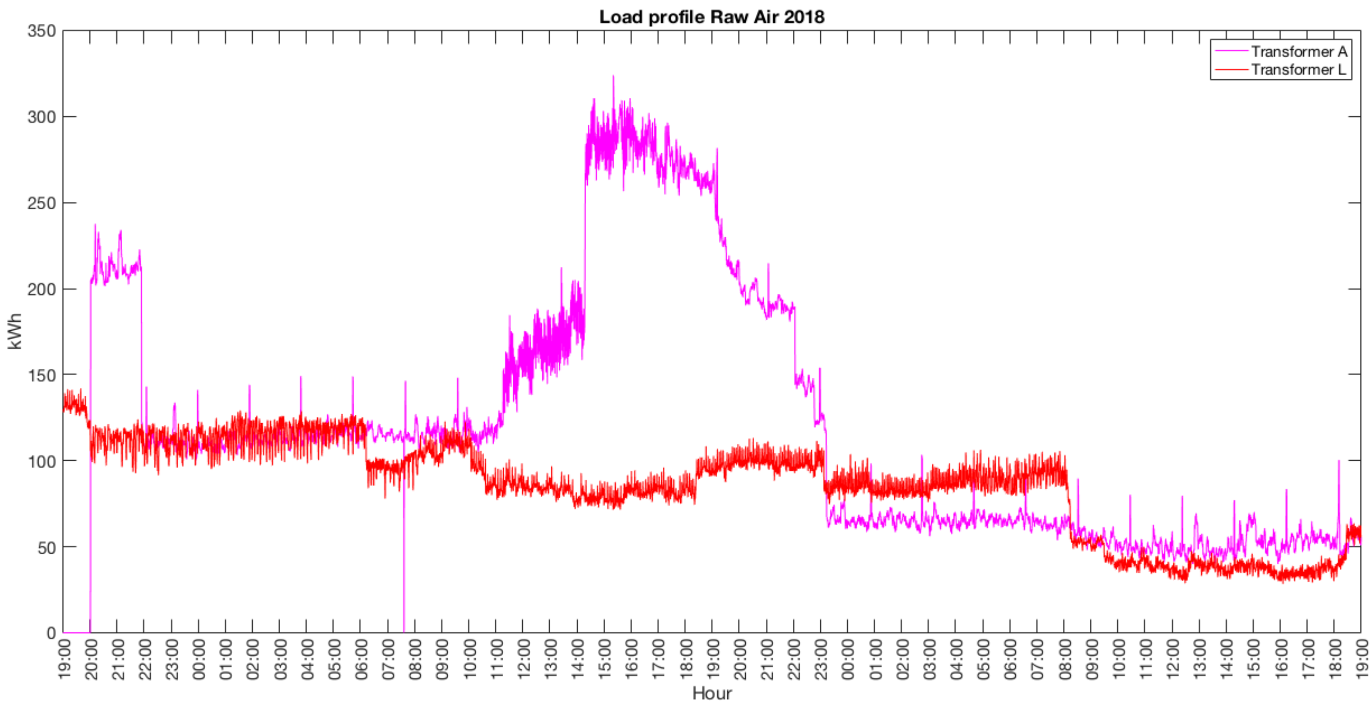
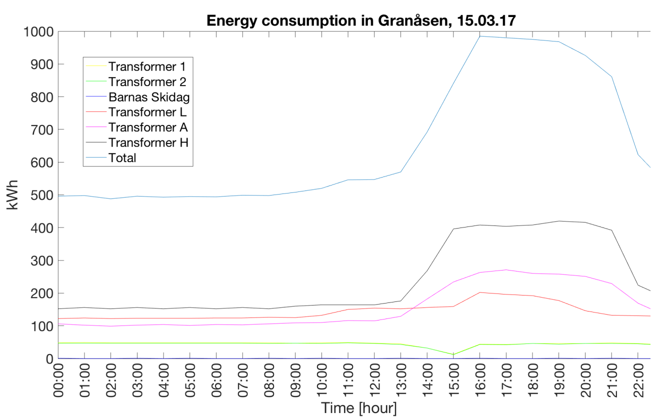


Table 4.6: Comparison of load profiles connected to Youth cup and Barnas skidag in 2016 and 2017 respectively.

Raw Air
2018



2017



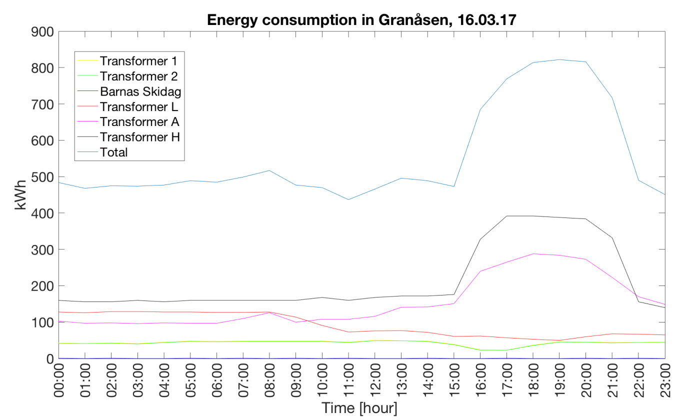


Table 4.7: Load profiles for Raw Air 2018 and 2017 respectively.

Comparison of events

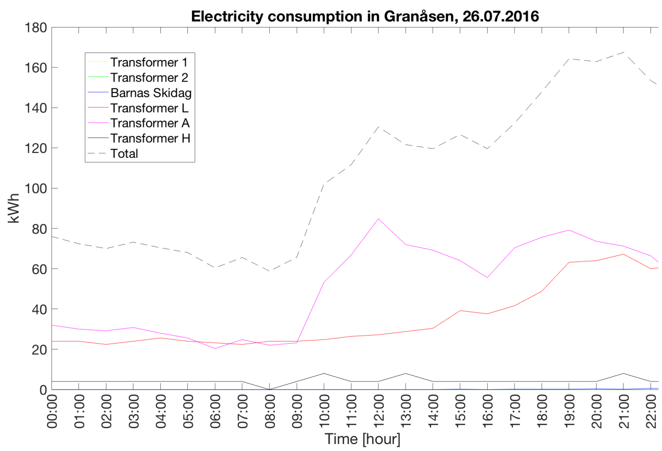
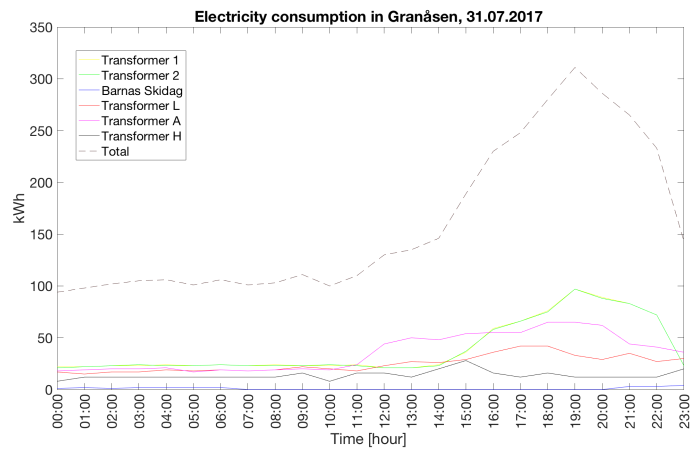
Concert	
Bruce Springsteen (2016)	**Robbie Williams (2017)**
	

Table 4.8: Load profiles for BS concert and RW concert in Granåsen

4.3 Development Plans at Granåsen

The development in Granåsen is planned in four phases, as described in Tab. 1.1. These phases involve several expansions and upgrades, including floodlit trails and a roller track.[53] Approximately 100 new lighting points will be acquired in connection with the new flood lit trail.[13] The expansion of the new tracks will lead to an increased demand of snow production. Requirements for quantity is set to be 50 000 m^2 for a normal season and 90 000 m^2 for a WC season. [13] The existing buildings described in 4.2 will be demolished and replaced by the buildings described in Tab. 4.9[6]. [50] [53]

[6] This is the current, provisional regulation plan. It should be taken into account that changes may occur.

Phase	Building	BTA(m^2)	Floors	Building category	Description
1	Arena building, CC	2500	3	School	Angular roof
2	Arena building, jump	1500	3	School	Angular roof
2	Various	200	-	-	Judge tower, etc.
3	Shooting hall	3000	1	Sports centre	Shooting range for biathlon at the roof
4	Football hall	10 000	1	Sports centre	Angular roof

Table 4.9: Development plans for Granåsen

Chapter 5

Load Profile Aggregation Methodology

For grid investment decisions and planning of energy systems, prognosis of future electric load profiles constitute a key element. [40] Prognoses for future load profiles in Granåsen are based on a bottom-up approach to load modelling, as described in section 3.1. The general methodology applied for this purpose is illustrated in fig.5.1. It is furthermore distinguished between statistical and engineering load modelling, which are classified for the different loads in the following sections. Annual scenarios of load profiles are modelled in Matlab, further presented in Ch.7. The main objective with obtaining load prognoses for Granåsen involves two aspects:

- Power
- Energy consumption

The aggregation of the total load profiles are modelled in a weekly resolution, which makes sense when energy consumption is studied. However when power is analyzed, it is necessary to look at a resolution no lower than an hourly basis. The load profiles that involve statistical load modelling are presented individually in an hourly resolution.

The purpose of this work is mainly to demonstrate the methodologies and how the various loads depend on various variables, rather than the actual numerical results.

This chapter describes the system boundaries of this work, the process of data retrieval, sub methodologies for obtaining load profiles for the individual loads and a methodology for obtaining PV production potential.

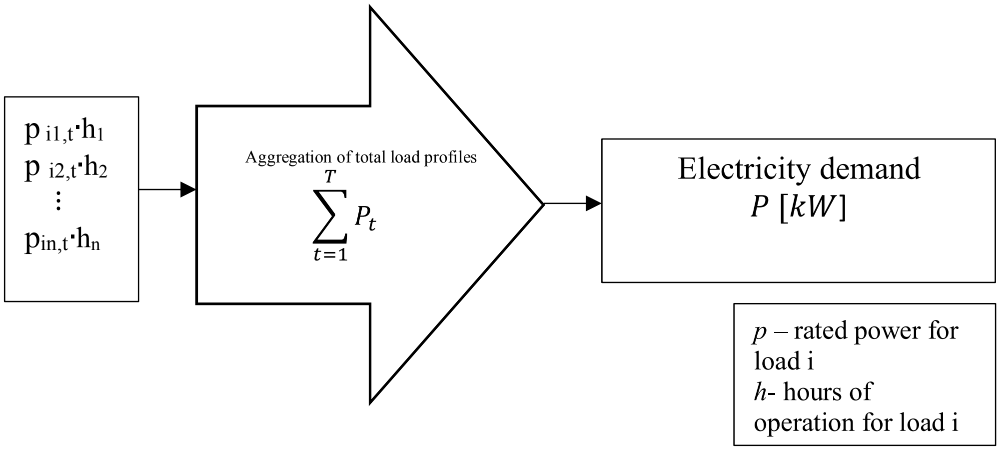


Figure 5.1: Load profile aggregation methodology

5.1 System Boundaries

The system boundaries of this work are chosen to encompass four central loads of Granåsen. They are illustrated in fig. 5.2.

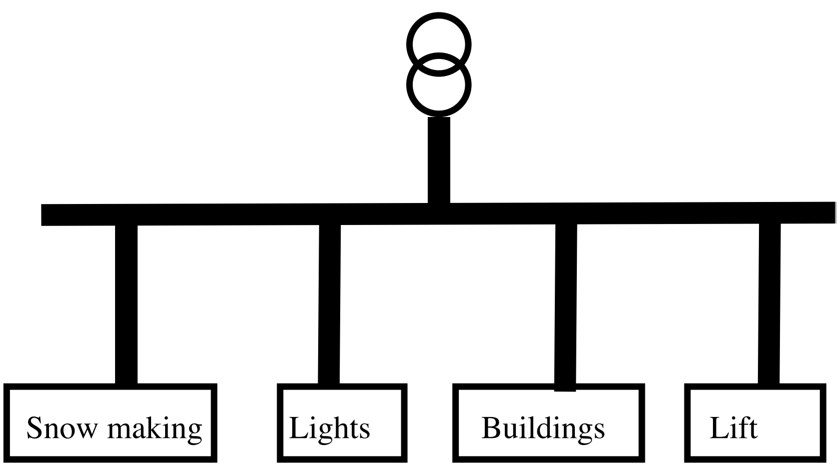


Figure 5.2: Four primary loads of Granåsen which will be encompassed in the load analysis.

5.2 Data retrieval

The process of collecting relevant data for this work has constituted an extensive part. Consumption profiles presented in chapter 4 has been obtained from the municipality of Trondheim and is used as verification in relation to prognosis of future energy consumption.

Data retrieval for statistical load modelling It has been attempted to procure load data from buildings and facilities in Norway which can serve as reference buildings. The obtained data are described in App.D

Data retrieval for engineering load modelling It has been attempted to procure information about individual power ratings and operating times from several parties, which is used as input in the engineering approaches to load modelling.

5.3 Load Profile Aggregation Sub Methodologies

Sub methodologies for the individual loads are described in the following sections. Specific assumptions which have been necessary to make will be described in Ch.7.1.

5.3.1 Snow production

The energy demand for snow production is predicted using an engineering model, and is based on information from SIAT, i.e. the two graphs in fig. 5.4 and 5.3.

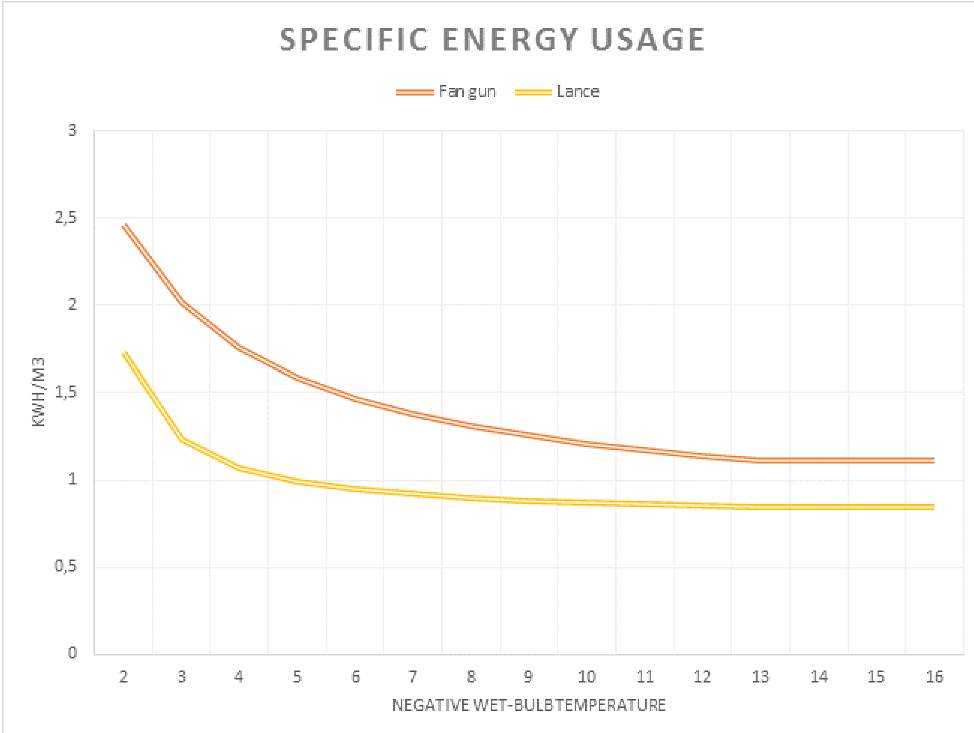


Figure 5.3: Average specific energy usage for snow production equipment[13]

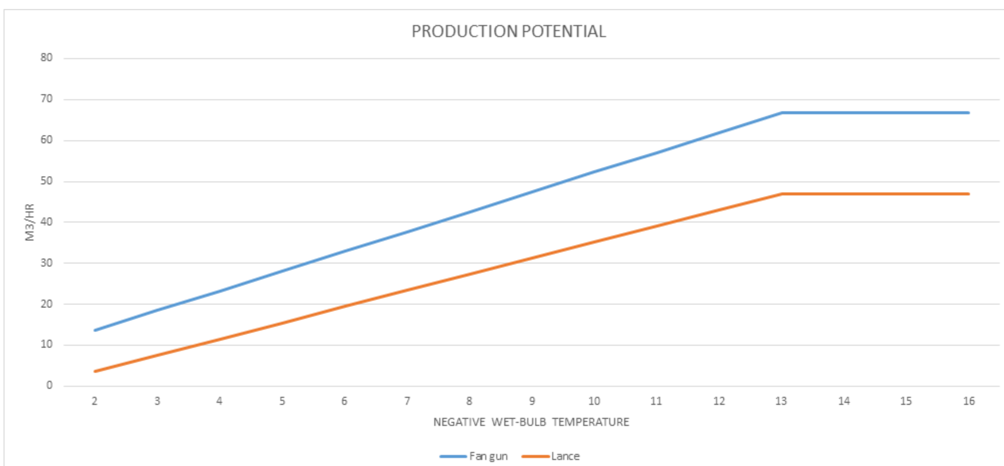


Figure 5.4: Average production capacity for snow production equipment[13]

It can be seen that temperature is the determining variable for snow production capacity and energy consumption. The production capacity and hence the energy consumption, is modelled according to an average temperature scenario.

A mathematical representation of the methodology for obtaining an energy forecast for snow production is shown in fig.5.5

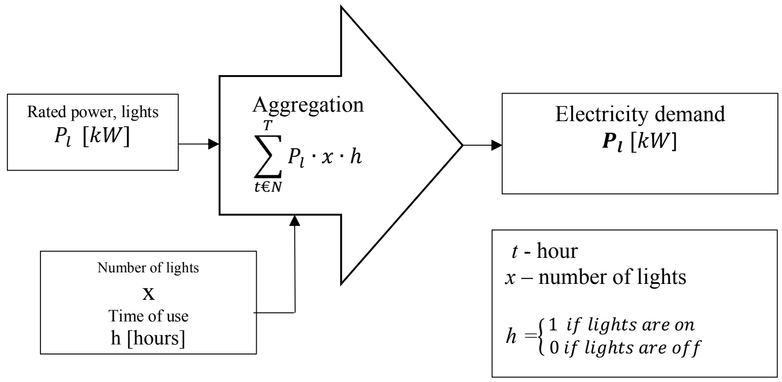


Figure 5.6: Load profile aggregation methodology used to obtain prognosis of energy consumption linked to lights.

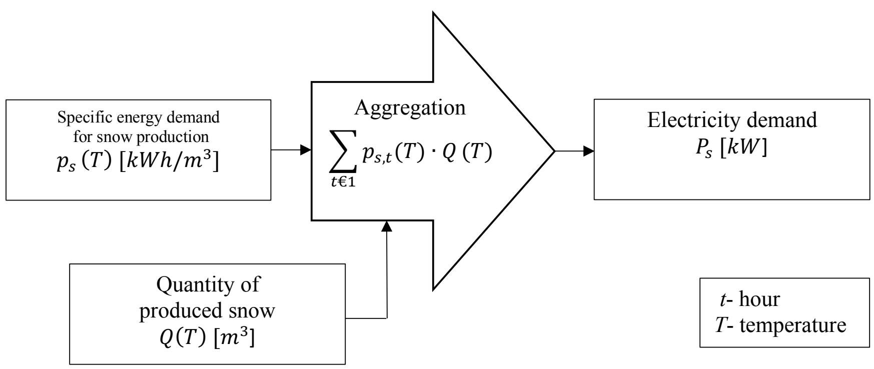


Figure 5.5: Load profile aggregation methodology for snow production

5.3.2 Lights

Load profiles of the lights in Granåsen are obtained through an engineering approach to load modelling. A graphical representation is shown in fig.5.6.

Subsystem boundaries It has not been possible to obtain information of all the lights in Granåsen. The lights encompassed in the prognosis include:

- Existing lights:

Floodlights jump stadion (yellow squares in fig.4.2)

Floodlights CC

Floodlit trail Nilsbyen

- Future lights:

Floodlit trails (4 km)

5.3.3 Elevator

The prognosis of the energy consumption of the elevator is based on a statistical bottom up load model, and reference data is obtained from Holmenkollen National Ski Arena. The obtained consumption prognosis is adjusted for relevant factors, further described in ch. 7.

5.3.4 Buildings

If the surrounding temperature is at approximately the same level, buildings with similar functions can be chosen as reference buildings and provide an indication of future energy consumption.[58] The prognosis of the energy consumption of building x in Granåsen is based on a statistical bottom up load model, and can be summarized with the following steps:

1. Data for hourly energy consumption have been obtained for a building which can serve as a reference building.
2. It is assumed that the shape of the load profile for the chosen reference building can be transferred to the respective building in Granåsen.
3. The energy consumption for building x in Granåsen is scaled according to Eq. (5.1) or Eq. (5.2), depending on the technical standard of the reference building and available information.
4. The load profile has to some extent been adjusted for significant events.

Reference information can be found in App.D.

$$E_{x,G} = \frac{A_{x,Granåsen}}{A_{ref}} \tag{5.1}$$

$$E_{x,G} = \frac{A_{x,Granåsen}}{E_{ref}} E_{spec,passive} \tag{5.2}$$

where

- $E_{x,G}$ is the energy consumption of building x in Granåsen, i.e. one of the buildings listed in Tab. 4.9.
- E_{ref} is the total annual energy consumption of the respective reference building
- $A_{Granåsen}$ is the area of building x in Granåsen
- A_{ref} is the area of the respective reference building
- $E_{spec,passive}$ is the specific energy consumption of passive buildings. described in section 3.2.2

$E_{spec,passive}$ can be calculated from Tab.3.7, Tab.3.3 and Tab.3.4, but have in this work from section3.2.2 been set to 80 kWh/m^2/year due to simplicity.

5.4 Methodology of Assessing PV Potential

Site specific solar irradiance incident on a horizontal surface has been provided.

The methodology for estimation of the exploitable area for solar energy at roof and fasades is developed by International Energy Agency (IEA). IEA provides a utilization factor of 0.4 for roofs and 0.15 for facades. That is , for every m^2.there is 0.4 m^2 roof and 0.15 facade exploitable for solar power installations.[48]. Using Eq. (2.2) and Eq. (B.5), the annual potential for solar energy is modelled in Matlab, as illustrated in fig.5.7

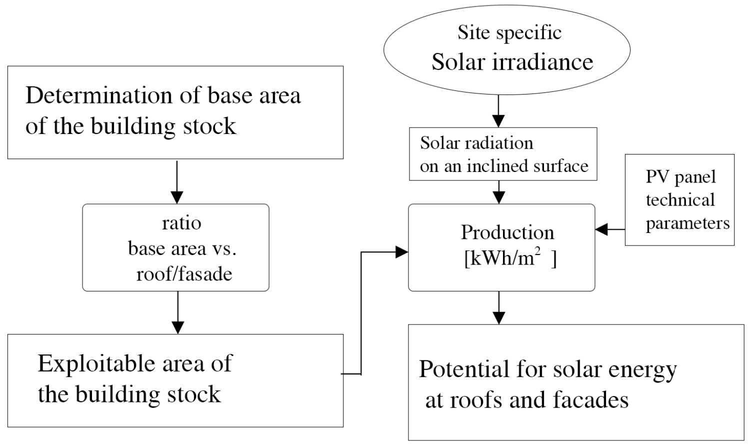


Figure 5.7: Methodology for assessing PV potential

5.5 Assessing Load Scenario With Integration of PV

The net electric load profile with integration of PV in Granåsen is modelled by using Eq. (2.1). The results will be presented in Ch. 7.3.2, in a weekly resolution. Load profiles modelled with a statistical approach, i.e. the buildings in Granåsen, are after integration of PV presented in an hourly resolutions for a selection of periods.

Chapter 6

PV potential

PV production potential for Granåsen is modelled using the methodology described in 5.4. This chapter will describe the prerequisites for the analysis, and the corresponding results.

6.1 Prerequisites for Modelling PV potential at Granåsen

The prerequisites for the analysis involve:

- Available area
- Inclination angle
- Solar radiation data

Assessment of PV potential at Granåsen is based on four different scenarios, concerning two different angles and two different areas. Available area is based on information from Tab.4.9 and section 5.4 and either includes or excludes the football hall. On the basis of section 2.3.1, an inclination angle of 30° is chosen for the calculations. Additionally, output is modelled for an inclination of 90 °, as it may be of interest to maximize the production during the winter when the facility has the tallest power peaks and the highest energy consumption. Solar irradiance data for Granåsen are received from Siemens and presented in fig. 6.1 and 6.2. This data was perceived troublesome and solar radiation data for Frosta in the county of Trønderlag is used instead. [15]

6.2 Solar Irradiance at Granåsen

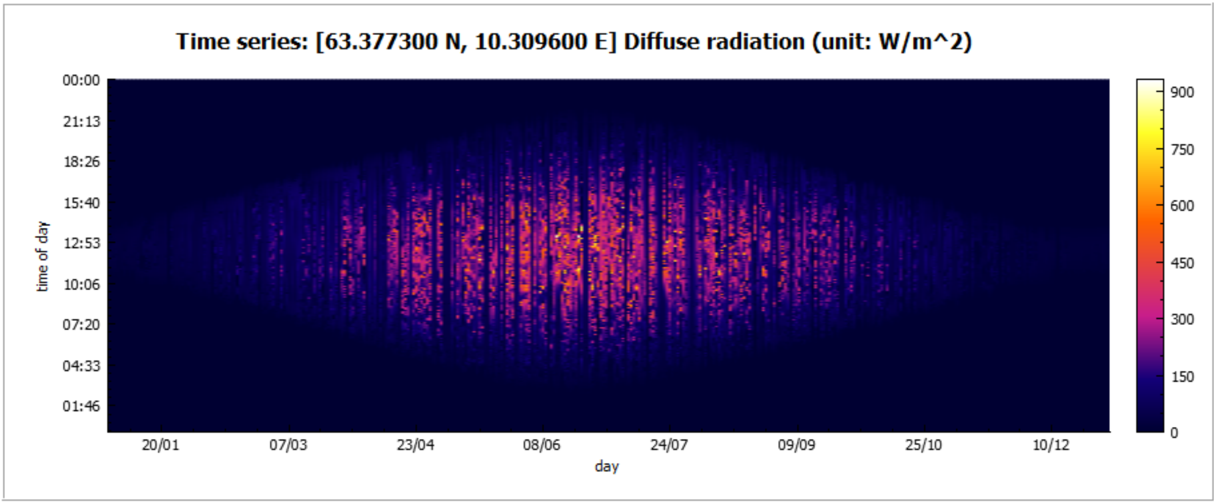


Figure 6.1: The intensity of diffuse irradiance at Granåsen [4]

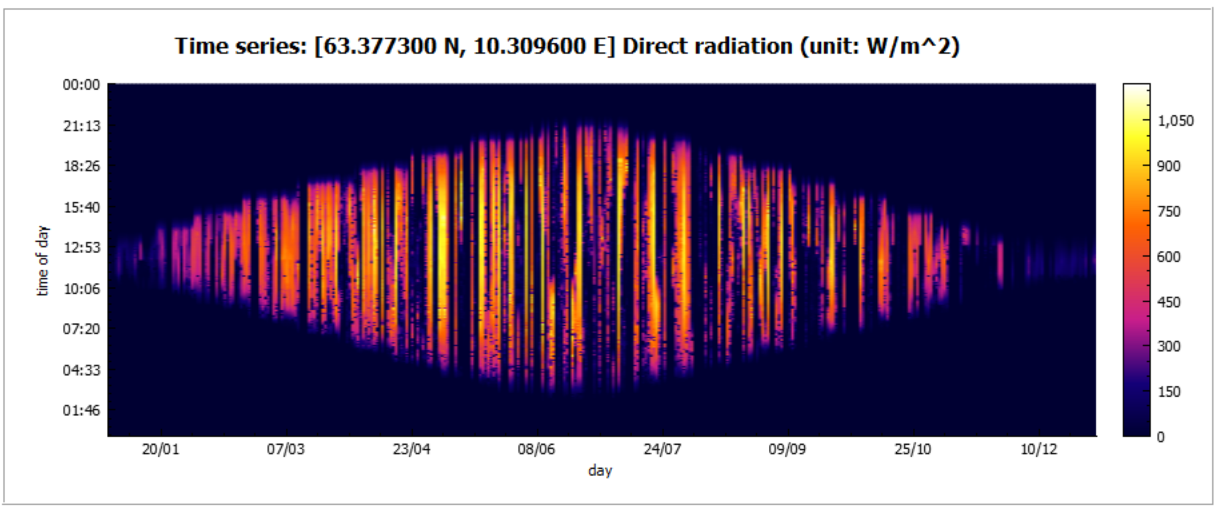


Figure 6.2: The intensity of beam irradiance in Granåsen[4]

6.3 Annual PV Production Potential at Granåsen

An overview of the scenarios with the corresponding output is presented in Tab.6.1. 3 of the scenarios are shown in fig. 6.3, 6.4 and 6.5 respectively.

Exploitable Area	**Inclination angle β**	**Installed capacity**	**Sum of Annual production**
573 m^2	30 °	94.050 kW_p	81820 kWh/year
573 m^2	90 °	94.050kW_p	74582 kWh/year
4573m^2	30 °	750.750 kW_p	652790kWh/year
4573m^2	90 °	750.750 kW_p	632230kWh/year

Table 6.1: PV output of the four different scenarios

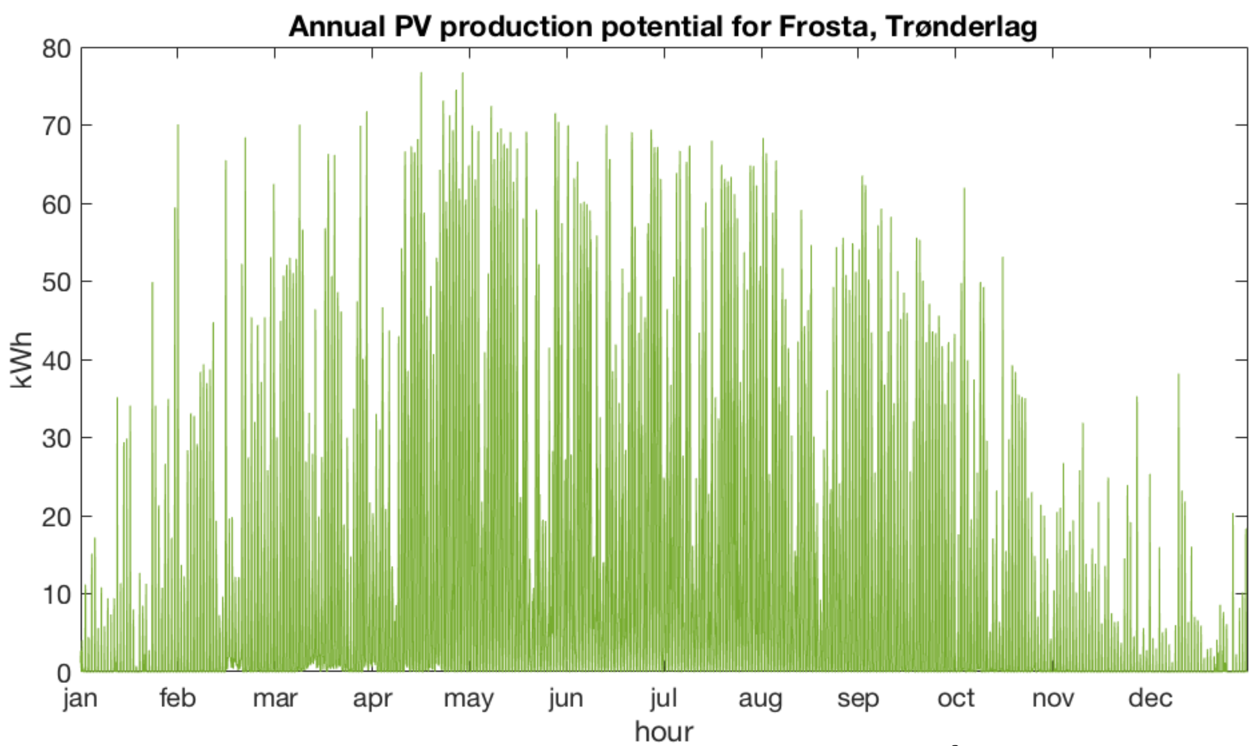


Figure 6.3: Annual PV production potential, Area 573 m^2 and β=30°

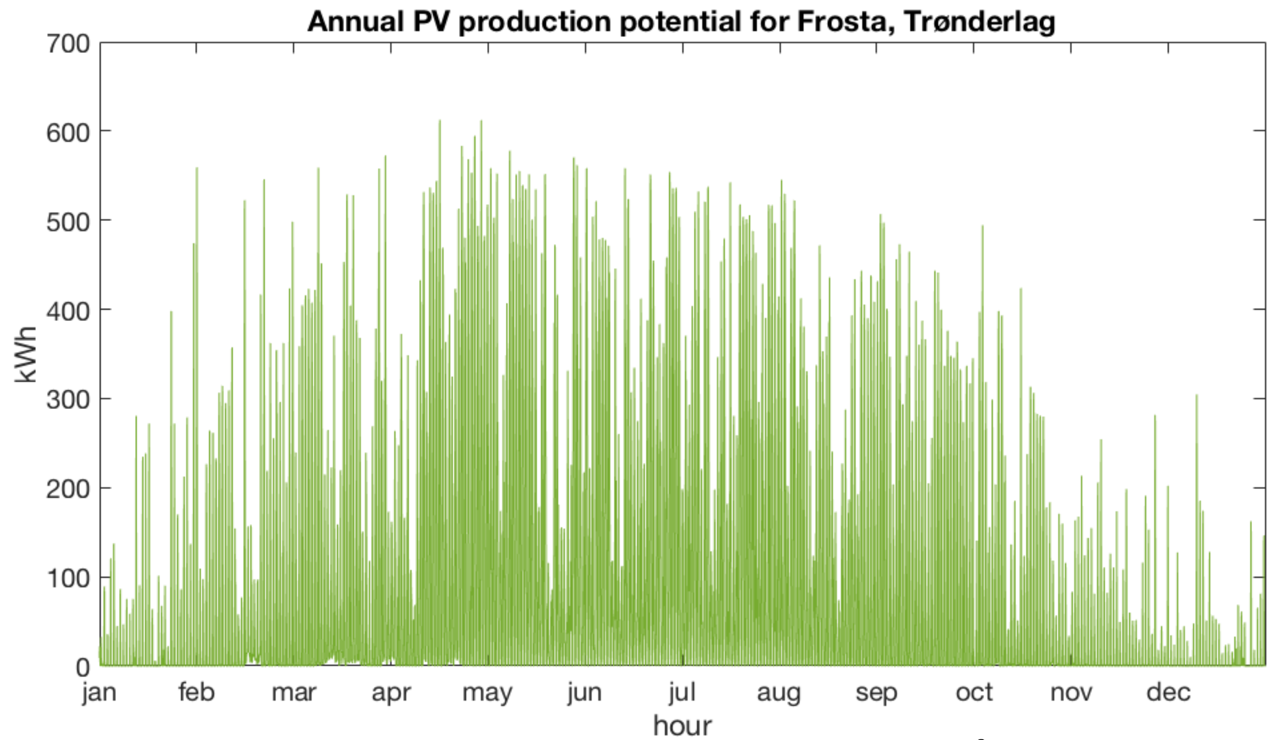


Figure 6.4: Annual PV production potential, Area 4573 m^2 and β=30°

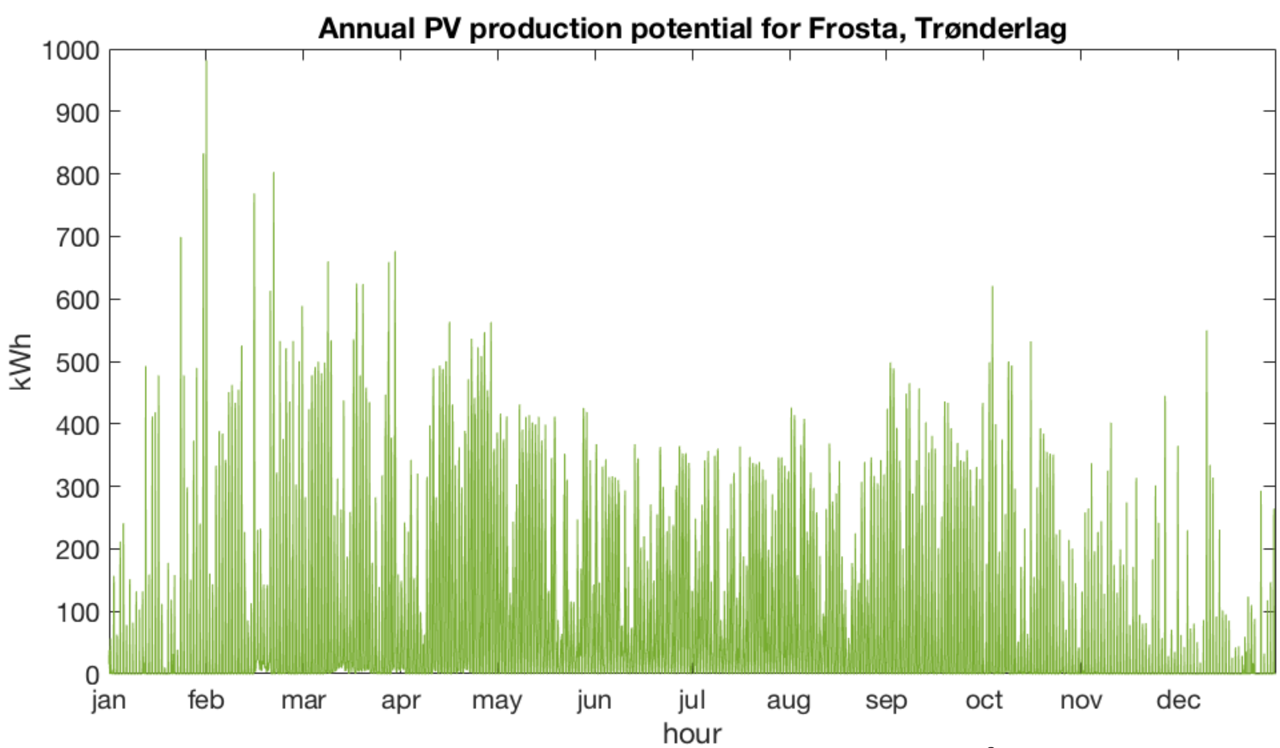


Figure 6.5: Annual PV production potential, Area 4573 m^2 and β=90°

Chapter 7

Prognosis of future energy consumption in Granåsen

This chapter will present the specific prerequisites for the load prognosis, description of scenarios and present a load prognosis for Granåsen.

7.1 Description of Prerequisites

In order to construct load prognoses at Granåsen, it has been necessary to make several assumptions, which will be described specifically subsequently.

Snow production Production of snow is possible during subzero temperatures. For Granåsen, this will in practice correspond to approximately -2 ° [13].

The calculations are based on daily normal mean temperatures, obtained from Trondheim in 1961-1990.[8] The weather station is based in Voll, which is at 127 meters above sea level, and not quite representative for Granåsen. Experiences indicate that the ski stadium is located in a cold pit, and the actual temperature can hence be assumed to be 1 or 2 degrees lower. [16]

It is suggested to acquire 8 fan guns, but the plant will rarely be run at full capacity. [13]. Due to simplicity, both operation time and number of fan guns in operation are modelled as constants.

Lights As a starting point, the following assumptions have been made:

- The energy consumption of the existing lights remains the same.
- The power ratings of the new lights that will be acquired are equal to the current lights.
- The operation times for the new floodlit trail will be equal to the existing ones.

The operation of the stadium lights depend on when Granåsen hosts the events listed in Tab.4.1.[3] Lights are generally not on during the summer. Load modelling of the lights will rely on information from Tab.7.1 and Tab. 4.1. [3]

Event	Lighting requirement
Raw Air (WC)	5-6 hours of full lighting Wednesday +Thursday, 2-3 hours of exercise lighting evenings beforehand (depending on weather)
NC	3-4 hours per day if weather conditions require lighting. Organizer may need setup light the day before.
COC	Weather dependent

Table 7.1: Description of the lighting requirements during annual events at Granåsen [3]

For exercises, on-time of the lights are assumed to be 2 hours.

Additionally there can be three cases concerning the lights:

- Full lighting required during an event due to bad weather
- Half lighting required during an event due to uncertain weather
- No lights required during an event.

Buildings Load data for the buildings listed in Tab. 7.2 have been obtained and applied as reference buildings for the planned buildings at Granåsen. A full description of the buildings and the adjustment made for the calculations can be found in App.D. The Granåsen buildings listed in Tab.7.2 are the included buildings for the analysis.

Elevator The energy consumption of the elevator, concourse and elevator lobby is based on reference values provided by Holmenkollen, which are described more closely in App. D.3.

[1] National Ski Arena
[2] Plus judges tower etc.
[3] Multi purpose hall in Fosnes

Reference building	**Granåsen**
Holmenkollen NSA[1] Arena Building CC	Arena Building CC
Holmenkollen NSA Aarena building jump[2]	Arena building Jump
Fyret flerbrukshus[3]	Shooting hall/ Multi purpose hall
Leirskallen gymnastic hall	Football hall

Table 7.2: Overview of reference buildings.

The following assumptions have been made:

- The existing cable car will be replaced with a new one
- The future power ratings and the consumption pattern can be comparable with the elevator in Holmenkollen
- The consumption in Holmenkollen during the summer (week 18-37) is due to tourists
- The consumption due to tourists at Granåsen can be neglected
- The consumption that is due to tourists is constant and can be subtracted when the load prognosis of Granåsen is generated.

7.1.1 Description of Scenarios

The energy consumption of the loads described in fig. 5.2 is, based on the data retrieval presented in Ch.4, functions of various external variables. Tab.7.3 present which variables the various loads are assumed to depend on. The energy consumption in buildings are, from section 3.2, also strongly affected by temperature variations. However, temperature dependence in buildings is disregarded in this analysis.

Load	**Variable**	**Function**
Lights	Events,Weather	L(E,W)
Elevator	Events	E(E)
Buildings	Events	B(E)
Snow production	Temperature	S(T)

Table 7.3: Description of the load variables

Scenario 1

Scenario 1		
Prerequisites		**Affected Load**
Fan Guns	4	Snow production
Operating hours	10	Snow production
Quantity	50 000 m^2	Snow production
Weeks of NC	6, 8, 33	All ex. snow production
Weeks of WC	11	All ex. snow production
Weeks of COC	38	All ex. snow production
Weeks of EJ[4]	51, 2, 1, 12	All ex. snow production
Weeks of MC[5]	29	Lights
Weather	Bad	Lights

Table 7.4: Description of scenario 1

Scenarios With PV

The effect of PV is shown on the load profiles based on scenario 1. The scenarios with PV are based on the two different production potentials obtained in fig. 6.3 and fig.6.4. Inclusion of the football hall is referred to as scenario pv1 and exclusion of the football hall is referred to as scenario pv2.

7.2 Prognosis of Individual Load Profiles at Granåsen

This section will present the individual load prognoses based on the scenario described in Tab.7.4

[4]EJ - Exercise Jump
[5]MC- Music concert

7.2.1 Snow production

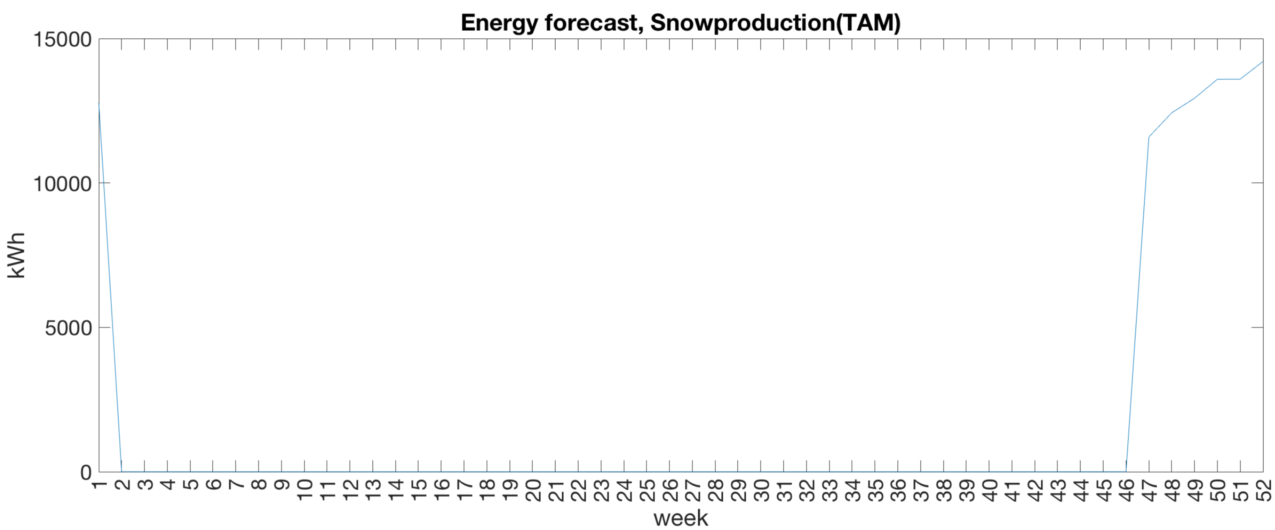


Figure 7.1: Weekly prognosis of the energy consumption due to snow production at Granåsen

7.2.2 Elevator

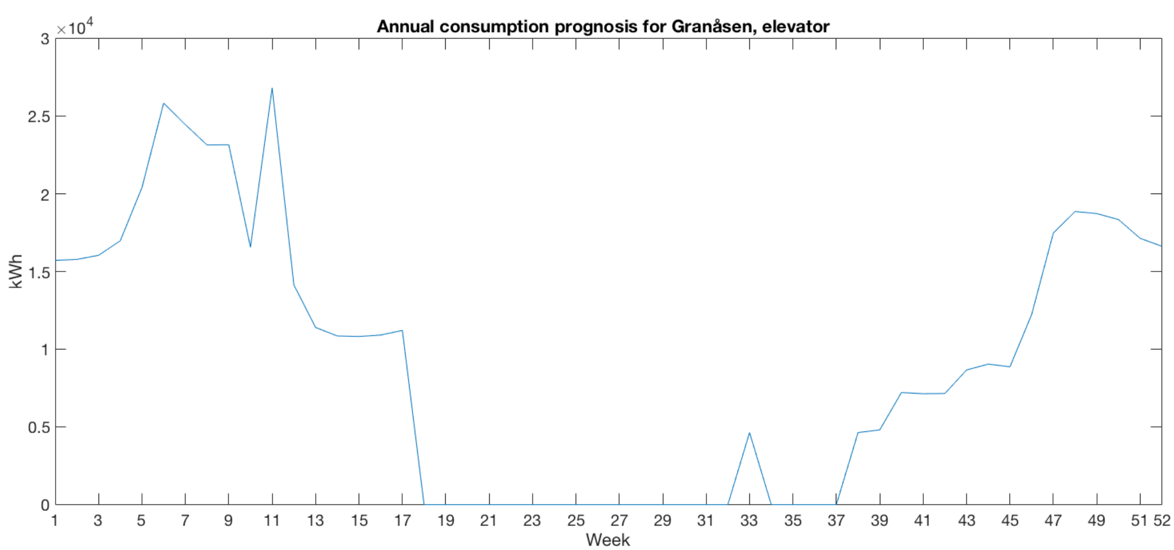


Figure 7.2: Weekly prognosis of the energy consumption due to the elevator, lobby and concourse

7.2.3 Lights

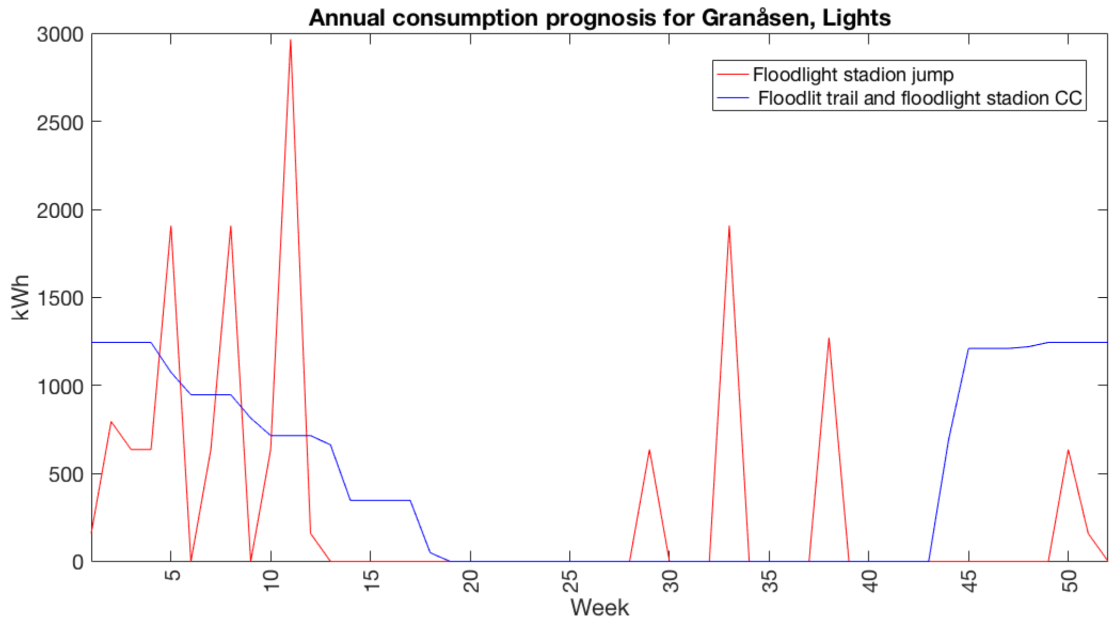


Figure 7.3: Weekly prognosis of annual energy demand for lights, scenario 1

7.2.4 Buildings

Arena building CC

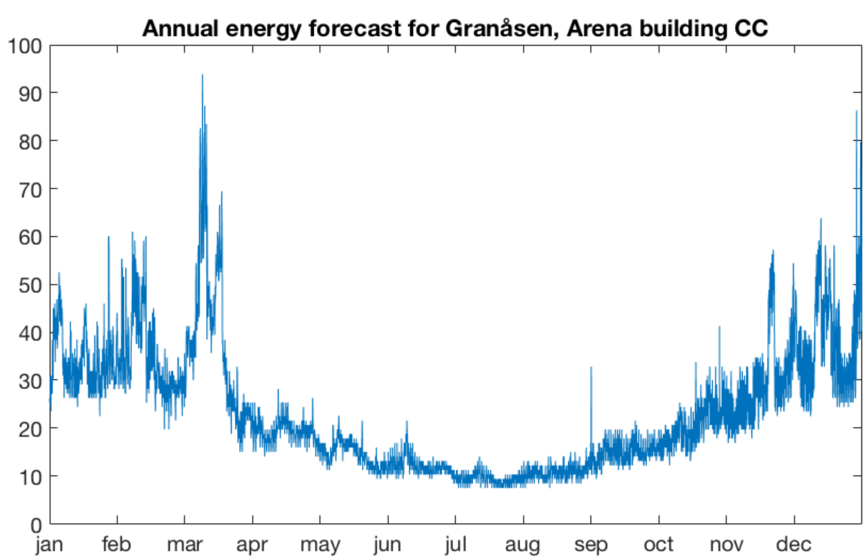


Figure 7.4: Prognosis of annual energy demand for Arena building CC, hourly resolution.

Arena building jump

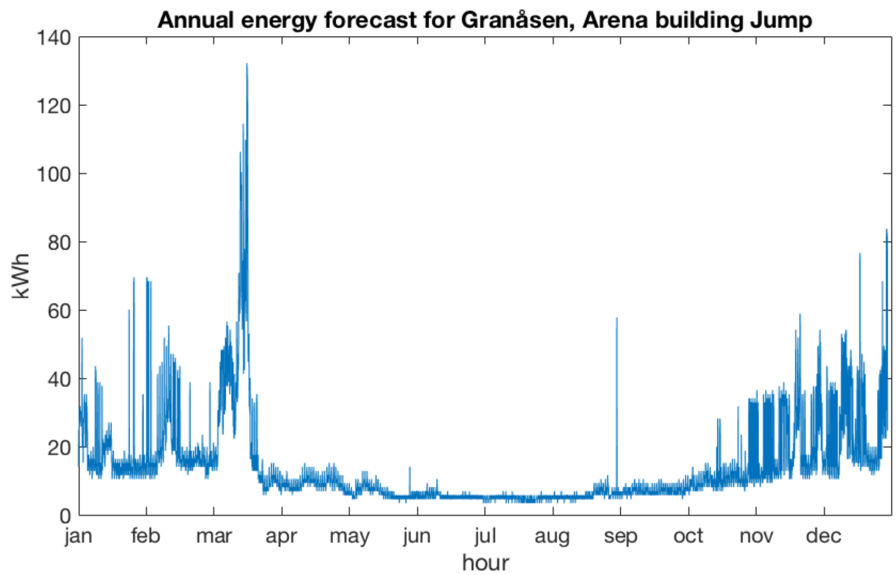


Figure 7.5: Prognosis of annual energy demand for Arena building jump, hourly resolution.

Football hall

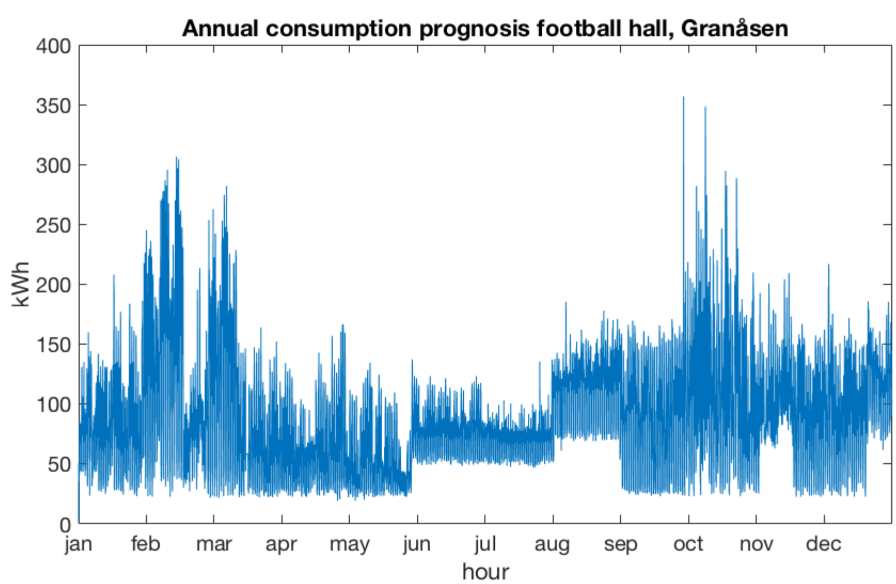


Figure 7.6: Prognosis of annual energy demand for football hall, hourly resolution.

Shooting hall (multipurpose hall)

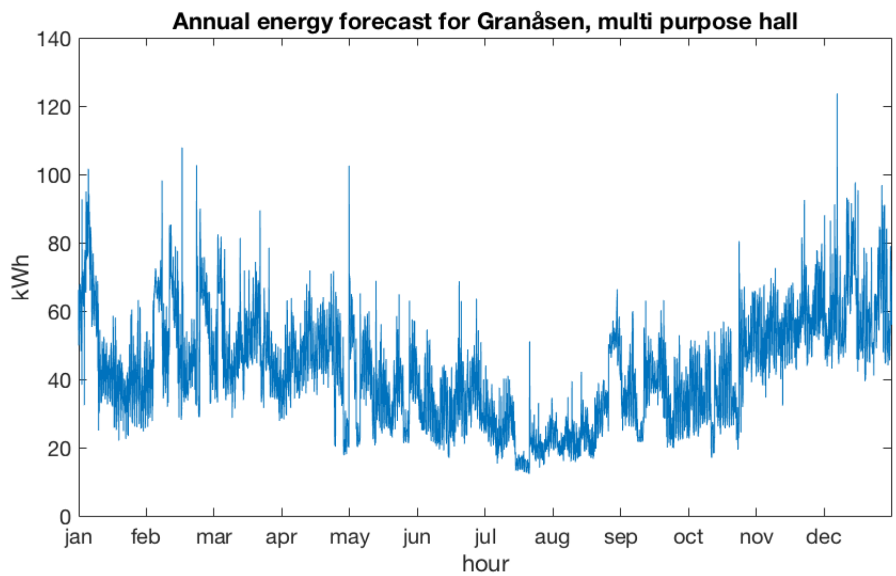


Figure 7.7: Prognosis of annual energy demand for multipurpose hall, hourly resolution.

7.3 Aggregation of Load Profiles

An aggregation of the individual loads will follow.

7.3.1 Scenario 1

An aggregation of the invidual loads from scenario 1 is presented in fig.7.8. Key figures are presented in Tab.7.5

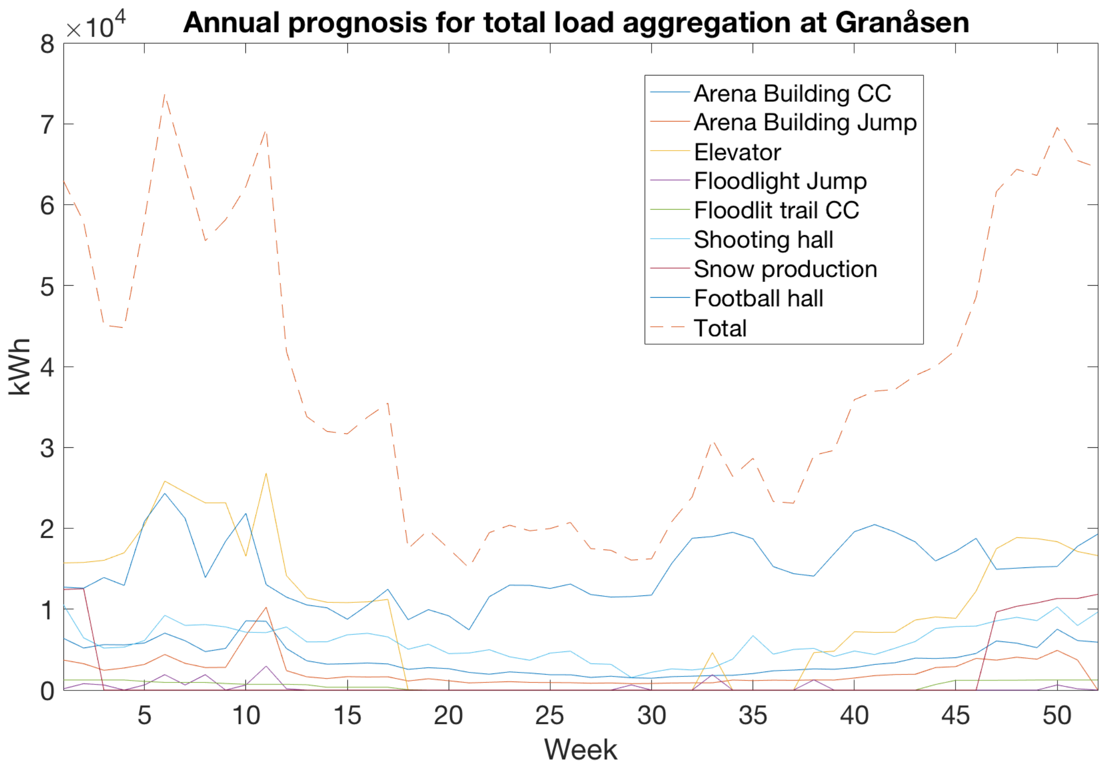


Figure 7.8: Annual prognosis of total energy consumption within the system boundaries for scenario 1, weekly resolution

	Total	SP[6]	Lift	Lights	AB[7] CC	AB Jump	FH[8]	SH[9]
Total (kWh/year)	2002700	90242	475713	39530	198630	115790	774270	308480
Spec.(kWh/m^2/year)	-	-	-	-	80	80	77.43	102.83

Table 7.5: Key figures from the total load aggregation, scenario 1

7.3.2 Scenario with Integration of PV

Key numbers resulting from integration of the PV modules presented in section 6.3, are presented in Tab.7.6. The effect on the total load profiles are presented in fig. 7.9 and 7.10. The effect of PV when only buildings are included in the loads are consecutively presented in hourly resolutions in fig.7.11, 7.12, 7.13 and 7.14.

[6]Snow Production
[7]Arena Building
[8]Football hall
[9]Shooting hall

Scenario	Annual saving potential	Percentage	Annual surplus Energy
Pv1	86890 kWh	4.34 %	0
Pv2	693240 kWh	34.62%	69,442kWh

Table 7.6: Theoretical annual saving potential

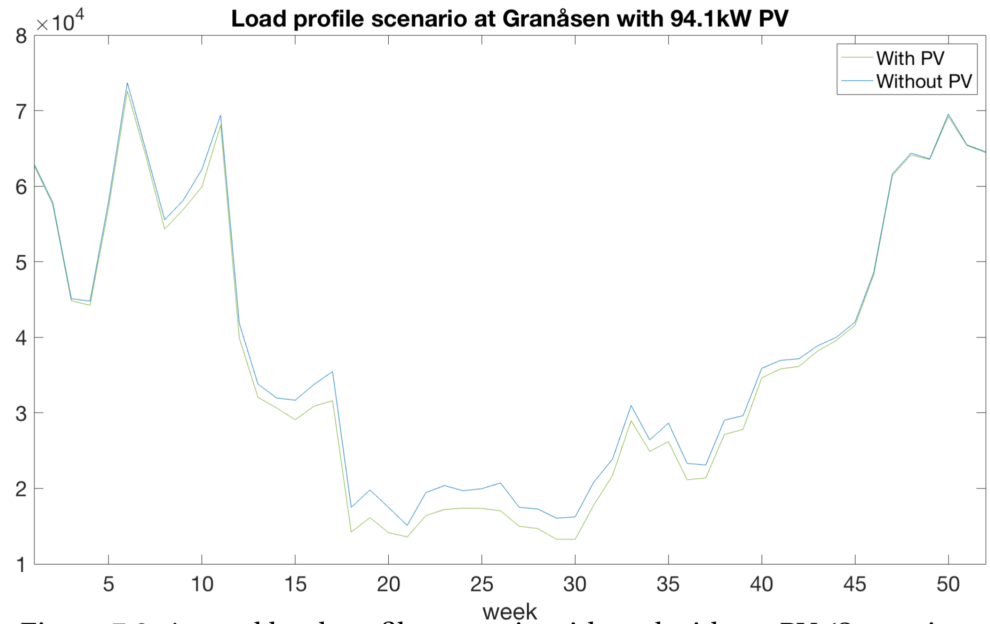


Figure 7.9: Annual load profile scenario with and without PV. (Scenario pv1)

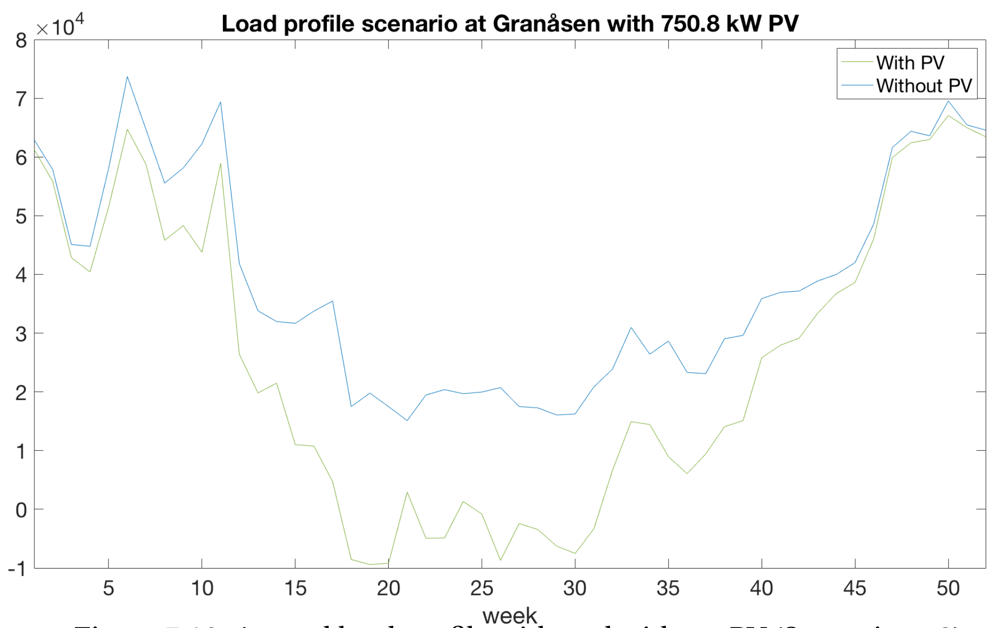


Figure 7.10: Annual load profile with and without PV (Scenario pv2)

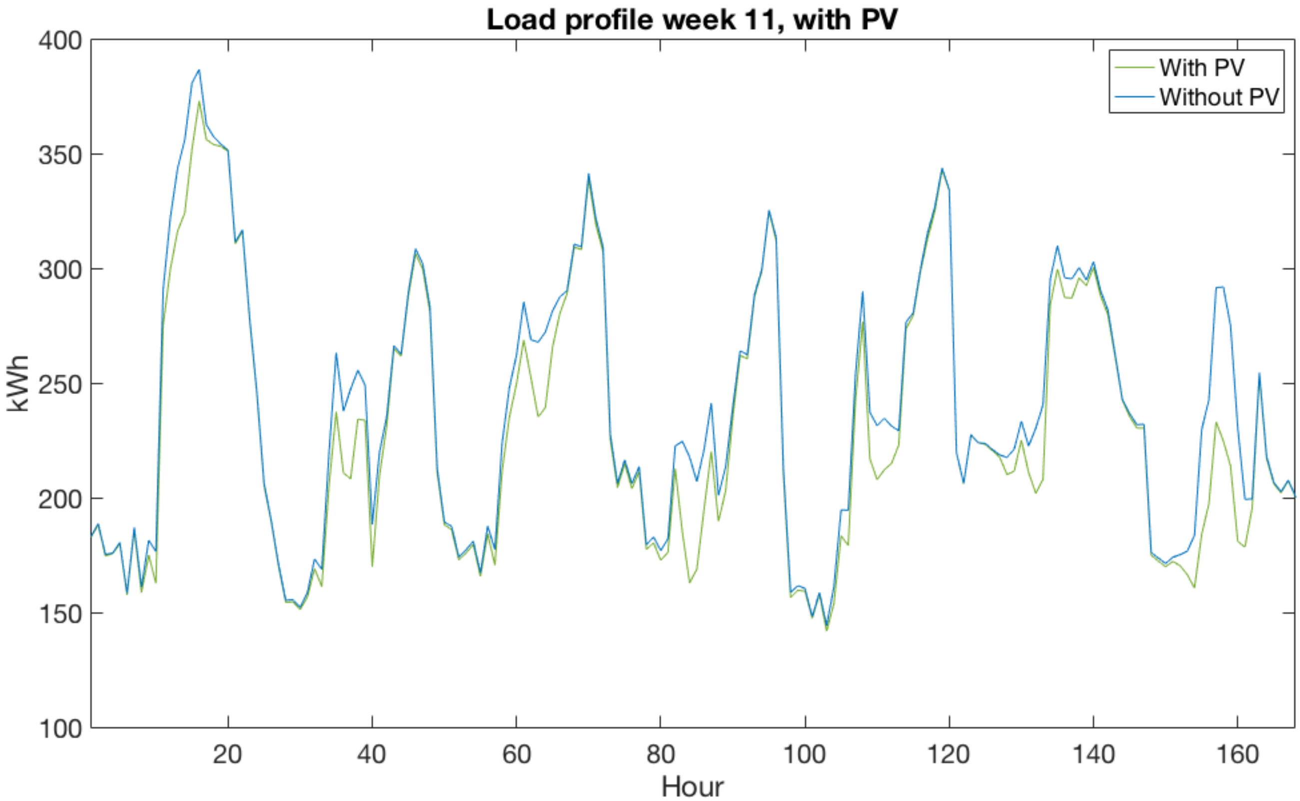


Figure 7.11: Load profiles of buildings at Granåsen with PV installed in week 11, hourly resolution (Scenario pv1)

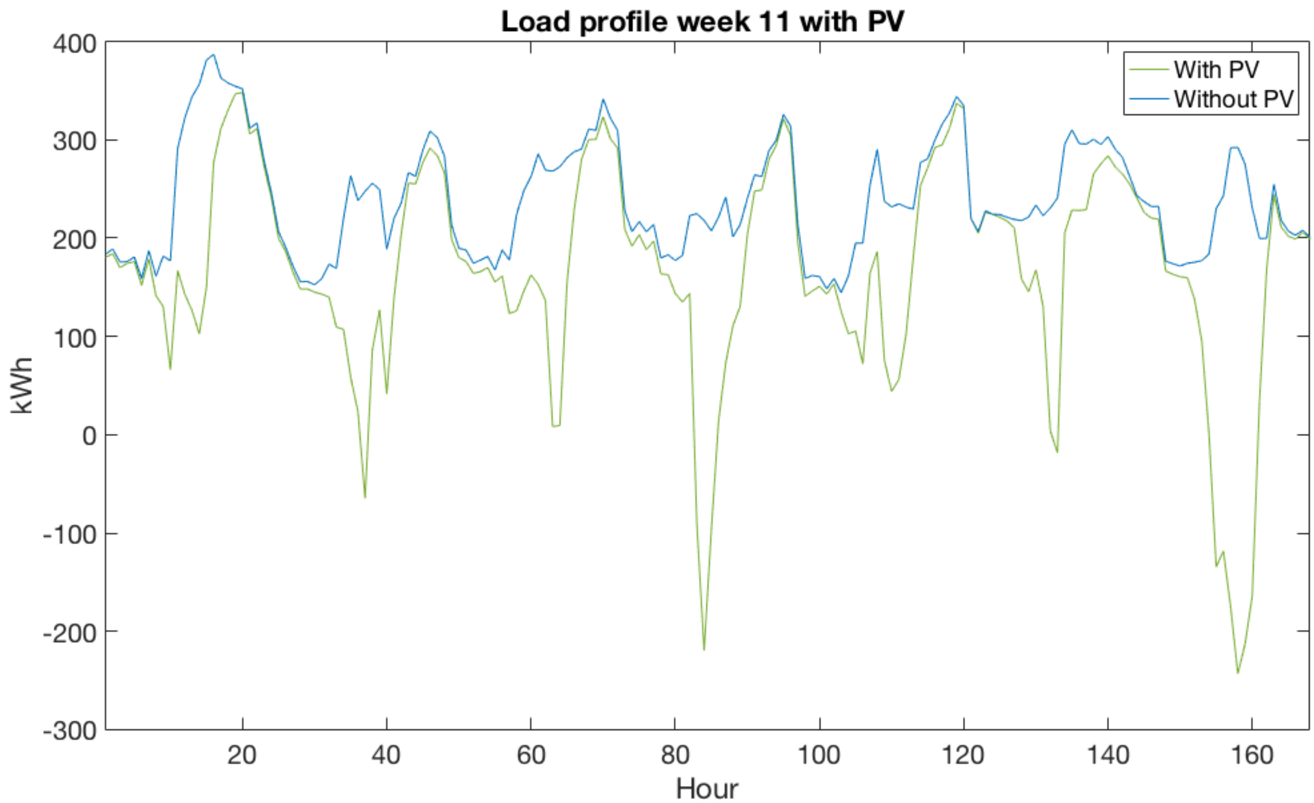


Figure 7.12: Load profiles of buildings at Granåsen with PV installed in week 11, hourly resolution (Scenario pv2)

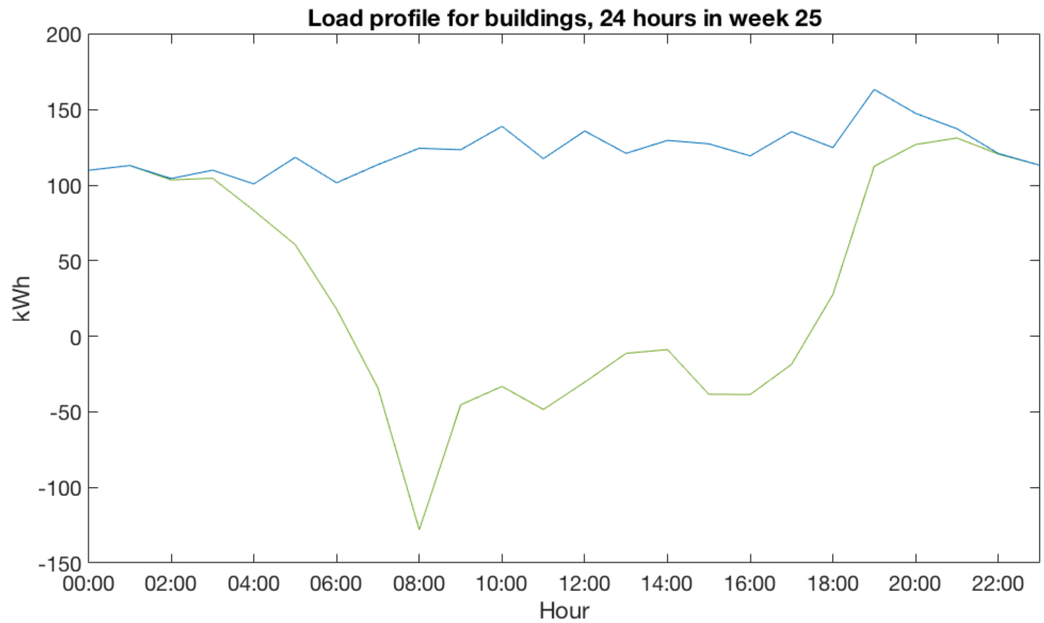


Figure 7.13: 24 hourly load profile scenario for the future building stock at Granåsen, with 0.750 MW PV installed. (Summer day)

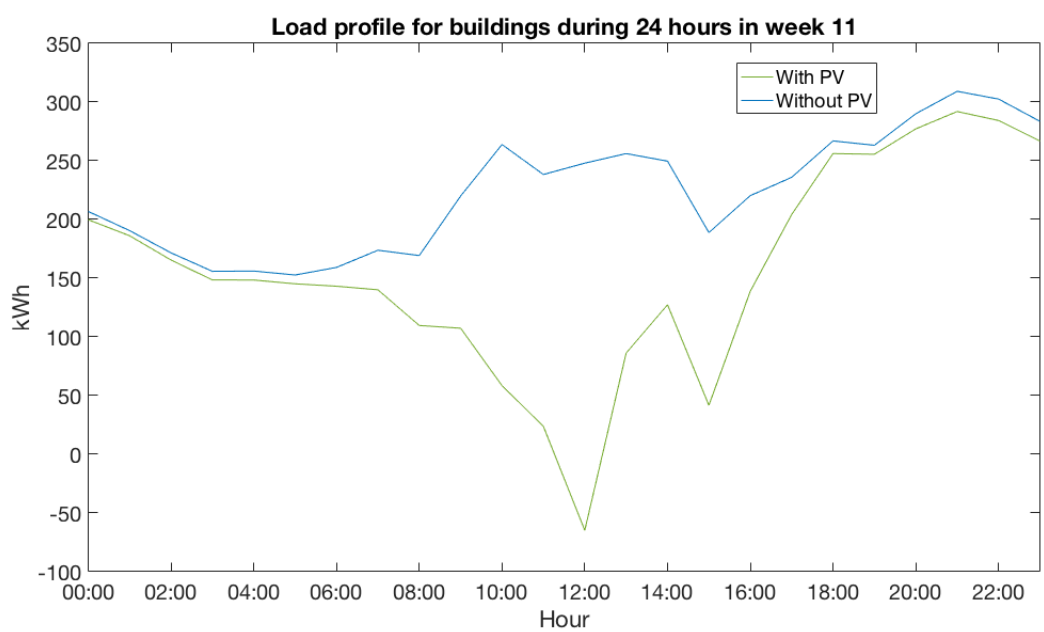


Figure 7.14: 24 hourly load profile scenario for the future building stock at Granåsen, with 0.750 MW PV installed. (Day in WC week)

Chapter 8

Discussion

This chapter will discuss:

- Existing load profiles of Granåsen
- Load profile aggregation methodology
- Prognoses of future load profiles
  - Future scenarios
- PV potential
- To which extent Granåsen can be self sufficient
  - Integration of PV
  - Load flexibility
  - Energy storage
  - Other aspects

8.1 Discussion of Existing Load Profiles

As fig.4.3 and 4.4 illustrates, the current load profiles of Granåsen are characterized by large power peaks. The events listed in Tab.4.4 correspond to the different power peaks. The energy consumption during the summer is also not insignificant, which in turn can be a driver to utilize solar energy.

The power peaks occurring outside the events listed in Tab.4.4 are most likely due to snow production, as it also can be seen from the annual load profiles for snow production. It is clear, however, that those meters don't show the complete consumption due to snow production. From App. E, it is stated an energy consumption of 72,068 kWh due to snow production the first two weeks in 2016, while fig.4.6 only sums up to 32,920 during the same period.

Fig. 4.6 and 4.7 also demonstrate that the snow production has varying operation times. There was, from fig. 4.7 and fig. 4.4 significant spike due to snow production in week 6, 2017. At the same time, it can from fig.4.10 be seen an even consumption during the whole day and week.

The overview of the events in Tab.4.6 indicates that the load profiles of the various events look similiar from 2016 to 2017. There is a slight increase in energy consumption in 2017. The BS concert had a lower consumption than the RW concert, which can be explained by the diesel generators that were used during the first mentioned.

Meters were set up by Trønder Energy, in order to measure the energy consumption during Raw Air 2018 in a higher resolution, i.e. every 30 seconds. The measurements were done at Transformer L instead of the intended Transformer H. It is thus not as relevant to make a comparison between the two events, but it can be seen that the power peak in 2018 lasts for a longer interval compared to 2017.

A disadvantage and thus a challenge with Granåsen, is nevertheless that there are no separate meters installed, such that it cannot be said with certainty exactly what draws power. The information about the energy distribution at Granåsen is perceived as cluttered.

8.2 Discussion of Load Profile Aggregation Methodology

It has become evident during this work, that the main purpose of this thesis is to demonstrate the methodology for obtaining load profiles for the different loads, and how they can be affected with local production of solar energy.

Limitations with a bottom up engineering approach to load modelling is the uncertainty with the assumptions made connected to consumer behaviour. Frequently implemented statistical methods are typically based on regression models, which creates a higher degree of accuracy than the simplified statistical approach in this thesis. Regression models, however, require a sufficient quantity of data, which furthermore have not been possible to obtain. The purpose with the chosen approach is to construct an example of how a load scenario may unfold.

8.3 Discussion of Prognoses of Future Load Profiles

As discussed in 8.2, the assumptions made for this analysis, together with uncertainties connected to data and development plans, make the actual results of the load prognosis less relevant. However, it may form an image of a possible scenario, and illustrate what the different loads depend on. Short discussions of the individual and aggregated loads will follow.

Lights The energy consumption of the lights are roughly estimated and constructed in a weekly resolution. They may nevertheless be of most relevance as they are based on actual data from Granåsen, and the uncertainty is mainly connected to when the different events unfold and the corresponding weather. According to operational manager Vidar Finnland[3], the energy forecast of the lights is reasonable.

Snow production Fig. 7.1 shows the prognosis for snow production. The prognosis results from Tab.7.5, in a total annual energy consumption which only corresponds to 86% of the 2017 consumption that belongs to the meter for snow production.

There is a lot that indicates that this prognosis is less realistic, including the fact that the requirement to quantity is more than doubled under the prerequisites for the prognosis. The model is based on constant operation time and capacity, and it can be seen from the snow production load profiles of 2016 and 2017 that the actual production happens more discontinuously. Additionally, the model is based on daily mean temperatures, while the temperature in reality varies greatly through the day, which furthermore, from fig.5.4, has a great impact on the actual production capacity and hence energy consumption. It also appears that this model provides lower energy consumption when compared to the same produced amount in App.E.That is, approximately 16 000 m^3 lead in App. E to an energy consumption close to 72 000kWh, while the same amount modelled with the TAM scenario provides an energy consumption of just below 30 000 kWh. Therefore, there is much to suggest that the prognosis of snow production is too low. However it may also be due to advances in equipment, or the fact that the model doesn't account for melting of the already produced snow. Additionally, the snow production from E was run on full capacity in two weeks. From the analysis, what clearly emerges is that more fan guns in operation will lead to a faster snow production but on the other hand higher power peaks and higher energy consumption.

Lift The energy prognosis of the lift does from Tab.7.5 indicate a quite high energy consumption. It does, however include more than just the actual lift, which is closer described in App. D.1.2. It may be reasonable to assume that the equivalent functions will take place in Granåsen. Holmenkollen is, however, one of the most attractive tourist attractions in Norway, and it is hence natural to assume that the influx to the lift at Granåsen will not be as high as in Holmenkollen. Throughout the year, Holmenkollen most likely has higher activity rate, especially during the spring and summer months.

Buildings During events, significant power peaks can also be observed from the load profiles of the arena buildings, presented in section 7.2.4. This may be due to outdoor lightning attached to the buildings, rush in the showers and locking rooms, etc. There is a reason to assume that this pattern also may apply to future arena buildings in Granåsen.

However, the arena buildings with references from Holmenkollen carry a high level of uncertainty with respect to the numerical results. The arena building CC from Holmenkollen in App.D.2 has a total annual energy consumption of 1 067 395 kWh/year. Applying eq.(5.1) and from 3.2.2, down scaling with 55% [1], provides a specific annual energy consumption more than ten times higher than if the average energy consumption for passive houses from section 3.2.2 are used, i.e. eq.(5.2). The prognosis in fig. 7.4 is based on the last version. It is nevertheless reason to believe that the consumption in the Arena buildings in Granåsen will be somewhat higher, when the gap described above is so huge. The energy consumption in buildings are nevertheless, as described in section 3.2 strongly dependent on temperature, which will vary every year. The simplified assessment performed in this work, is a comparison of Trondheim and the reference site in fig. F.1, and does not involve further temperature corrections.

It may be reasonable to assume that the energy forecast for the multipurpose hall and the football hall can correspond to an actual scenario. However, as described in section 3.2.1, the

[1] Downscaling with 55 to obtain a consumption level closer to passive house standard, from the theory described in section3.2.2

energy consumption in sports centres are complex to compare as it highly depends on timetables and public attendances. Especially Fosnes is a much smaller municipality than Trondheim, which most likely will affect the activity rate and hence the energy consumption. Therefore, the obtained load profiles serve more as examples. From Tab.7.5, the annual specific energy consumption of the shooting hall is higher than for a typical passive building. This can for example be due to under estimating the subtracted consumption due to the indoor swimming pool from the reference data. However, if the prognosis is compared with the representative specific consumption from 3.2, it corresponds to about 43% of the convenient sports centre, which agrees quite well to the findings described in 3.2.2

Total loads The aggregation of the total load profile scenario presented in fig.7.8 testifies to an energy consumption which almost equals the double of the current energy consumption in Granåsen. There are presumable several reasons to this, as an expansion will as described in Ch.1.1 normally lead to greater energy needs. Also, the energy consumption due to the elevator and what is around, together with the energy consumption of the football hall, contribute to pull up the total annual consumption considerably.

However, it is difficult to compare the scenario to the current energy consumption in Granåsen, due to e.g.the restricted system boundaries of this work, which does not encompass the complete energy consuming services of Granåsen.

8.3.1 Discussion of Future Scenarios

The load prognoses only involve one scenario. It would have been appropriate to include several scenarios in the analysis. Daily mean temperatures do not reflect reality, several temperature scenario could have been included. It has instead been emphasized to illustrate what the different loads are dependent on, so that several scenarios could be implemented in potential further work.

8.4 Discussion of PV Potential

Based on Ch.6.3 this section will discuss:

- PV output results
- Sources of error, including

    Data input

    Simplifications

The production curves for PV show significant output, especially during May. As expected from the literature described in section 2.3.1, the output is higher during the winter with a 90° tilt, but the total electricity produced during a whole year is lower, compared to a 30 ° tilt.

8.4.1 Sources of error

The data for solar radiation is obtained from Frosta, which was the closest available site. The output from this analysis will most likely be much higher than at Granåsen, due to a more flat terrain at Frosta.

The PV production potential is based on Eq. (2.2). This equation does not account for factors as shading, temperature impacts and aging. Granåsen is surrounded with a numerous amount of trees, which most likely will contribute to reduce the output of a PV plant due to shading.

8.5 Discussion of to which extent Granåsen can be self sufficient

This thesis is a preparatory work as a contribution to eventually be able to determine to what extent Granåsen can be self sufficient with energy. With such insecure numbers, it is currently difficult to draw any conclusions. However, different aspects are discussed in this section.

8.5.1 PV

The effect of integration of solar panels in Granåsen is shown for two scenarios in fig. 7.9 and 7.10 respectively, i.e. excluding (scenario pv1) and including (scenario pv2) solar cells on a 10 000 m^2 football hall.

For scenario pv1, the weekly load profile appears the same, only with a slight decrease. For scenario pv2, however, the yield is more significant. As listed in Tab.7.6, the annual saving potentials for the two scenarios are 4.34% and 34.62% respectively. It can be seen from fig. 7.10 that the load profile with pv is negative during the summer. Hence, with no energy storage implemented, scenario pv2 would generate a total annual excess energy of 69,442 kWh which would go to waste in the summer months. Even though the solar generation is larger during the summer, it becomes evident that also during the winter and early spring, i.e. weeks with the highest activity rate at Granåsen, can solar power contribute to decrease the net energy demand required from the grid.

These considerations are, however based on weekly resolution load profiles, and that there is sufficient demand at any given time so that all of the production can be utilized. That will most likely deviate from a real scenario without energy storage implemented.

Hourly load profiles are modelled with only the buildings included in the analysis. Fig.7.11 and fig.7.12 shows the effect of PV (scenario pv 1 and 2 respectively) on the total load profiles of the buildings in Granåsen during the week of WC. Fig.7.14 shows the load profiles through out a day during the same week (scenario pv2). It can from fig.7.12 be seen that the installed PV modules can contribute to remove parts of the power peaks, however they also contribute to create the gap between the base load and peak load even greater, when no energy storage is implemented.

Fig.7.13 shows the effect of PV on potential buildings at Granåsen with scenario pv2 on a day during the summer. Again, it becomes evident that with no energy storage, PV will contribute to decrease energy consumption, but in turn lead to a load profile characterized by even higher peaks, as the base load is removed during the day and not during the evening.

8.5.2 Energy Storage

Important aspect with sustainability for sports facilities as Granåsen, is to reduce the energy consumption, but also to reduce peak demand. Latter can PV alone contribute to a small extent. PV together with batteries, on the other hand, can change the prospects. Batteries can store the excess energy generated from PV during the summer, and the energy can be utilized when needed. Alternatively, they can contribute to remove power peaks for shorter periods of time during events, dependent on the capacity. Batteries are well known technology that serve for its purpose, and rather an economical trade off. There are mainly two aspects with batteries, redundancy verses peak shaving, where the latter may be most relevant for Granåsen.

The batteries described in ... were suggested by Siemens for Granåsen in particular, and could respectively contribute with 100 kW for one hour and 250 kW for two hours, based on peak shaving. [4]. Selecting the one with larger capacity still requires just below 100 batteries in order to store all the excess energy generated with scenario pv2, given that the load scenario plays as in fig.7.8.

Another execution model which could be of interest in Granåsen, is to implement transportable energy storage (TBESS), as described in section2.3.2. That is, battery packs which works as peak shaving units other places on a daily basis, but retrieved at Granåsen for special events. As described in section2.4, different ownership models could be implemented.

8.5.3 Other Aspects

Load flexibility

The loads within the system boundaries do to a small extent carry slack. Both lights and lift are *on demand* loads. The only way of reducing peak demand concerning the lights, is simply to turn them off. Alternatively, LED lights could be implemented, shortly described below.

Snow production, however, possesses characteristics of *deferrable loads*, as it to some extent can be scheduled. A huge aspect of load flexibility which presumably carries great potential in Granåsen lies nevertheless outside the system boundaries of this work, namely EV's.

LED lights

Rough calculations performed in App.C indicate that the energy demand of lights could be reduced by 24%, by replacing HIT lights with LED. As described in section3.3, the implementation of LED light at sports arena becomes more widespread.

Chapter 9

Conclusions and proposal to further work

9.1 Conclusions

It is desirable to determine to what extent a fully developed Granåsen can be self sufficient with energy. This work has primarily consisted of mapping present energy consumption in Granåsen, analyzing of load profiles, estimation of possible load profiles and assessing integration of PV. The following main conclusions can be drawn based on the work that has been done:

- The load prognoses indicate an annual energy consumption which corresponds to the double of the present.
- The load prognoses indicate that Granåsen will be characterized by tall power peaks also in the future, especially during extensive events as World cup.
- Even with passive house standards, is it unlikely that a future facility will be able to not exceed the present energy consumption with no further measures.
- Annual PV production potential on all the planned building roofs with a 30 °tilt is 652790 kWh/year.
- A 90°tilt provides higher output during the winter months but a lower annual production potential in total.
- PV alone contributes to a small extent to remove power peaks

- PV installed at the future available roof area does not enable Granåsen to be self sufficient with energy, but provides an annual saving potential of 694240 kWh, which corresponds to 35% of the predicted consumption scenario. With no energy storage, an annual excess energy of 69 442 kWh would go to waste during the summer.

- Energy storage can be implemented to store excess energy, or to function as a peak shaving unit. Just below 100 of the suggested batteries must be implemented in order to be able to store all the excess energy, for the calculated load scenario.

Granåsen is still a conceptual study and there are great uncertainties connected to the numerical results. It is also difficult to compare the results of the prognosis to the current energy consumption due to different system boundaries. It has thus become evident that the methodology for obtaining the load profiles is in this work more relevant than the numerical results.

9.2 Further Work

This thesis can be seen as a preparatory work to ensure Granåsen to be a sustainable facility. Suggestions to further work include:

- Construct more scenarios, including different temperatures, and perform a sensitivity analysis

- Compute heating demand, cooling demand and energy demand for lights specifically for the buildings in Granåsen, in order to get a more accurate estimate of the energy consumption in buildings

- Conduct temperature corrections

- Calculate the effect of implementation of batteries and implement control strategies for optimal power control.

- Investigate potential for PV production at the facades of the planned buildings in Granåsen.

- Investigate potential for other forms RES and energy storage, including solar collectors and thermal storage.

- Include EV's in the system boundaries and investigate potential for energy storage in EV's as peak shaving units
- Set up separate meters on the loads in Granåsen
- Ever more parties are implementing separate energy meters on an hourly basis, including Oslo Kommune, which will set up separate meters at the snow production in Holmenkollen National Ski Arena as of Fall 2018. This and similar data could be collected and utilized for references.

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Acronyms

AB Arena Building

AC Alternating Current

BIPV Building Integrated Photo Voltaic

BS Bruce Springsteen

BTA Brutto Areal (Gross Area)

CC Cross country

CIGRE International Council on Large Electric Systems

COC Continental Cup

DC Direct Current

EJ Exersice Jump

ES Energy Storage

EV Electric Vehicle

FIS The International Ski Federation

GHG Greenhouse Gases

HIT Tubular Metal Halide-Single Ended

HVAC Heating Ventilation and Air Conditioning

IEA International Energy Agency

LED Light Emitting Diodes

NC Norway Cup

NOK Norske kroner

NS Norsk Standard

NVE Norges Vassdrag- og Energidirektorat

PCU Power Conditioning Unit

POC Point of Coupling

PV Photo Voltaic

RES Renewable Energy Sources

RW Robbie Williams

SP Snow Production

SH ShoothinG Hall

TAM Daily Mean Temperature

TEK Byggteknisk forskrift

WC World Cup

ZEN Zero Emission Neighbourhood

Appendix A

Documentation

A.1 Documentation of lights in Granåsen

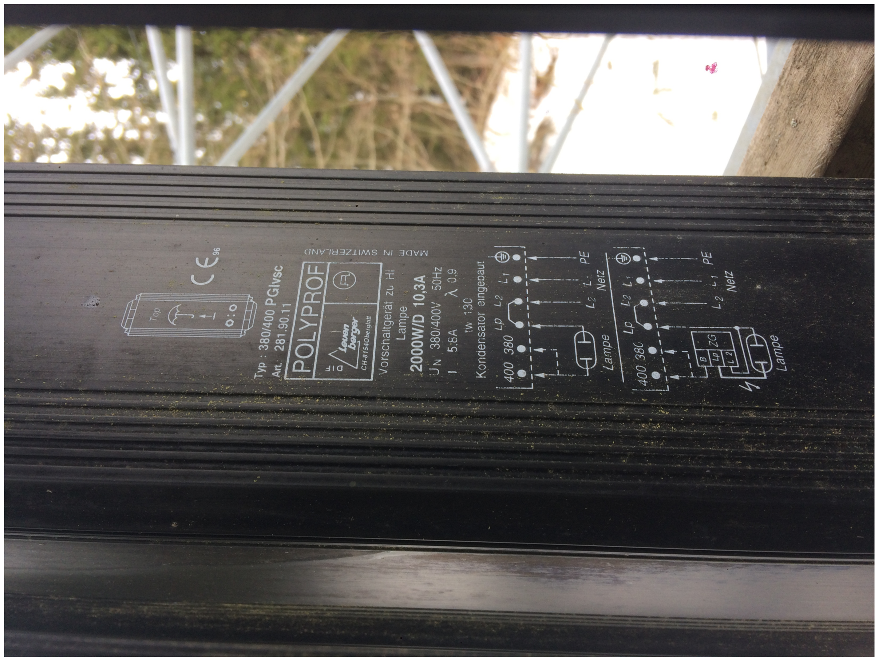


Figure A.1: Power ratings of the HIT in Granåsen

Figure A.2: Power ratings of lights in Granåsen

Figure A.3: Overview of Granåsen

Figure A.4: Light poles in conjunction with jump stadium, which has not been included in the calculations

Appendix B

Solar

B.1 Solar radiation

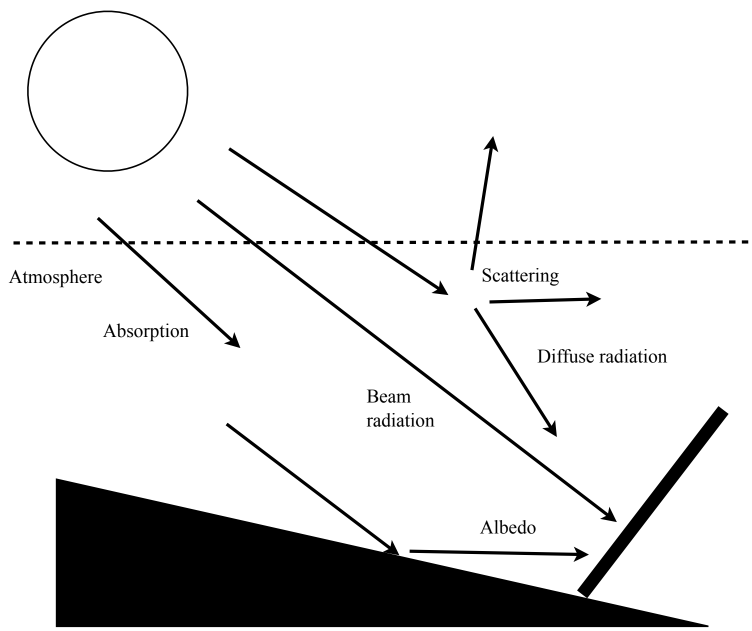


Figure B.1: Solar radiation in the atmosphere.[33]

Eq.(B.1)describes the total radiation incident on a horizontal surface. Beam radiation is the radiation that directly hits a receiver without any impact from the atmosphere. If the direction has been affected by the atmosphere, the radiation is referred to as diffuse radiation. Radiation that reaches a receiver due to reflection is called albedo. The total solar radiation is also known as the global radiation, and the different components are illustrated in fig.B.1.

[33]

$$S_G = S_B + S_D + S_A \tag{B.1}$$

where S_G is the global, i.e. total radiation, S_B is the beam, i.e. direct radiation, S_D is the diffuse radiation and S_A is the albedo radiation, i.e the radiation that hits a receiver due to reflection.

Radiation on an inclined surface The radiation incident on an inclined surface is given from Eq.(B.2)

$$S_G(\beta) = S_B(\beta) + S_D(\beta) + S_A(\beta) \tag{B.2}$$

B.1.1 Solar angles

Declination angle The declination angle δ is the angle between the equatorial plane and the line drawn beteen the center fo the sun and the center of the earth. It ranges from +23.45° to -23.45° at the summer and winter solstice respectively, and can be calculated using Equation (B.3),

$$\delta = 23.45 \sin\left[\frac{360}{365}(284 + N)\right] \tag{B.3}$$

where N is the N^{th} day of the year.

Solar elevation The elevation angle, α, is the angle between a horizontal plane and the rays of the sun and can be calculated using Equation (B.4),

$$\sin\alpha = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega = \cos\theta_z \tag{B.4}$$

where ϕ represents the geographical latitude, and ω is the hour angle.The hour angle describes the angular displacement of the sun. At noon, $\omega = 0°$. The earth rotate 360 $degree$ in 24 hours, thus 15°in one hour. At 11AM, $\omega = 15°$ and $\omega = -15°$ at 1PM. [41]

Month	Elevation angle α [$\circ$]
January	4.9601
February	12.0091
March	21.8171
April	34.1606
May	44.1433
June	49.6384
July	48.8659
August	41.9902
September	30.8423
October	18.9022
November	8.7136
December	3.5772

Table B.1: Calculated average elevation angles for Granåsen

$$S_\beta = S_H \frac{\sin(\alpha + \beta)}{\sin \alpha} \tag{B.5}$$

B.1.2 Calculations for Granåsen

The elevation angle for Granåsen is calculated for solar noon, the 10th of every month, and can be shown in table B.1

Appendix C

Comparasion of LED and HIT lights

The efficiency of a HIT lamp is given by Eq.(C.1)

$$\eta = \Phi / P * \eta_{armature} \tag{C.1}$$

where Φ is the luminous flux [lm], and P is the rated power [W]

For metal halogen lamps, a typical armature efficiency lies between 60-90 % [18]. For the calculations, an efficiency of 80‰ is assumed. From the on-site inspection at Granåsen, the HIT lamps were rated at 2000 W. Comparing such a lamp with the attached data sheet in G.1 gives an efficiency of 115 lm/w.

The chosen LED armature has a system efficiency equal to 120 lm/w. In simplified manners, that means that approximately only 76% of the rated watts of the HIT lamps are required to obtain the same amount of lights.

Appendix D

Reference buildings

D.1 Holmenkollen National Ski Arena

Holmenkollen arena is one of the worlds most well known sport arenas.

"*Holmenkollen is a state-of-the-art arena for cross-country skiing, biathlon and ski jumping, and includes the famous Holmenkollen Ski Jump, Midtstubakken Ski Jump, five smaller recruitment slopes, cross-country skiing trails and a ski stadium. The ski jumps and arena were completely rebuilt for the 2011 FIS Nordic World Ski Championships, and hosts annual World Cup events in ski jumping, cross-country skiing, Nordic combined and biathlon. Holmenkollen is one of Norway's most visited tourist attractions, and includes a ski museum, jump tower, souvenir shop, ski simulator and café. The viewing platform at the top of the tower is open to the public and offers panoramic views of Oslo and the surrounding forests.* [2]

D.1.1 Buildings

The buildings in Holmenkollen have electrical heating and have energy ratings G or F. None of them are passive houses, hence the energy consumption is not directly transferrable. Considering that all new buildings in Granåsen are going to have passive house standard, the consumption profiles are adjusted according to Eq.(5.2).

Arena building CC

It is assumed that Arena building CC corresponds to the building shown in fig.D.1.

The meter for Arena building CC includes buildings in connection to the CC stadium, and parts of the flood lights in the jump hill. Technical manager Anfinn Geiran estimates them to corresponds to approximately 40 % of the total floodlights, i.e. 70 lamps at 2000 W. However, the floodlights are rarely on, except during NC and WC events. Beyond that, the energy consumption of arena CC is mainly base load. [9] The annual energy consumption of arena building CC is presented in fig. D.2. A sufficient spike can be seen 12 of march, which coincidence with ski jumping WC. Race-start was 10.30 and 14.15 for women and men respectively, and lighting was on at full capacity.

Therefore, when transferring the load profile to Granåsen, it has been assumed that 140kWh can be removed every hour between 09.00 and 18.00.

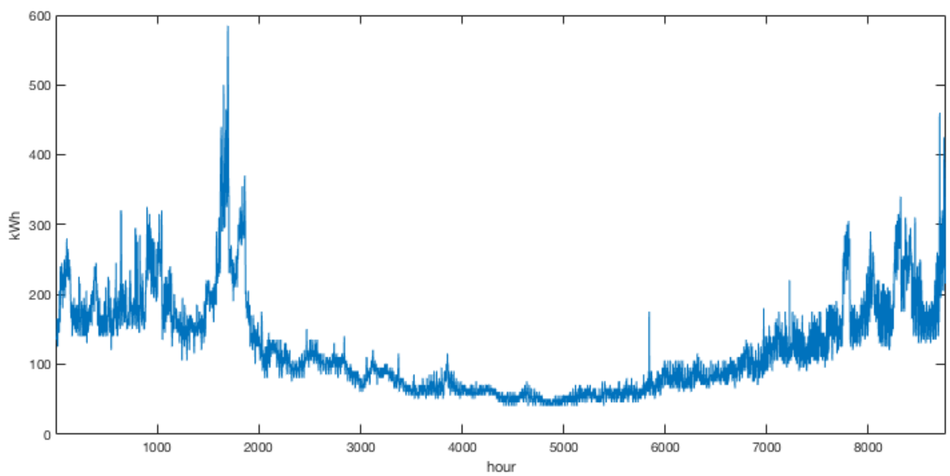


Figure D.2: Annual energy consumption of Arena building CC in Holmenkollen

Arena building Jump

Arena building Jump includes judge stands,*Kongetribune*, commenting boxes,

D.1.2 Elevator lobby

The energy consumption linked to the elevator in Holmenkollen is presented in fig. D.3

Figure D.1: Overview of Arena building CC in Holmenkollen, obtained from Google maps. [1]

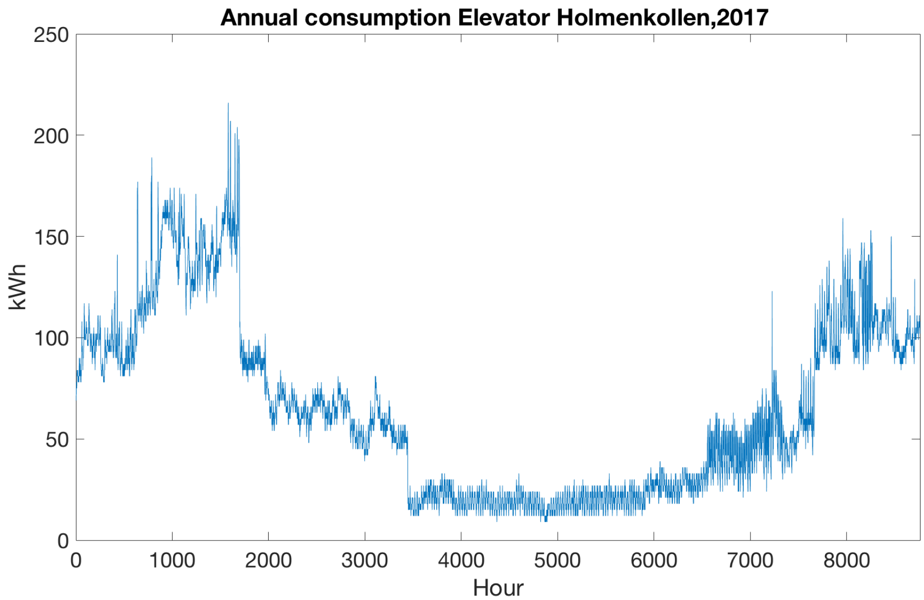


Figure D.3: The annual energy consumption in connection to the elevator and concourse in Holmenkollen

The data provided measures energy consumption for:

- Elevator
- Lobby of the elevator
- Light poles above jumping edge
- Concourse

    Starting house (ventilation, heating and lights)

    Technical room below the jumping edge

    Cooling of the tracks

These are loads that are asssumed to be included in Granåsen as well, hence they are also included in the prognosis for Granåsen. Opening hours of the elevator is between 09.00-16.00 during the winter and 09.00-20.00 during the summer.

D.2 Multi purpose hall

Fyret flerbrukshus is a multipurpose hall with a BRA of 2765 m^2. The facility contains a 106.25 m^{2}swimming pool, fitness room, library, shooting hall, cafe, and an outdoor artificial ice surface which serves as a solar collector during the summer. The calculated net energy demand is approximately 310 000kWh, but delivered energy has been 158000 kWh. However the solar collector has not been in operation.

Energysources are:

- Energy well for heating or cooling
- Heating pump for heat recovery from the ventilation system to air, tap water and the water in the swimming pool.
- A 900 m^2 solar collector under the parking lot.
- Electric boiler for backup and peak load.

Implemented energy efficiency measures:

- Extensive use of LED lights with motion sensors
- Economy shower
- Demand controlled operation of the ventilation system
- Improved user interface of the SD system.

The annual energy consumption in 2017 is presented in fig. D.4

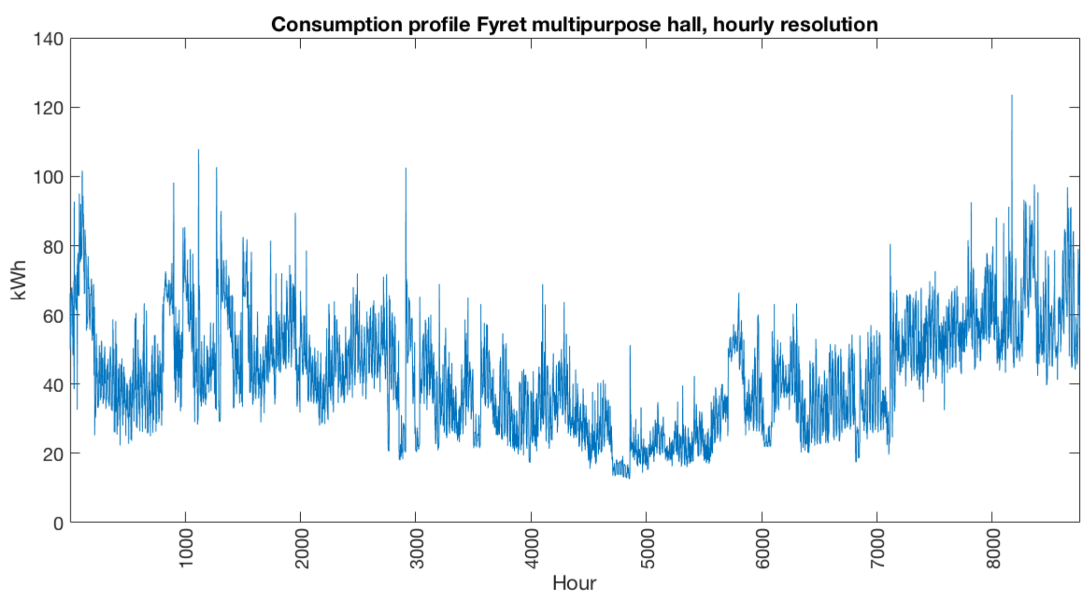


Figure D.4: Annual energy consumption of Fyret multipurpose hallin 2017, hourly resolution

It can be seen in fig. F.1 that the annual mean normal temperatures in Trondheim and Fosnes are similiar. Hence, the energy consumption of Fyret can in simplified manners be transferred to a shooting hall in Granåsen.

An average energy consumption for swimming facilities is 25 kWh/visitor [55]. There was no available statistics about the visitor traffic in Fyret flerbrukshus, hence some simplification has been made.

In the indoor swimming pool of Kongsvinger, the number of visitors in December are typically 5000. This corresponds to 28% of the 18000 residents of Kongsvinger.

On this basis, the number of visitors in the swimming pool in Fyret is assumed to correspond to about 30% of the residents in Fosnes. Furthermore, it is assumed that the number of visitors is halved during the summer months. The assumed energy consumption E_{SP} that is due to the swimming facility is based on Equation (D.1), and presented in Tab D.1.

$$E_{SP} = 25kWh * n \tag{D.1}$$

where n is the assumed average number of visitors per month.

$\mathbf{E}_{SP,winter}$	$\mathbf{E}_{SP,summer}$
4900kWh/month	2450 kWh/ month

Table D.1: The estimated energy consumption in Fyret multipurpose hall that is due to swimming facility, for winter and summer months respectively

The estimated montly en This is assumed constant for the corresponding months, and are simply subtracted from the given load profiles.

Appendix E

Data retrieval in conjunction with Snowproduction

E.1 Snowproduction log, Trondheim kommune

Snøproduksjon Granåsen skianlegg — Side 15 av 25

Skjema for driftslogg snøproduksjon

TRONDHEIM KOMMUNE

2018

Driftslogg snøproduksjon

Dato	Sign.	Start	Stopp	Maks temp.	Min temp.	Merknader for driftsavvik
19.02	BL/AB	08^00		÷16		4 ringer
	TF	12^00		÷6		1 ring
19/2	FS EM	17^00		-6,5		2 ring (Cager)
-//-	-//-	19^00		-10		3 ring
	PES	23^15		÷17		4 ringer
20/2	-//-	0100		÷18		Flytta ca 5 m begge Kanoner
-//-	PES/[illegible]	0230		÷18		
-//-	-//-	0400		÷19		
-//-	-//-	0450		÷18		
	-//-	0600		÷19		
	-//-	0800		÷13		Flytta midt i vakken 2 kanoner 4 ringer
	-//-	1000		-11		Flytta nesten ned av vakken
		1030		-9		3 ringer
		1045		-9		2 ringer
-//-	TF	17^40		-3,5		1 ringer
20/2	ML		21^00	-2,0		Rigget ned
27/2	RK	0830		÷22		Oppstart 4 ringer
		11^00		÷17		1 ring
		14^30		÷13		2 ringer [illegible]
T	TFF	17^00		-11		3 ringer [illegible]
	TFF	18^30		-14		4 ringer
	PES	23^30		-17		Flytta kanoner
	PES	~~18~~	10^00			Nedrigging

E.2 Kostnadsberegninger

Snøproduksjon januar 2016 - Kostnader

Bakgrunn og forutsetninger

- Ca 6.000 m3 snø ble det kjørt ut fra lager til langrenn i november 2015. Gjennomsnittlig snødybde ca 0,4 m og løypebredde ca 8 m holdt til ca 1.800 m løypetrase. Ingen snødekning, kun løype på stadion.
- Søndag 3. januar, dagen før tilstrekkelig kulde for snøproduksjon, var utkjørt snø nesten smeltet bort/omdannet til blåis. Fra mandag 4. januar ble det kaldt nok til snøproduksjon.
- Snøproduksjon langrenn 4-15. januar.
- På det meste ble det produsert med 8 viftekanoner og 23 lanser samtidig
- Det ble produsert nok snø til å dekke stadion pluss ca 3.000m løypetrase utover stadion. Snødybde min 0,5 m, snittbredde 8 m pluss fylling av grøfter etc.
- Totalt ble det produser ca 16.800 m3 snø
- Produksjonskostnadene er basert på vaktlister og reell timepris

Produksjonskostnader		
Mønstringstimer mannskap	384.030	kr
Påslag maskin- og utstyrskostnader 15%	57.605	kr
Påslag planlegging og administrasjon 10%	38.403	kr
Energikostnader forbruk	57.654	kr
Sum	537.692	kr

I tillegg kommer årlig effektavgift på de to målerne som forsyner snøproduksjon langrenn, ca:

	450.000	kr/år

Beregningsgrunnlag

Mannskapskostnadene er beregnet på bakgrunn av vaktlistene

		Antall personer							Sum timer og kostnader		
Uke 1 - mandag 4.- søndag 10.	Timer	Man	Tirs	Onsd	Tors	Fre	Lør	Søn	h/uke	Kr/h	Kr
Dag (7-15)	7,5	5	5	5	5	5			187,5	340	63750
Kveld (15-19) 50 % overtid	4	4	4	5	5				72	510	36720
Kveld (19-23) 100 % overtid	4	4	4	5	5				72	680	48960
Natt (23-07) 100% overtid	8	4	4	4	4				128	680	87040
Helg 1 100%,	11						1		11	680	7480
Helg 2 100%,	9							1	9	680	6120
Vidar, natt 100% (mønstrer ikke)	8	1		1					16	680	10880
Sum mannskapskostnader snøproduksjon uke 1									496		**260.950**
Uke 2 - mandag 11. - søndag 17.	Timer	Man	Tirs	Onsd	Tors	Fre	Lør	Søn	h/uke	Kr/h	Kr
Dag (7-15)	7,5		5	5	5	5			150	340	51000
Kveld (15-19) 50 % overtid	4		2	2	2				24	510	12240
Kveld (19-23) 100 % overtid	4		2	2	2				24	680	16320
Natt (23-07) 100% overtid	8		2	2	2				48	680	32640
Helg 1 100%,	11								0	680	0
Helg 2 100%,	9								0	680	0
Vidar, natt 100% (mønstrer ikke)	8		1	1					16	680	10880
Sum mannskapskostnader snøproduksjon uke 2									262		**123.080**
Sum mannskapskostnader snøproduksjon uke 1 og uke 2										**Kr**	**384.030**

Energiforbruk snøproduksjon (kWh)	**uke 1**	**uke 2**	**Tot kWh**
Langrenn, trafo L (229975323)	4.472	4.326	8.799
Snøproduksjon langrenn pumpehus (7350049087611731)	24.906	6.402	31.308
Hopparena skåla (luftkompressor), (229983134)	22.127	9.834	31.961
Totalt energiforbruk snøproduksjon uke 1 og 2 2016			**72.068**

Energipris	0,8 kr/kWh
Energikostnad snøproduksjon uke 1 og 2	**Kr 57.654**

Effektavgift kr/mnd	Kr/mnd	Kr/år	
Langrenn (ca 6.000)	6.000	72.000	Belastes langrenn
Snøproduksjon pumpehus (ca 21-22.000)	21.000	252.000	Belastes langrenn
Hopparena skåla (ca 15-18.000)	15.000		Belastes hoppanlegg
Sum langrenn		**324.000**	

- Pga behov for høy effekt under prod. tida ved snøproduksjon har vi fast effektleie per mnd. Dette utgjør ca 400-500.000 per år for de to målerne som benyttes til snøproduksjon langrenn
- Avregningseffekten fastsettes ved å ta den høyeste timeverdi de siste 12 måneder. I lavlastperioder reduseres målte timeverdier med 20 % i effektberegningen. Trafo "Hopparena skåla" forsyner i hovedsak hoppbakkene og effektkostnaden belastes følgelig hopp.

Mengdeberegning snø	**lengde**	**bredde**	**høyde**	**m3**
Stadion	160	60	0,5	4.800
Løyper	3000	8	0,5	12.000
Totalt produsert				**16.800**

E.3 Snowproduction in Holmenkollen

Parts of the energy consumption linked to snow production have been provided. This can be used to give an overview of the share of power that is for snow production at the two meters which can be seen during periods of peak values.

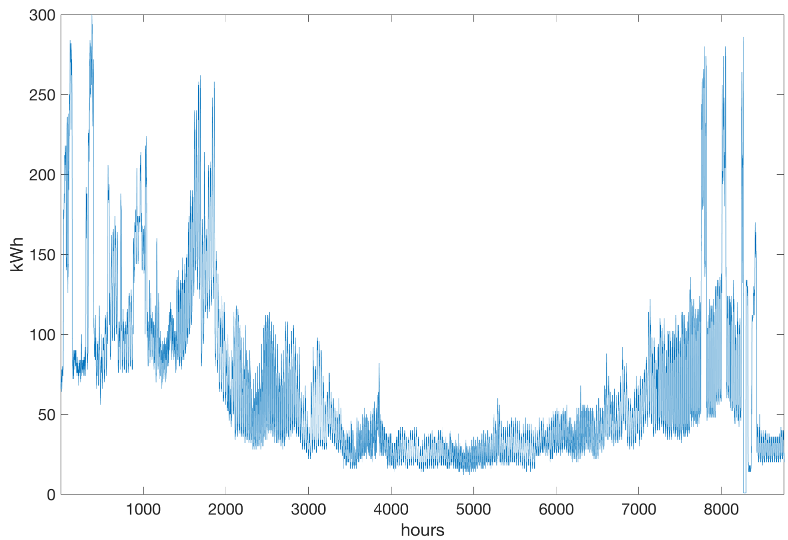


Figure E.1: Annual load profile of parts of the snow production in Holmenkollen

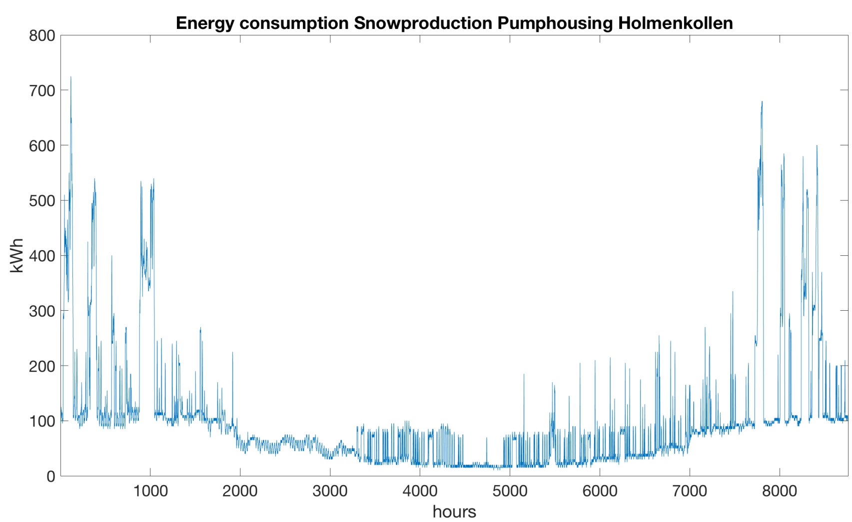


Figure E.2: Annual load profile of parts of the snow production in Holmenkollen

Appendix F

Annual mean normal temperatures in Norway

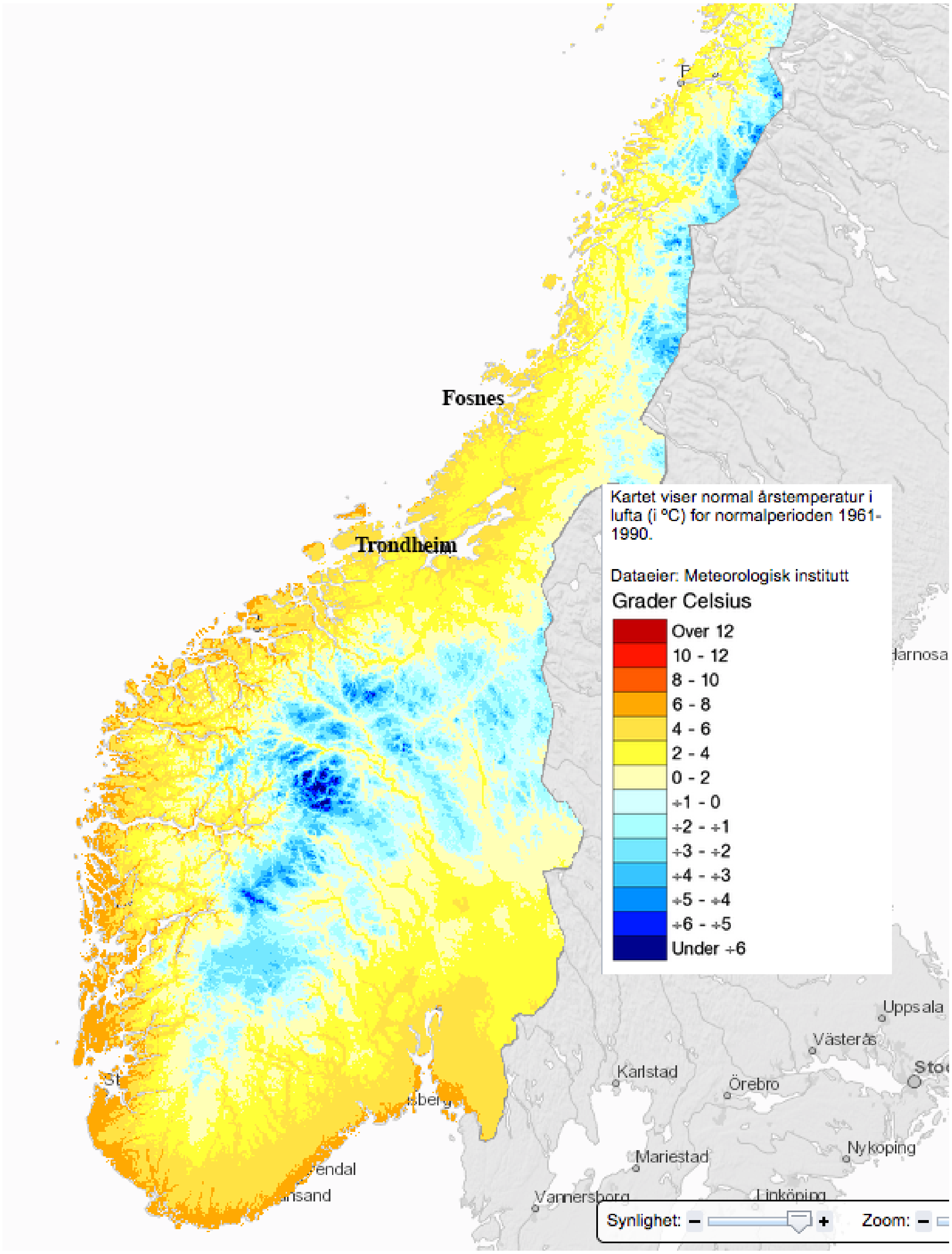


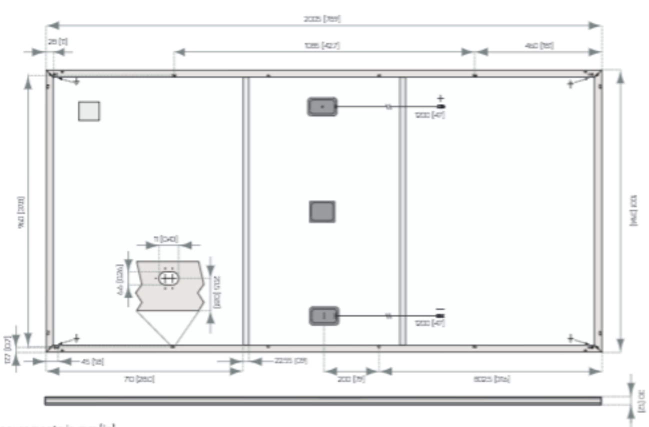
Figure F.1: Annual normal mean temperature in Norway (1961-1990)[11]

Appendix G

Datasheets

G.1 PV module datasheet

REC TWINPEAK 2S 72 SERIES



All measurements in mm [in]

17.7%	EFFICIENCY
10	YEAR PRODUCT WARRANTY
25	YEAR LINEAR POWER OUTPUT WARRANTY
DUTY+FREE	US IMPORT DUTY FREE

ELECTRICAL DATA @ STC	Product Code*: RECxxxTP2S 72					
Nominal Power - P_{MPP} (Wp)	330	335	340	345	350	355
Watt Class Sorting - (W)	-0/+5	-0/+5	-0/+5	-0/+5	-0/+5	-0/+5
Nominal Power Voltage - V_{MPP} (V)	38.1	38.3	38.5	38.7	38.9	39.1
Nominal Power Current - I_{MPP} (A)	8.67	8.75	8.84	8.92	9.00	9.09
Open Circuit Voltage - V_{OC} (V)	46.0	46.2	46.3	46.5	46.7	46.8
Short Circuit Current - I_{SC} (A)	9.44	9.52	9.58	9.64	9.72	9.78
Panel Efficiency (%)	16.5	16.7	16.9	17.2	17.4	17.7

Values at standard test conditions STC (airmass AM 1.5, irradiance 1000 W/m², cell temperature 77°F (25°C).
At low irradiance of 200 W/m² (AM 1.5 and cell temperature 77°F (25°C)) at least 95% of the STC module efficiency will be achieved.
*xxx indicates the nominal power class (P_{MPP}) at STC, and can be followed by the suffix XV for modules with a 1500 V maximum system rating.

ELECTRICAL DATA @ NOCT	Product Code*: RECxxxTP2S 72					
Nominal Power - P_{MPP} (Wp)	244	252	257	260	264	268
Nominal Power Voltage - V_{MPP} (V)	34.9	35.5	35.7	35.8	36.0	36.2
Nominal Power Current - I_{MPP} (A)	6.99	7.10	7.19	7.25	7.32	7.39
Open Circuit Voltage - V_{OC} (V)	42.3	42.8	42.9	43.1	43.2	43.3
Short Circuit Current - I_{SC} (A)	7.44	7.74	7.79	7.84	7.90	7.95

Nominal cell operating temperature NOCT (800 W/m², AM 1.5, windspeed 1 m/s, ambient temperature 68°F(20°C).
*xxx indicates the nominal power class (P_{MPP}) at STC, and can be followed by the suffix XV for modules with a 1500 V maximum system rating.

CERTIFICATION

C US

UL 1703, Fire classification: Type 1 (1500 V XV); Type 2 (1000 V); IEC 61215, IEC 61730, IEC 62804 (PID), IEC 62716 (Ammonia), IEC 61701 (Salt Mist level 6), ISO 11925-2 (Class E)

WARRANTY

10 year product warranty.
25 year linear power output warranty
(max. degression in performance of 0.7% p.a.).

TEMPERATURE RATINGS	
Nominal Operating Cell Temperature (NOCT)	44.6°C (±2°C)
Temperature Coefficient of P_{MPP}	-0.36 %/°C
Temperature Coefficient of V_{OC}	-0.30 %/°C
Temperature Coefficient of I_{SC}	0.066 %/°C

GENERAL DATA	
Cell type:	6 strings of 24 REC HC multicrystalline PERC
Glass:	0.13" (3.2 mm) solar glass with anti-reflection surface treatment
Back Sheet:	Highly resistant polyester
Frame:	Anodized aluminum (silver)
Support bars:	Anodized aluminum (bonded to backsheet)
Junction Box:	IP67 rated with 3 bypass diodes 12 AWG (4 mm²) PV wire, 47" + 47" (1.2 m + 1.2 m)
Connectors:	Tonglin TL-Cable01S-F (4 mm²) (1500V) Tonglin TL-Cable01S-FR (4 mm²) (1000V)
Origins:	Silicon: Made in USA & Norway Wafer/Cell/Module: Made in Singapore

MAXIMUM RATINGS	
Operational Temperature:	-40 ... +185°F (-40 ... +85°C)
Maximum System Voltage:	1000 V / 1500 V* *Dependent on product type
Design Load:	(+) 75.2 lbs/ft² (3600 Pa)
Design Load:	(-) 33.4 lbs/ft² (1600 Pa) Refer to installation instructions
Max Series Fuse Rating:	20 A
Max Reverse Current:	20 A

MECHANICAL DATA	
Dimensions:	78.9" x 39.4" x 1.2" (2005 x 1001 x 30 mm)
Area:	21.6 ft² (2.01 m²)
Weight:	48.5 lbs (22 kg)

Note! Specifications subject to change without notice.

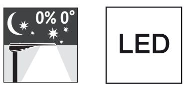
Ref: NE-05-07-13 Rev-C 08.17

G.2 LED light datasheet

Product data sheet

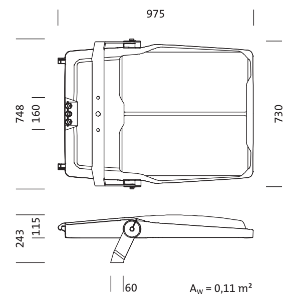
siteco
AN OSRAM BUSINESS

Overview of product data:
5XA7693F3A1AB **FL20mx,PL43,LED108000lm750,Basic,bracket**



Product description

Floodlight 20 maxi LED, floodlight, primary light control with lens, of PMMA, primary optical cover: cover panel, of toughened safety glass, transparent, light distribution: PL43, light emission: direct distribution, installation type: surface-mounted, LED, §: 108.000 lm, luminous efficacy: 120lm/W, light colour: 750, colour temperature: 5000K, control gear: ECG Basic, control: power reduction, overheat protection, electronic power reduction, with terminal, 4-pole, max. 2.5mm², mains connection: 220..240V, AC, 50/60Hz, LED unit, luminaire module, of diecast aluminium, Siteco® metallic grey (DB 702S), housing frame, of diecast aluminium, mounting bracket, of steel, galvanised, ON/OFF, protection rating (complete): IP66, insulation class (complete): insulation class I (protective earthing), certification: CE, ball protection: ball impact resistant, permissible ambient temperature for indoor applications: -40..+40°C, permissible ambient temperature for outdoor applications: -40..+50°C, packaging unit: 1 piece

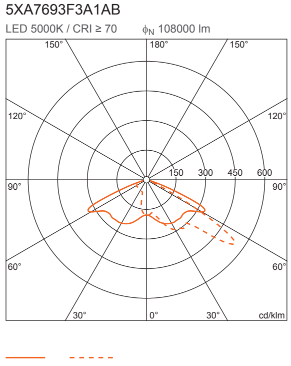


IP 66 CE

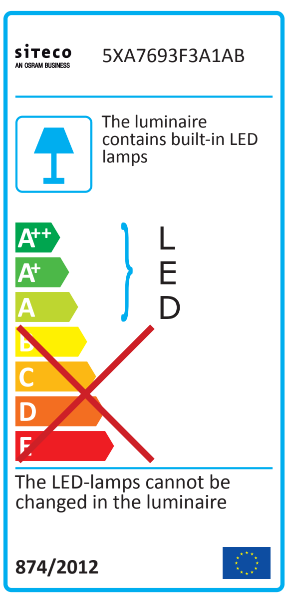
Lamps:	LED
Wt. (kg):	39.2
Order No.:	5XA7693F3A1AB
GTIN (EAN):	4058352117163

5XA7693F3A1AB: 2x LED 5000K / CRI ≥ 70

4058352117163
5XA7693F3A1AB



Luminous intensity class according to
EN13201-2: G6



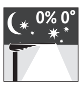
G.3 HIT Datasheet

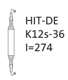
Product data sheet

siteco
AN OSRAM BUSINESS

Overview of product data: 1/4

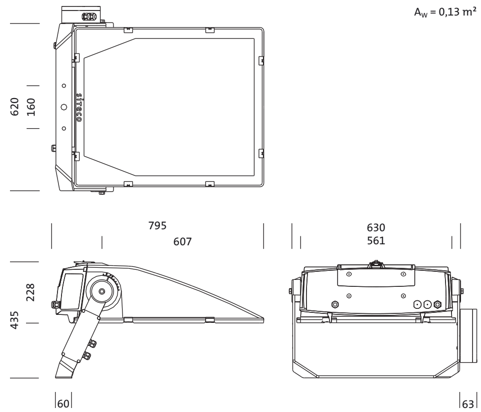
5NA76901WB03 **A3mx,1x2000W,HITDE,L274,w/o.CG,TSG,dir**





Product description

SiCOMPACT® A3 MAXI, floodlight, primary light control with reflector, of aluminium, highly specular, primary optical cover: cover panel, of toughened safety glass, light emission: direct distribution, primary light characteristic: asymmetric, installation type: surface-mounted, for 1 x HIT-DE l=274, 2000W, metal halide lamp, superimposed pulse ignitor, internal, control gear: without control gear, with terminal, 3-pole, max. 2.5mm², mains connection: 400V, AC, 50Hz, luminaire housing, of diecast aluminium, sandblasted, natural, length: 795 mm, width: 620 mm, height: 228mm, mounting bracket, of steel, galvanised, protection rating (complete): IP66, insulation class (complete): insulation class I (protective earthing), certification: CE, ENEC, VDE, impact resistance: IK08, standard: EN 50419, packaging unit: 1 piece



IP 66 IK 08

Lamps:	1x HIT-DE l=274 2000W
Socket:	K12s-36
Wt. (kg):	22.1
Order No.:	5NA76901WB03
GTIN (EAN):	4050737070544

You can find a complete overview of lighting technology / planning data from page 4.

Appendix H

Contact Form

A contact form is presented in Tab.H.1 + and - indicate whether the requested data were obtained or not.

Name	email	Position/company	Remark	Data
Anfinn Geiran	anfinn.geiran@kid.oslo.kommune.no	Technical manager, Holmenkollen Ski Arena	Reference load data	+
Vidar Finnland	vidar.finnland@trondheim.kommune.no	Operations manager, City operation of Trondheim *Sports, park and forest*	Operational times,lights information about events	+
Sindre Solberg	sindre.solberg@siemens.no	Siemens	Solar irradiance Battery ratings	+
Heidi Arnesen	heidi.arnesen@trondheim.kommune.no	Operating planner, City operation of Trondheim *Sports,park and forest*	Operation times, lights	+
Lars Martin Asmyhr	lars.asmyhr@kid.oslo.kommune.no	Energy consultant Cultural and sports, Oslo	Leirskallen Turnhall	+
Christian Nilsen	Christian@aha.no	Operation manager AHA Eiendom	Energy data TIS	-
Brynjar Lakså	brynjar.laksa@afconsult.com	Specialist Energy and Environment	Data from Power House	-
Jan Arne Løvås	jan-arne.lovas@fosnes.kommune.no	Technical manager	Energy consumption, Fyret flerbrukshus	+
Øystein Lindland	oystein.lindland@trondheim.kommune.no	Energy consultant	Load profiles, Granåsen	+

Terje Skulbru	terje.skulbru@ramboll.no	Rambøll	Lights at Granåsen	+
Geir Paulsen	geur.paulsenn@trondheim.kommune.no	Development manager Granåsen	Regulation plan and areas	
Roar Klette	Roar.klette@trondheim.kommune.no	Foreman at Granåsen	Lift, Granåsen	-

Table H.1: Contact form

Appendix I

Matlab Script

The following scripts have been made to estimate future load profiles.

I.0.1 Flood lights Arena

```
% Floodlights jump arena

h=1:8760;
weekFloodlight=zeros(52,1);

numberofLights=106;
Prated=2; %kW


%Scenario 1:
%bad weather, all lights are on during competitions
%
NC=[6 8 33]; % Weeks of NC
COC=38;% week of continental cup
GC=[50 2 3 5 7 10]; % weeks of Granaasen Cup
EJ=[51 2 1 12]; %Weeks of exercises
MC=29; %week of music concert
weekFloodlight(11)=(Prated*12*(numberofLights)+(Prated*4*(numberofLights/2)));%12 hours of full wed+thur, +
    exercise light


for i=1:52
    if ismember(i,NC)
        weekFloodlight(i)=weekFloodlight(i)+Prated*9*(numberofLights);
    end
```

```
    if ismember(i,COC)
                weekFloodlight(i)=weekFloodlight(i)+Prated*6*numberofLights;
    end
    if ismember(i,GC)
        weekFloodlight(i)=weekFloodlight(i)+Prated*3*numberofLights;
    end
    if ismember(i,EJ)
        weekFloodlight(i)=weekFloodlight(i)+Prated*3*numberofLights/4;
    end
    if ismember(i,MC)
        weekFloodlight(i)=weekFloodlight(i)+(Prated*3*numberofLights);
    end
end
```

I.0.2 Floodlit trail

```


%% Import the data
[~, ~, raw] = xlsread('/Users/marenhhansen/Documents/5 klasse/Masteroppgave/Data/sunrise.xlsx','Ark1');
raw = raw(15:end,2:end);

%% Create output variable
data = reshape([raw{:}],size(raw));

%% Create table
sunrise = table;

%% Allocate imported array to column variable names
sunrise.des = data(:,1);
sunrise.jan = data(:,2);
sunrise.feb = data(:,3);
sunrise.mars = data(:,4);
sunrise.apr = data(:,5);

%% Clear temporary variables
clearvars data raw;

%Floodlit
hour=1:24;
kWhFloodlit=zeros(24,5);
Pnils=0.060*55; %kW, 60W*55, Rated power floodlit Nilsbyen
Pnew=0.060*100; % kW, assumed Rated power for future floodlit trail
PCCstadion=0.600*17;%kW, double during competitions
```

```
A=table2array(sunrise);
annualKwh=zeros(365,1);
for i=1:5
    for j=1:24
        if j >12
          kWhFloodlit(j,i)=(Pnils+Pnew+PCCstadion)*A(j,i);
        elseif j<12
            kWhFloodlit(j,i)=(Pnils+Pnew)*A(j,i);
        end
    end
end

kWhH=zeros(8760,1);
%annualKwh(1:24)=kWhFloodlit(:,1);
%annualKwh(25:48)=kWhFloodlit(:,2);
%annualKwh(49:72)=kWhFloodlit(:,3);
%annualKwh(73:96)=kWhFloodlit(:,4);

for i=1:24:8760
    if i < 744 || i==744
        kWhH(i:i+23)=kWhFloodlit(:,2);
    elseif i>744 && i<1416 || i==1416
        kWhH(i:i+23)=kWhFloodlit(:,3);
    elseif i>1416 && i<2160||i==2160
        kWhH(i:i+23)=kWhFloodlit(:,4);
    elseif i>2160&&i<2880||i==2880
        kWhH(i:i+23)=kWhFloodlit(:,5);
    elseif i>7296 &&i<8016||i==8016
   kWhH(i:i+23)=kWhFloodlit(:,1);
    elseif i>8016 && i<8760 ||i==8760
        kWhH(i:i+23)=kWhFloodlit(:,2);

end
end
weekLit=zeros(52,1);
h=1;
for v=1:52
    weekLit(v)=sum(kWhH(h:h+167));
    h=h+168;
end
```

I.0.3 Snow Production

```


%% Import the data
[~, ~, raw] = xlsread('/Users/marenhhansen/Documents/5 klasse/Masteroppgave/Data/TAM.xlsx','TAM');
raw = raw(:,1:4);
raw(cellfun(@(x) ~isempty(x) && isnumeric(x) && isnan(x),raw)) = {''};

%% Exclude rows with non-numeric cells
I = ~all(cellfun(@(x) (isnumeric(x) || islogical(x)) && ~isnan(x),raw),2); % Find rows with non-numeric cells
raw(I,:) = [];

%% Create output variable
TAM = reshape([raw{:}],size(raw));

%% Clear temporary variables
clearvars raw I;

%% Snowproduction
totprodsnow=0;
s=1;
i=306;
Snowprod=zeros(366,1); % Daily snow production
energySnowprod=zeros(366,1);
hours=input('Daily Hours of production:');
Fangun=input('Number of fanguns in operation:');
quantity=input('Quantity of snow [m^3]:');
while totprodsnow<quantity
        Snowprod(i) = snowProduction2(TAM(i,4))*hours*Fangun;
        energySnowprod(i)=specEnergyUsage(TAM(i,4))*Snowprod(i);
        i=i+1;
        totprodsnow=sum(Snowprod);
    if i>366
        i=1;


    end
end
weeklySnowprod=zeros(52,1); % Weekly resolution of the energy consumption due to snow production
m=1;
for l=1:52
    weeklySnowprod(l)=sum(energySnowprod(m:m+6));
    m=m+7;
end
```

Function for snow production capacity

```
function prod=snowProduction2(T)

x=10/(9.5-7.5);

if T > 0 || T==0
     prod=0;
elseif T<0 && abs(T)<2
          prod =0;
     elseif abs(T)>13
          prod=67;
     else
          prod= (x*(-T))+2.5;

     end
end
```

Function for specific energy consumption

```
function specEnergy=specEnergyUsage(T)
kwh0=1:29; %kwh0 is based on the graph provided from SIAT

kwh0(1)=2.5;
kwh0(2)=2.25;
kwh0(3)=2;
kwh0(4)=1.85;
kwh0(5)=1.75;
kwh0(6)=1.67;
kwh0(7)=1.6;
kwh0(8)=1.5;
kwh0(9)=1.45;
kwh0(10)=1.39;
kwh0(11)=1.35;
kwh0(12)=1.32;
kwh0(13)=1.3;
kwh0(14)=1.28;
kwh0(15)=1.25;
kwh0(16)=1.23;
kwh0(17)=1.22;
kwh0(18)=1.21;
kwh0(19)=1.19;
kwh0(20)=1.18;
kwh0(21)=1.17;
```

```
kwh0(22)=1.16;
kwh0(23)=1.15;
kwh0(24)=1.15;
kwh0(25)=1.15;
kwh0(26)=1.15;
kwh0(27)=1.15;
kwh0(28)=1.15;
kwh0(29)=1.15;


x=2:0.5:16;

for i=1:29
    if T*(-1)<2 ||T*(-1)>16
    specEnergy=0;
    end
 if T*(-1)==x(i)
specEnergy=kwh0(i);

else
x0=(-1)*ceil(T);
for j=1:29
if x0==x(j)
specEnergy=kwh0(j)-((T+x0)*((kwh0(j+1)-kwh0(j))));


end
end
end
end

end
```

I.0.4 Lift

```


%% Import the data
[~, ~, raw] = xlsread('/Users/marenhhansen/Documents/5 klasse/Masteroppgave/Data/Heis2017.xlsx','M lerverdier'
    );
raw = raw(6:end,:);
raw(cellfun(@(x) ~isempty(x) && isnumeric(x) && isnan(x),raw)) = {''};

%% Replace non-numeric cells with NaN
```

```
R = cellfun(@(x) ~isnumeric(x) && ~islogical(x),raw); % Find non-numeric cells
raw(R) = {NaN}; % Replace non-numeric cells

%% Create output variable
Heis2017 = reshape([raw{:}],size(raw));

%% Clear temporary variables
clearvars raw R;



weekElevator=zeros(52,1);
k=1;
    for i=1:52
    weekElevator(i)=sum(Heis2017(k:k+167,2));

    if i>17 &&i<38
        weekElevator(i)=0;
    end
    k=k+168;
    end
        temp=weekElevator(10);
        weekElevator(10)=weekElevator(11);
        weekElevator(11)=temp;
        weekElevator(33)=weekElevator(38);
```

I.0.5 Buildings

Arena Building CC

```


%% Import the data
[~, ~, raw] = xlsread('/Users/marenhhansen/Documents/5 klasse/Masteroppgave/Data/ArenaHolmenkollen.xlsx','
    M lerverdier');
raw = raw(6:end,:);
raw(cellfun(@(x) ~isempty(x) && isnumeric(x) && isnan(x),raw)) = {''};

%% Replace non-numeric cells with NaN
R = cellfun(@(x) ~isnumeric(x) && ~islogical(x),raw); % Find non-numeric cells
raw(R) = {NaN}; % Replace non-numeric cells

%% Create output variable
ArenaHolmenkollen = reshape([raw{:}],size(raw));
```

```
%% Clear temporary variables
clearvars raw R;

%% Adjust for floodlights in Holmenkollen

ArenaGranansen=zeros(8760,1);
for i=1689:1700
    ArenaHolmenkollen(i,2)=ArenaHolmenkollen(i,2)-140;

end

tot=sum(ArenaHolmenkollen(:,2));
%% Adjust for area and passive standard
for j=1:8760
    ArenaHolmenkollen(j,2)=ArenaHolmenkollen(j,2)*(2500*80)/tot; %Adjust for passive standard
end


%% Aggregate to daily and weekly consumption
daily=zeros(365,1);
m=1;
for n=1:365
    daily(n)=sum(ArenaHolmenkollen(m:m+23,2));
    m=m+24;
end

weekArenaCC=zeros(52,1);
k=1;
    for i=1:52
    weekArenaCC(i)=sum(ArenaHolmenkollen(k:k+167,2));
    k=k+168;
    end
```

Arena Building Jump

```

%% Import the data
[~, ~, raw] = xlsread('/Users/marenhhansen/Documents/5 klasse/Masteroppgave/Data/ArenaRestHolmenkollen.xlsx','
    M lerverdier');
raw = raw(6:end,:);
raw(cellfun(@(x) ~isempty(x) && isnumeric(x) && isnan(x),raw)) = {''};
stringVectors = string(raw(:,1));
stringVectors(ismissing(stringVectors)) = '';
```

```
raw = raw(:,[2,3,4,5,6]);

%% Replace non-numeric cells with NaN
R = cellfun(@(x) ~isnumeric(x) && ~islogical(x),raw); % Find non-numeric cells
raw(R) = {NaN}; % Replace non-numeric cells

%% Create output variable
data = reshape([raw{:}],size(raw));

%% Create table
ArenaRestHolmenkollen1 = table;

%% Allocate imported array to column variable names
ArenaRestHolmenkollen1.TidTime = stringVectors(:,1);
ArenaRestHolmenkollen1.Energi = data(:,1);
ArenaRestHolmenkollen1.Kostnad = data(:,2);
ArenaRestHolmenkollen1.PeakHigh = data(:,3);
ArenaRestHolmenkollen1.Snittlast = data(:,4);
ArenaRestHolmenkollen1.Utetemperatur = data(:,5);

%% Clear temporary variables
clearvars data raw stringVectors R;
%

temp=zeros(168,1);
T=1;
tot=sum(ArenaRestHolmenkollen1.Energi);
for j=1:8716


 %% Adjust for world cup
if j>1512&&j<1680
        temp(T)=ArenaRestHolmenkollen1.Energi(j);
        ArenaRestHolmenkollen1.Energi(j)=ArenaRestHolmenkollen1.Energi(j+168);
ArenaRestHolmenkollen1.Energi(j+168)=temp(T);
T=T+1;
end
 ArenaRestHolmenkollen1.Energi(j)=ArenaRestHolmenkollen1.Energi(j)*(1500*80/tot); %Adjust for area of granaasen and passive standard

end

ArenaRestHolmenkollen1.Energi(5544:5712)=ArenaRestHolmenkollen1.Energi(6384:6552);
```

```
weekArenaRest=zeros(52,1); %Weekly energy consumption of the arena buildings connected to jump stadium
k=1;

    for i=1:52
        if i==52
            weekArenaRest(i)=sum(ArenaRestHolmenkollen1.Energi(k:8569));
            break
        end
    weekArenaRest(i)=sum(ArenaRestHolmenkollen1.Energi(k:k+167));
    k=k+168;

    end
```

Football Hall

```
%% Import the data
[~, ~, raw] = xlsread('/Users/marenhhansen/Documents/5 klasse/Masteroppgave/Data/Leirskallen2017.xlsx','
    M lerverdier');
raw = raw(:,2);
raw(cellfun(@(x) ~isempty(x) && isnumeric(x) && isnan(x),raw)) = {''};

%% Exclude rows with non-numeric cells
I = ~all(cellfun(@(x) (isnumeric(x) || islogical(x)) && ~isnan(x),raw),2); % Find rows with non-numeric cells
raw(I,:) = [];

%% Create output variable
Energi = reshape([raw{:}],size(raw));

%% Clear temporary variables
clearvars raw I;
Energi(1)=0;
%% Adjust for area in Granaasen
FootballHall=(Energi*10000)/2284;
LeirskallenWeek=zeros(52,1); % weekly energy consumption in football hall
week=1;
for i =1:52
    LeirskallenWeek(i)=sum(FootballHall(week:week+167));
    week=week+168;
```

```
end
```

Shooting Hall

```
%% Import the data
[~, ~, raw] = xlsread('/Users/marenhhansen/Documents/5 klasse/Masteroppgave/Data/Fosnes.xlsx','183051');
raw = raw(6:end,:);
raw(cellfun(@(x) ~isempty(x) && isnumeric(x) && isnan(x),raw)) = {''};

%% Replace non-numeric cells with NaN
R = cellfun(@(x) ~isnumeric(x) && ~islogical(x),raw); % Find non-numeric cells
raw(R) = {43}; % Replace non-numeric cells

%% Create output variable
Fosnes = reshape([raw{:}],size(raw));

%% Clear temporary variables
clearvars raw R;
%%

multiHallhour=zeros(8760,1);
weekShootinghall=zeros(52,1); % Weekly energy consumption, Shooting hall
h=1;
for j=138:502
for i=3:26
    multiHallhour(h)=Fosnes(j,i); %Transfer reference data to a 8760x1 vector
    h=h+1;
    if h>8760
        break

        if i>5 && i <9 % Remove swimming pool load
    hour(i)=hour(i)- 6.731;
    else
        hour(i)=hour(i)-3.33;
    end

end


end
end
x=1:52;
```

```
k=1;
    for i=1:52
    weekShootinghall(i)=sum(multiHallhour(k:k+167));
    k=k+168;
    %
if i>5 && i <9 % Remove swimming pool load
    weekShootinghall(i)=weekShootinghall(i)- 612.5;
    else
        weekShootinghall(i)=weekShootinghall(i)-1225;
    end

    end
```

I.0.6 PV production potential

```
%% Import the data
[~, ~, raw] = xlsread('/Users/marenhhansen/Documents/5 klasse/Masteroppgave/Data/Frosta.xlsx','export (3)');
raw = raw(2:end,:);
raw(cellfun(@(x) ~isempty(x) && isnumeric(x) && isnan(x),raw)) = {''};

%% Exclude rows with non-numeric cells
I = ~all(cellfun(@(x) (isnumeric(x) || islogical(x)) && ~isnan(x),raw),2); % Find rows with non-numeric cells
raw(I,:) = [];

%% Create output variable
solinnstralingFrosta = reshape([raw{:}],size(raw));

%% Clear temporary variables
clearvars raw I;

%% PV SUPPLY
etasys = str2double(input('System Efficiency :', 's')); %set to 0.77
etaPV = str2double(input('PV Efficiency:', 's')); %set to 0.17
prod=zeros(8760,1);
A=input('Available Roof Area:'); %calculated for 1433m^2 and 11433 m^2

%% Adjust for tilted panel
delta=0; %declination angle
phi=63.3732; %Latitude Granaasen
omega=0; %Hour angle
alpha=zeros(8760,1); %Elevation angle
beta=30; %Inclination angle
```

```
Sbeta=zeros(8760,1); %Solar radiation incident on a tilted panel
factor=zeros(8760,1);

for b=1:365
    delta=23.45*sind((360/365)*(284+b)); %Declination angle
    alpha(b)=90-phi+delta; %Elevation angle
end

  for f=1:8758

      if f>0&&f<745

      factor(f)=sind(alpha(10)+beta)/sind(alpha(10));
      elseif  f>744 && f<1417
          factor(f)=sind(alpha(41)+beta)/sind(alpha(41));
      elseif f>1416 && f<2161
        factor(f)=sind(alpha(69)+beta)/sind(alpha(69));
      elseif f>2160&&f<2881
          factor(f)=sind(alpha(100)+beta)/sind(alpha(100));
      elseif f>2880&&f<3625
          factor(f)=sind(alpha(130)+beta)/sind(alpha(130));
      elseif f>3624&&f<4345
           factor(f)=sind(alpha(161)+beta)/sind(alpha(161));
      elseif f>4344&&f<5089
           factor(f)=sind(alpha(191)+beta)/sind(alpha(191));
      elseif f>5088&&f<5833
         factor(f)=sind(alpha(222)+beta)/sind(alpha(222));
      elseif f>5832 &&f<6552
         factor(f)=sind(alpha(253)+beta)/sind(alpha(253));
      elseif f>6551&&f<7297
          factor(f)=sind(alpha(283)+beta)/sind(alpha(283));
      elseif f>7296&&f<8017
          factor(f)=sind(alpha(314)+beta)/sind(alpha(314));
      elseif f>8016&&f<8761
        factor(f)=sind(alpha(344)+beta)/sind(alpha(344));

      end

       Sbeta(f)=solinnstralingFrosta(f,2)*factor(f)*0.001;
       prod(f)= A*0.4*etasys*etaPV*(Sbeta(f));
  end

  PVprodWeek=zeros(52,1); % Weekly PV production potential
  u=1;
  for w=1:52
```

```
    PVprodWeek(w)=sum(prod(u:u+167));
    u=u+168;
end


prodMonth=zeros(12,1); % Monthly PV production potential
hj=1;
for mo=1:12
    prodMonth(mo)=sum(prod(hj:hj+719));
    hj=hj+720;
end
```

I.0.7 Aggregation and PV

```
%% AGGREGATION
weekTot=weekArenaCC+weekArenaRest+weekElevator+weekFloodlight+weekLit+weekShootinghall+weeklySnowprod+
    LeirskallenWeek; %Total load before integration of PV


%% PV scenario

LoadPVweek=zeros(52,1); %Net load after integration of PV
SurplusEnergy=0; %Excess energy from PV
for i=1:52

    LoadPVweek(i)=weekTot(i)-PVprodWeek(i); %PVprodWeek(i) is the production potential in Granaasen in week i
    if LoadPVweek(i)<0
        SurplusEnergy=SurplusEnergy-LoadPVweek(i);
    end
end
%LoadPVWeek=weekTot-PVprodWeek;
Difference=sum(weekTot)-sum(LoadPVweek) %Saving potential
SavingPotential=Difference/sum(weekTot);%percentage saving potential


%% PV week
%Hourly effect of integration of PV in a chosen week
weekPV=11; %week 11
ArenaRest=zeros(8760,1);
ArenaRest(1:8716)=ArenaRestHolmenkollen1.Energi(:);
load=FootballHall(1:8760)+multiHallhour+ArenaHolmenkollen(:,2)+ArenaRest; %load including the buildings of
    Granaasen
loadwPV=zeros(168,1);
```

```
loadwPV=load(((weekPV-1)*24*7):(((weekPV-1)*24*7)+168))-prod(((weekPV-1)*24*7):(((weekPV-1)*24*7)+168)); %Net
    load with PV
loadwoPV=load(((weekPV-1)*24*7):(((weekPV-1)*24*7)+168)); %Load without PV


%% Effect of PV on a particular day
starthour=4200; %corresponds to a day in week 11
loadwPVDay=load(starthour:(starthour+24))-prod(starthour:(starthour+24));
loadwoPVDay=load(starthour:(starthour+24));
b=1:24;
```