Impact of Football Season Extension and Temperature Fluctuation on Stadium Energy Consumption

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Declaration

I hereby declare that the dissertation entitled "**Impact of Football Season Extension and Temperature Fluctuation on Stadium Energy Consumption**" is my original work and is completely based on data I have collected and analyzed. The acknowledgment of all other sources of information has been done and the dissertation has not been submitted to other institutions for reward of any other degree.

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I would like to extend my thanks to the energy suppliers of the four stadiums who generously provided data for further analysis. Having said that I must not overlook Knut's efforts in contacting the relevant energy supplier and persistently following up to obtain the data.

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Abstract

Football is a popular and widely played sport across the globe. Growth in the popularity of football in Norway has coincided with the extension of the domestic season of the top national division. Previously, football was a summer sport in Norway but the extension of the football season by approximately 8 weeks has led to an earlier start and a later end of the season.

In this study, I investigated how the extension of the football season and temperature fluctuations affect monthly energy consumption, and determined which of these two factors contributes to changes in energy consumption during specific months. Data on energy specially used to de-ice the football pitch was obtained from energy suppliers and the monthly average temperature was derived from daily measurements from the nearest meteorological station of four stadiums in different regions of Norway. To analyze the relationship between these variables, linear regression with detrending was used.

The results show, that increasing energy usage during December, January, and February was mostly due to the increase in the use of football pitches, probably due to the extension of the football season and participation in UEFA football competitions by the clubs, whereas temperature fluctuations were more responsible for declining energy use during the April and March. I discuss the implications of these findings, particularly in relation to a likely future rise in temperature due to climate change, which might mean less snow in Norway and other countries with cold climates, making football potentially less energy-demanding in northern climates.

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Acronyms

UEFA	Union of European Football Associations
GHG	Greenhouse Gases
HVAC	Heating Ventilation and Air conditioning
KWh	Kilowatt Hours
MWh	Megawatt Hours
GWh	Gigawatt Hours

1. Introduction

Sport is widely considered as a tool for creating a national identity (Mutz & Gerke, 2018). For example, the success of athletes playing in international tournaments on behalf of a nation enhances the national reputation (Mutz & Gerke, 2018; Storm & Jakobsen, 2020). Among several sports, football is the most popular sport worldwide, which is played by over 265 million people and is participated in by almost every country (Wallace & Norton, 2014). The extensive media attention to elite league competitions and matches, such as the English Premier League, has played a significant role in enhancing the visibility and appeal of football to a wider audience, motivating countries to strive for better performance and establish a stronger presence in the sport (Fleischmann & Fleischmann, 2019). The key challenges to achieving this goal are encouraging participation at multiple skill levels and providing quality facilities for coaching, regular practice, and improvement. However, many countries with extreme climates require extra arrangements. For example, Norway experiences harsh cold weather in the winter, which is not suitable for maintaining playing surfaces, so elite teams require facilities such as undersoil heating to enhance the playing conditions.

Norway is not an ideal location for playing elite football due to its long winter season (Goksøyr & Olstad, 2009). According to Helle-Valle (2008), football was initially limited to the summer season in Norway, because of the difficulties in preserving high-quality natural grass all year round (Ericson et al., 2016). To overcome this, many of the country's top football clubs converted to artificial pitches and underground heating facilities. The development of these facilities has coincided with the increase in popularity of football in Norway, partly achieved after the men's national team played in the World Cup in 1994 and 1998 (Mehus & Kolstad, 2011) and the availability of other leagues such as Premier League on TV (Fleischmann & Fleischmann, 2019). An increase in the number of spectators in the top division by 115% over the period of 9 years from 2000 (Mehus & Osborne, 2010) and, the high participation of more than 8% of the total population in football (Skogvang, 2009), is associated with the expansion of the size of the elite league in Norway and, therefore, the number of games played each season. Growth of the season has not just happened in Norway, other huge tournaments like Football World Cup (FWC) have expanded the team to 48 for the next World Cup in 2026 (FIFA, 2023).

Specially, the Norwegian football league has experienced an extension of around 8 weeks in the past three decades (T. Sandnes, n.d.). Prior to 1994, Eliteserien (Tippeligaen from 1990 to 2016) featured 12 teams, and matches were held between late April or early May and mid-October. In total, there were 132 games, and each team played 22 games (T. Sandnes, n.d.). From 1994 to 2008, the league expanded to 14 teams, with 182 games played, and each team played 26 games, which began in early April and concluded in mid-October, extending the season by approximately four weeks. Starting in 2009, the league grew to 16 teams, and 240 games were played, with each team participating in 30 games between mid-March and early November, lengthening the season by another four weeks (Torjusen, 2022). In addition, teams that finish the season in the top positions of the Eliteserien have the opportunity to take part in the UEFA Europa League and UEFA Champions League. Also, teams finishing below these qualification places get a chance to play in the relatively new UEFA Conference League (*UEFA Documents*, 2022). In these tournaments, a team needs to proceed through different qualifying round games to advance group stage games played during the autumn and winter. Further the team progresses in the tournaments, greater the number of games it is required to play. Since these are competitions progressing during the winter season, separate from the local football season in Norway, this leads to greater usage of the football pitch in winter months, which in turn may demand more energy consumption. The introduction of a third European competition, the UEFA Conference League, increases the likelihood that Norwegian clubs will be involved in European winter matches. Moreover, it has an adverse impact on the environment with the release of GHG gases, particularly in countries that rely on fossil fuels as their primary energy source. Despite this increase in the number of games, it is not known specifically how much extra energy is being used and what the consequences are.

Stadiums are significant consumers of energy, and extended football seasons could result in higher energy consumption due to increased use of lighting, heating, cooling, and other stadium facilities (Nord et al., 2015). Moreover, the use of artificial turf, flood lights, LED screens, undersoil heating, and other technologies in stadiums also contributes to energy consumption. A stadium of moderate size, which accommodates around 55,000 spectators, can consume up to 10,000 MWh of energy per year (Manni et al., 2018), which is equivalent to the energy used by 500 households for a year in Norway (*Energy Consumption in Households*, 2014). There are no available data on the total energy consumption of Norwegian stadiums, but data from one football stadium in Sweden shows that it uses 1 GWh of energy each year for undersoil heating. This indicates the likely scale of usage because of similar weather conditions in Norway as well (Danielski, n.d.). Furthermore, the rise in greenhouse gas (GHG) concentrations in the atmosphere has increased the earth's surface temperature significantly over the past century (Mukherji et al., 2023). Norway experienced a temperature rise similar to the global rise of 1^0 C between 1990 and 2014 (Hanssen Bauer, 2017). This rise in temperature is expected to increase in the future, affecting the energy consumption of households and industry in Norway (Jacob et al., 2018) as well as the sports sector, as mentioned by Wilby et al, (2023).

The initial aim of this study was to answer the research question: how has the energy consumption of football stadia in Norway changed over the last few decades? I aim to discover the association between energy consumption and two above factors (the extension of football season and temperature changes). However, a lack of available data and clear patterns lead to further exploration of the data at the monthly time scale. In particular, I was interested in the energy consumption during the months because the energy use in the stadium is complicated, as warming the pitch does not happen all year round, and effects might be masked by average temperatures across the year. This led to the second research question: how has monthly energy consumption in football pitches changed over time? Furthermore, to identify whether the change in energy consumption is due to the usage of a football pitch or temperature variation. The third research question is presented: Is the monthly energy consumption change associated with the extension of the football season or temperature fluctuation?

Overall, the extended season in Norway has likely led to increased energy usage by the football stadiums, as the extra matches are taking place during colder months when de-icing by underground heating is required to make the playing surface usable. However, football in Norway may also benefit from future changes in climate, because increasing temperatures may lead to less snow and ice, and an easing of the harsh conditions that make winter football unsuitable. However, this has not been studied before (Dingle & Stewart, 2018) and more research is needed to establish whether these two factors will cancel each other out or whether more needs to be done to make football more sustainable in Norway.

2. Materials and Methods

2.1. Data collection

Numerous authorized personnel and energy suppliers responsible for providing energy to various stadiums across Norway were approached to obtain secondary data on energy consumption. The intention was to gather data from various regions to analyze the long-term impact of climate on energy consumption. Out of the stadiums contacted, only four agreed to share their energy consumption data. Furthermore, while the data suppliers were obligated to retain data for a ten-year period, only 5 years of digital data were available. The only stadium with long-term energy consumption data was "Stadium A"(Changed name), which had data from 2005 to 2019. The data for Aspmyra and Sarpsborg covered the period from 2015 to 2020 and 2015 to 2022 respectively, while Fosshaugane Campus provided data from 2017 to 2022. Details about each stadium are mentioned as follows.

2.1.1 Stadium A

The "Stadium A" is the stadium in the western coast of Norway and "Team A " is the club in the top division that uses "Stadium A" that wish to remain anonymous. "Stadium A" has a seating capacity of 11,249 and used to have a natural grass pitch, which was later converted to an artificial one in 2014. The stadium serves as the home ground for the "Team A" club and is also used for Eliteserien League and UEFA Europa League matches. The stadium has underfloor heating which is carried by water pipes installed in the drainage layer ("Team A Football Club," 2017).

Weather conditions

City of "Stadium A" is situated in the southern boreal zone and in the markedly oceanic section. The climate is mild and wet with a mean annual temperature of 7.1 °C for the normal period 1991–2020. February is the coldest month with a mean temperature of 0.9 °C, and July is the warmest month with a mean temperature of 15.4 °C (Moen & Lillethun, 1999). Between 1991 and 2020, the region received an average yearly rainfall of 1500-2000 mm and experienced an average annual snow of 25-50 cm (*Senorge*, n.d.).

Source of data on energy consumption and temperature

Elinett, the energy supplier for "Stadium A", provided data on hourly energy consumption in Kilowatt-hours (KWh). The hourly energy consumption provided was summarized as a monthly sum. Additionally, monthly mean temperatures from 2005 to 2019 were obtained from station number SN62270 (*Norsk*

Klimaservicesenter, n.d.). Since the football season was extended from 2009, the available data could be divided into two parts for further analysis: data from 2005 to 2008 (before the extension of the football season) and data from 2009 to 2019 (after the extension of the football season).

2.1.2 Aspmyra

Aspmyra stadium (Fig 1) owned by Bodø Municipality is in the city of Bodø, in Nordland, County of northern Norway. It was established in 1966 and currently has a seating capacity of 8200. The stadium features an artificial grass playing field and is primarily used for Eliteserien league matches, as well as international matches. Although the stadium used to host various sports, it has now been exclusively designated for football (“FK Bodø/Glimt,” n.d.).

Fig 1: Pitch of Aspmyra Stadium (“FK Bodø/Glimt,” n.d.)

Weather conditions

In Bodø, the climate is subarctic with an average annual temperature of 2.4^{0}C. January is the coldest month with an average temperature of -6.2^{0}C and July is the warmest month with an average temperature 13^{0}C (Bodø climate: Climate-Data.org, 2019). Between 1991 and 2020, the region received an average yearly rainfall of 1500-2000 mm and experienced an average annual snow of 25-50 cm (*Senorge*, n.d.).

Source of data on energy consumption and temperature

Arva was the entity responsible for supplying energy to Aspmyra stadium. However, the available data on energy consumption is limited, covering only the period from 2015 to 2020. The data was initially in hourly Kilowatt-hours (KWh) and, was summarized as the monthly sum. Monthly mean temperature data for the area was obtained from Bodø Vi with station number SN82290 (*Norsk Klimaservicesenter*, n.d.)

2.1.3 Sarpsborg Stadium

Sarpsborg stadium (Fig 2), the home ground for Sarpsborg 08, is in the city of Sarpsborg, Østfold County, SE Norway. The stadium has been in operation since 1930, hosting Eliteserien league matches. The stadium has a seating capacity of 8022, which was achieved after several renovations and modernization efforts since 2000. The facilities have gradually improved to what they are now. The lighting system with the artificial grass in the pitch was installed in 2009 (*Kort Om Sarpsborg Stadion*, 2018).

Fig 2: Aerial view of pitch of Sarpsborg stadium ((*Kort Om Sarpsborg Stadion*, 2018))

Weather conditions

Sarpsborg has a warm humid continental climate, with an average annual temperature of 7.3^{0}C. July is the warmest month with an average temperature of 17.5^0 C and with an average temperature of -2°C, January is the coldest month (Sarpsborg climate: Climate-Data.org, 2019). Between 1991 and 2020, the region received an average yearly rainfall of 750-1000 mm and experienced an average annual snow depth of less than 25 cm (*Senorge*, n.d.).

Source of energy consumption and temperature

The energy supply at Sarpsborg stadium is handled by Østfold Energi. After obtaining access from the supplier, the data was obtained using (https://minside.ostfoldenergi.no/) from 2015 to 2022. The data was available in monthly energy consumption, so no additional program was needed for conversion. Monthly mean temperature data for the area was obtained from the Sarpsborg station with station number SN3190 (*Norsk Klimaservicesenter*, n.d.).

2.1.4 Fosshaugane Campus

Fosshaugane Campus (Fig 3) is in the city of Sogndal, Vestland County, western Norway. It was officially opened in July 2006 with a seating capacity of 5622. The pitch was made of artificial grass in 2012 and is primarily used for first division (Obos-ligaen) football matches. However, the stadium also hosts other activities such as sports, education, and business events (*Fosshaugane Campus*, 2016). The pitch is not heated from late November or early December until the end of February, during which the ground is covered with snow. Heating is only applied to the pitch one week prior to the start of the game.

Fig 3: Aerial view of pitch of Fosshaugane Campus Stadium (*Fosshaugane Campus*, 2016)

Weather conditions

The climate in Sogndal is cold and temperate with an average annual temperature of 3.4^{0}C. January being the coldest month, at an average temperature of -5.4°C, July is the warmest at an average temperature of 14.5°C (Sogndal climate: Climate-Data.org, 2019). Between 1991 and 2020, the region received an average yearly rainfall of 1000-1500 mm and experienced an average annual snow of 25-50 cm (*Senorge*, n.d.).

Source of data on energy consumption and temperature

Monthly energy consumption data in KWh was made available for the years 2017 to 2022. Mean temperature data for the area was obtained from Sogndal airport with station number SN55700 (*Norsk Klimaservicesenter*, n.d.).

2.1.5 Data Analysis

The R programming environment (version 4.1.1, R core team, 2021) was used for all statistical analysis, and the following procedure was used for all 4 stadia. Initially, to assess the association between energy consumption and average temperature, I explored the time series data graphically, using monthly datasets. This information allows me to narrow the focus to specific months when energy was used, disregarding those with no usage.

To assess whether fluctuations in annual average temperature were associated with annual energy consumption, I first decomposed both time series to remove the annual trend and seasonality components of the data. This is important because relating two time series can often lead to spurious correlation, where substantial correlation appears between two variables only due to a shared trend or seasonal pattern instead of a meaningful relationship. A subsequent regression of the decomposed energy consumption variable as a response against the decomposed average temperature as an explanatory variable, can then be interpreted as the underlying linear relationship of two variables without the influence of annual trend and seasonality (Mohammadi et al., 2023).

I explored the trends over time in the data by month graphically to determine the changes in the energy consumption in the different months over the period, and to establish whether any non-linear trends were evident. In all cases relationship seemed linear, so linear regression was deemed appropriate to test the significance of the trends, with either energy consumption or average temperature as a response variable and year as an explanatory variable. According to Yildiz et al. (2017) regression of the statistical models seems to be the most commonly applied method due to its simplicity in application and explanation of the result.

To answer the third research question concerning the link between energy use and average temperature for each month, I conducted similar regressions on decomposed variables. However, as the seasonal component is not relevant to the monthly data, it was only necessary to remove the annual trend. To achieve this, the residuals from the regression models of energy consumption vs. year and average temperature vs. year for each month were extracted and used as variables in new regressions. For each month and each stadium, a linear regression model tested the relationship between energy use (response) and average temperature (explanatory). A significant relationship would suggest that temperature is an important factor affecting energy use. A lack of a significant relationship would indicate that, other factors such as football season extension would be responsible for the changes in energy consumption. In all regression models, I checked the assumptions of regression (normality of residuals, homogenous variance, no influential outliers) graphically and no assumptions were violated.

3. Results

3.1 Overview of energy consumption and average temperature pattern

The average annual energy consumption in “Stadium A”, Aspmyra, Sarpsborg, and Fosshaugane Campus stadiums was 1.13, 1.21, 0.82, and 0.22 GWh respectively. Total energy consumption followed a specific and seasonal pattern in all four stadia, and I focus on “Stadium A” as this provides the longest time series (Fig 4). “Stadium A” experienced two distinct periods of high energy consumption each year. The first peak appeared in February and March and was characterized by a significantly larger amount of energy consumption due to the starting of the domestic football season. The second peak, which was smaller, took place in November and December indicating lower energy usage during the end of football season when the snowfall starts. Before 2011 there has been a noticeable gap in energy consumption between these two peaks during the month of January, with no energy being used during this time. However, since 2011 this gap has narrowed, and the peaks of energy consumption have been smaller than in previous years. The energy consumption at Aspmyra followed a similar pattern, with a drop in energy usage during 2019 and 2020, and continuous use of energy in the following two years during winter months.

In each stadium, it was apparent that average temperature and energy consumption were related, months in which the maximum average temperature was high, energy used was equal to zero whereas more energy has been used in the month with a lower average temperature. However, there was no overall trend in the energy consumption of the stadiums.

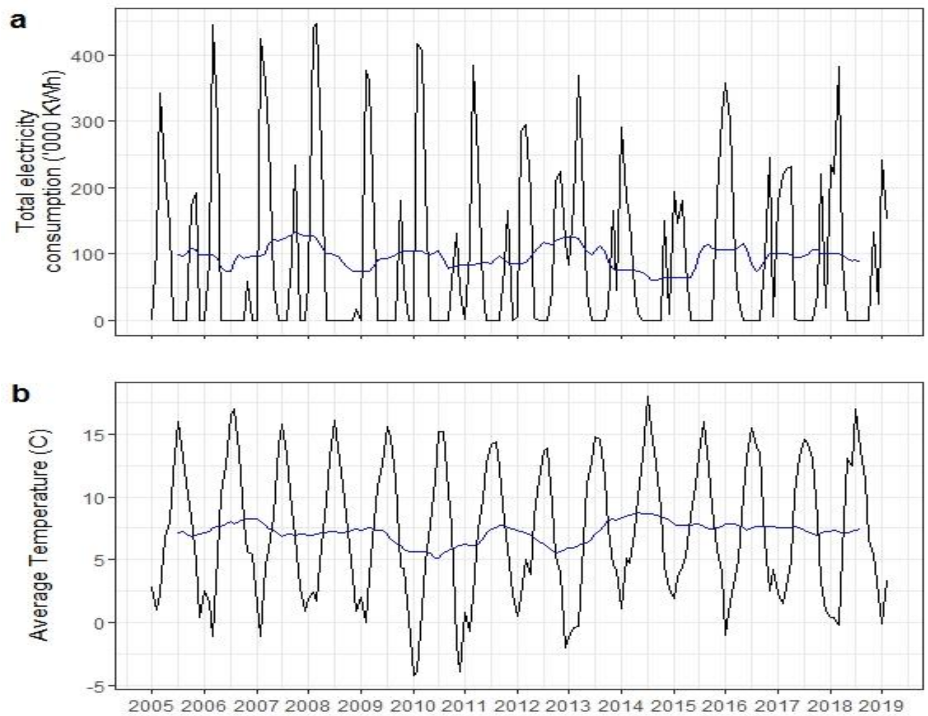

Fig 4: Time series of a) monthly electricity consumption ('000 KWh) and b) average temperature over time (Black Line) with moving trend (Blue line) of "Stadium A".

3.2 Association of temperature with the energy consumption

In all stadiums, there was a statistically significant ($p<0.05$) association between decomposed average temperature and electricity consumption (Table 1). However, the value of R square was notably lower in "Stadium A", where only 3% of the variation in energy consumption was explained by temperature (Fig 5). Furthermore, the explanation of variance in energy consumption in Aspmyra and Fosshaugane by average temperature was slightly higher at 13% and 20% than in "Stadium A". In contrast, the value of R square was much higher for the Sarpsborg stadium, where temperature explained 43% of the variation in energy consumption (Fig 5). This indicates that if the influence of the seasonality and the trend is removed temperature is still significantly associated with energy consumption in all stadia, but the link was strongest for Sarpsborg, and minimal in "Stadium A". It should be noted that this might be observed because there were many more years of data for "Stadium A" than for the other three stadia.

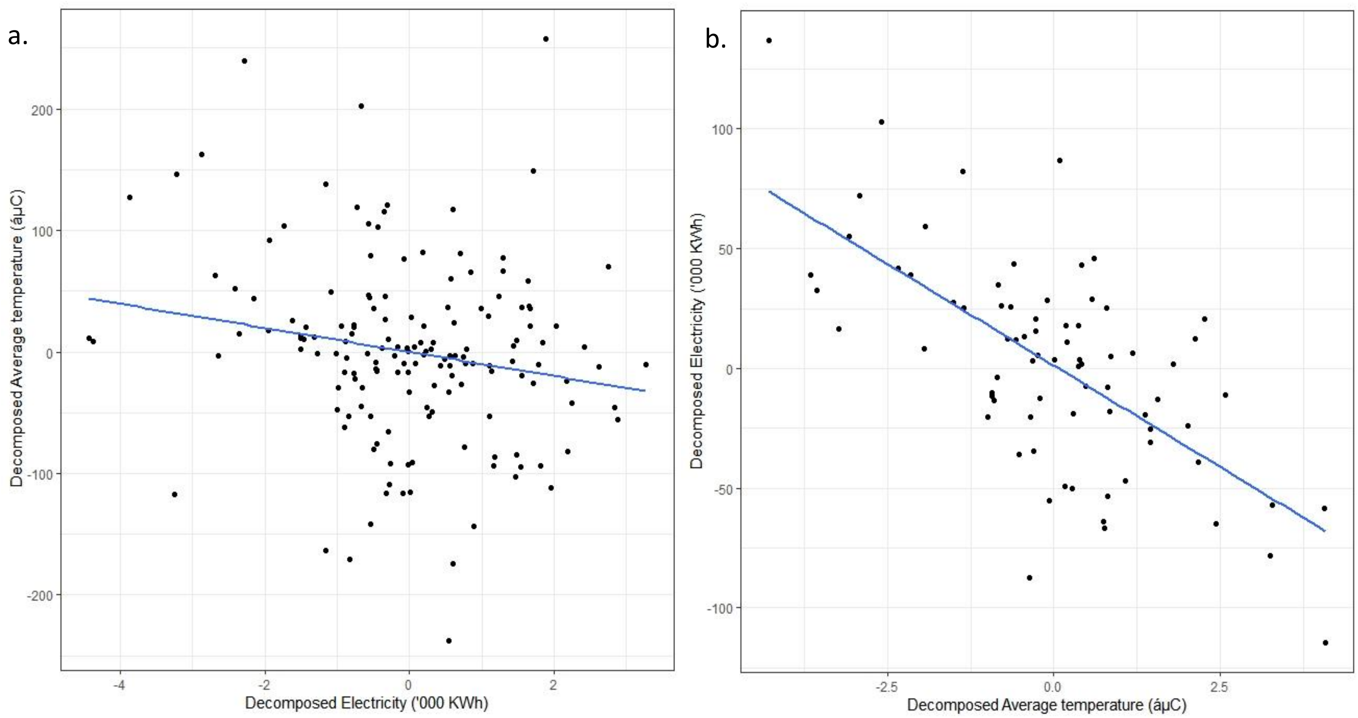

Fig 5: Scatter plot of decomposed electricity and average temperature in a) "Stadium A" and b) Sarpsborg Stadium. Each points represents a month in the time series from 2005-2019 for "Stadium A" and from 2015-2022 for Sarpsborg.

Table 1: P value, and R-square value after the linear regression of decomposed average temperature and energy consumption of four stadia.

Stadium	P-value	R-square
"Stadium A "	**<0.05**	**0.03**
Aspmyra	**<0.01**	**0.13**
Sarpsborg	**<0.05**	**0.43**
Fosshaugane	**<0.01**	**0.2**

3.3 Monthly fluctuation in total electricity consumption over the period

In "Stadium A", a positive trend was significant in January ($P < 0.01$, $R^2 = 0.65$), and November ($P = 0.02$, $R^2 = 0.34$) whereas, a negative trend was significant in April ($P = 0.01$, $R^2 = 0.42$) and March ($P = 0.02$, $R^2 = 0.36$) (Fig 6). No trend was visible in the energy consumption during the months of June, July, August, and September when energy for heating was not used (not shown). The energy use was increased in the coldest month of recent years.

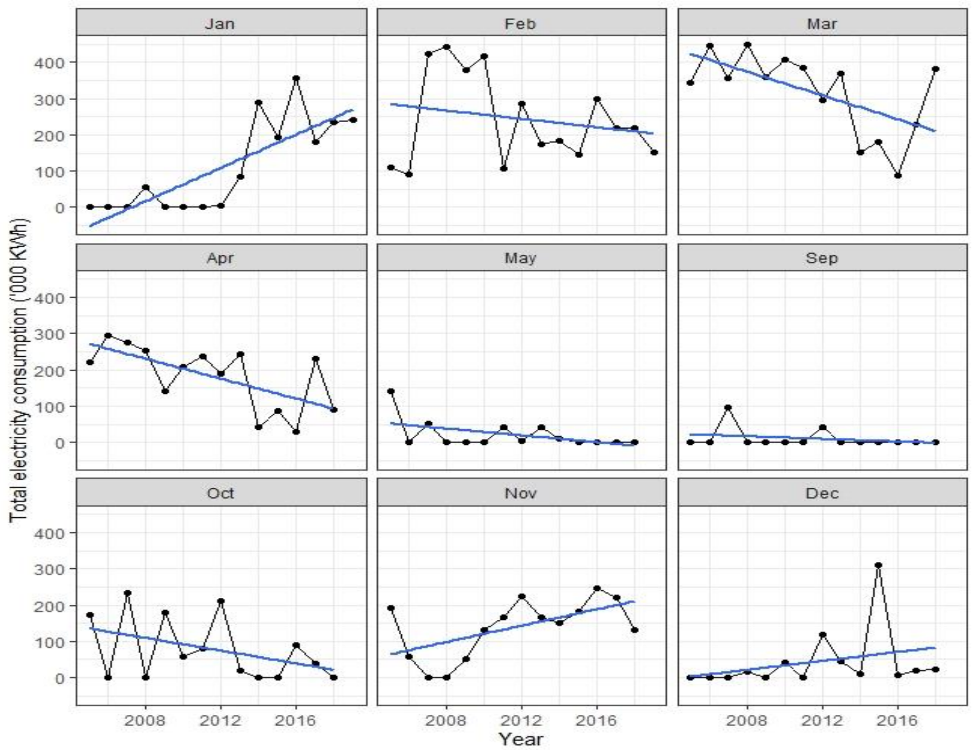

Fig 6: Monthly electricity consumption ('000 KWh) trend over time in "Stadium A". Amount of electricity used (Black line) and regression line (Blue line). Only those months with consumption values above zero are shown.

At Aspmyra, energy consumption was significantly explained by year (P=0.03) in January and December, with R-squared values of 0.65 and 0.63, respectively with a positive trend. The energy consumption during January and December was zero until 2020 but increased in 2021 and 2022 (Fig 7). These two years are clearly the reason why significant trends were found for these months, so this result should be viewed with caution. The value of energy consumption over the years was not significant in February and November (p>0.05), but the R-squared values were high at 0.35 and 0.37, respectively. On the other hand, higher energy consumption was observed during February and November, which correspond to the pitch preparation period and the end of the football season period, respectively. Furthermore, despite having only 8 data points, the graph displays a similar pattern to that of "Stadium A" in terms of energy used in the winter months.

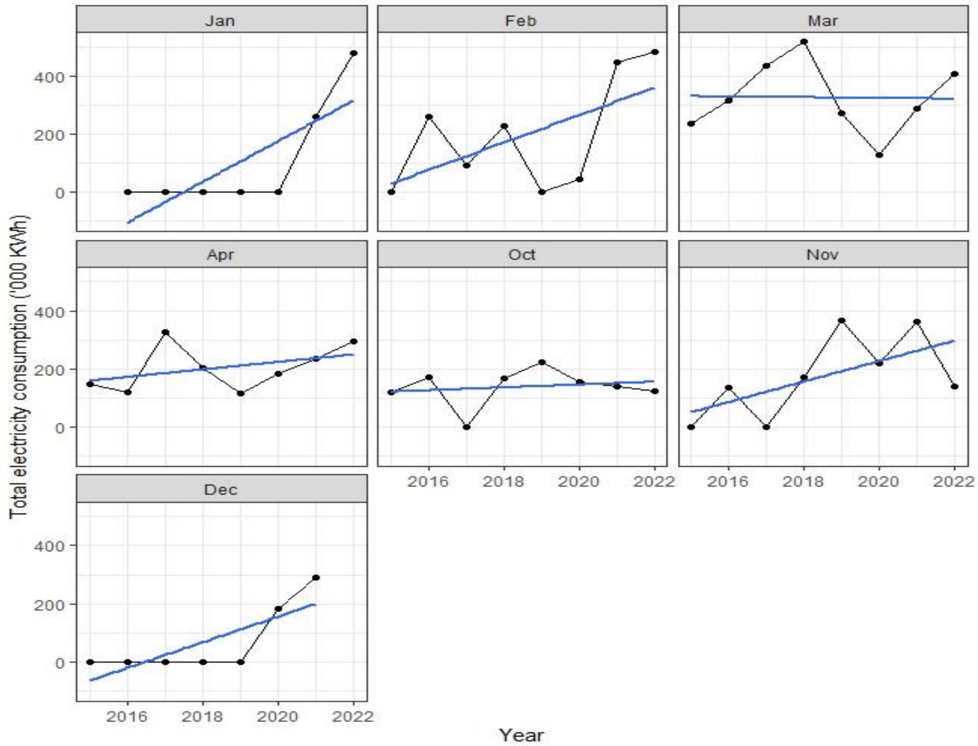

Fig 7: Monthly electricity consumption ('000 KWh) trend over time in Aspmyra. Amount of electricity used (Black line) and regression line (Blue line). Only those months with consumption values above zero are shown.

In Sarpsborg, although there was an overall decreasing trend in energy consumption, none of the monthly changes were significant as the P-value was greater than 0.05 and the R square value was very low.

There was nearly significant change in energy consumption at Fosshaugane Campus during February, November, and December (with p-values near 0.05), with R-squared values of 0.58, 0.55, and 0.75 respectively.

3.4 Factors responsible for the significant change in energy consumption

In "Stadium A", 52% of the variation in decomposed energy consumption in March and 36% in October was explained by temperature variation, indicating a clear association between the two variables in these months. For the remaining months, there was not a significant relationship with temperature.

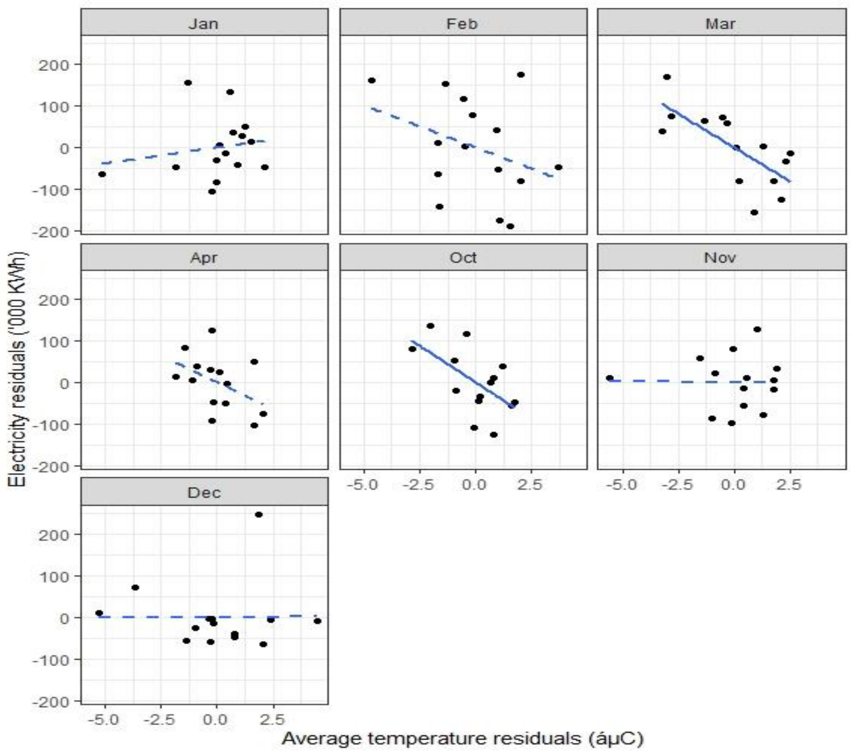

Fig 8: Linear regression between average temperature and energy consumed (‘000 KWh) in “Stadium A”. The data points are residuals extracted from regression of each variable against year, in order to remove the trend. Solid line: there is a significant influence of temperature in energy consumption, Dotted line: there is no influence of temperature in energy consumption.

In the spring season, energy consumption in most of the stadiums, including “Stadium A”, was linked to temperature (Table 2). In Aspmyra, the association was strongest in April, with temperature explaining 74% of the association. In Sarpsborg, temperature explained 90% of the variation in energy consumption during March. Towards the end of autumn, Fosshaugane Campus and “Stadium A” both showed a connection between temperature and energy consumption in October and November, respectively. Specifically, in November at Fosshaugane Campus, temperature accounted for 86% of the variation in energy consumption.

Unlike “Stadium A”, where no association between energy and temperature was observed in the first two months of the year (January and February), the other stadiums showed a link. In Aspmyra, temperature explained 45% of the energy consumption in February whereas in Sarpsborg, energy consumption was linked to temperature in January, accounting for 51% of the variation. In Fosshaugane, the relationship was observed in both January and February, with temperature explaining 77% and 87% of the variation in energy consumption, respectively (Table 2).

Table 2: Months with the significant outcome (P-value, and R square) from linear Regression of residuals of average temperature and energy consumed ('000 KWh) in "Stadium A", Aspmyra, Sarpsborg, and Fosshaugane stadiums.

"Stadium A"	P-value	R-square
March	0.03	0.52
October	0.02	0.36
Aspmyra stadium	**P-value**	**R-square**
February	0.06	0.45
April	<0.01	0.74
Sarpsborg Stadium	**P-value**	**R-square**
January	0.04	0.51
March	<0.01	0.9
Fosshaugane Campus Stadium	**P-value**	**R-square**
January	0.02	0.77
February	<0.01	0.87
November	0.02	0.86

4. Discussion

4.1 Overall pattern

There was no overall energy trend in each stadium possibly because extra energy used in the winter is cancelled out by the lower use in the spring and autumn. However, I found the expected relationship between temperature and energy consumption when looking at the data overall, after removing the strong seasonal variation component, although the strength of the relationship was often weak.

This finding is in line with some other studies, although according to Li et al. (2018), temperature influences energy consumption differently according to the sector. Energy consumption in industry, transportation, and commercial sectors is less dependent on temperature compared to the residential sector where energy consumption relies on the response of an individual to temperature change. Temperature is found to be a weak predictor of energy consumption in the stadiums, probably because the overall effect is masked by the monthly effects and other factors such as other weather conditions, the capacity of the stadium, and HVAC (Heating Ventilation, and Air Conditioning) system used also affects the energy consumption (Sport as a Business, 2021).

There is a difference in the strength of the relationship between energy use and temperature in 4 stadia. As “Team A” stands out as the most active participant in UEFA competitions and has made frequent use of the pitch compared to the other three clubs with long-term data on energy consumption, energy use is explained less by the temperature. Similarly, the Bodø/ Glimt club ranking second in performance among 4 clubs, has participated in UEFA several times, and also shows a weak association between energy consumption and temperature. Whereas the Sogndal and Sarpsborg 08 football club with weaker performance in national league than “Team A” and with shorter data on energy consumption of stadiums used by two club have more influence of the temperature on energy consumption. Overall, these patterns suggest that more usage of pitches during autumn and winter (UEFA competition season) is likely the reason for the reduced influence of temperature on energy consumption. Furthermore, all the stadiums are situated in different regions of Norway with different warming rates. “Stadium A” is situated on the western coast of Norway having the lowest warming rate per decade (Hanssen-Bauer et al., 2000) and the other stadiums are situated in regions with comparatively higher warming rates, which also probably has affected the strength of the relationship. However, more in depth study of the patterns is required to confirm this.

4.2 Monthly pattern

Energy consumption of the stadiums varied on a monthly basis throughout the period. During the winter months, energy consumption in stadiums tends to have a strong positive trend, while in spring it has a negative trend, suggesting that decreasing usage of pitch heating in warmer spring months may be offset by increased usage in winter months in some years. However further in-depth study is required to corroborate this.

The shift of starting of the football league in Norway from the end of April to mid of March due to the extension of the football season likely has led to an increase in the energy from February (for pre-season training and de-icing the pitch), at least for the stadium with the longest time-series. It is not possible to draw this conclusion for the other three stadiums due to the lack of data provided. However, it is quite surprising to see that there was an increase in energy use during January and December despite the absence of domestic football league matches. This indicates that other factors may be responsible for energy usage during these periods. One possible explanation is that the stadiums of high-performing clubs in the Eliteserien League were utilized for the UEFA Europa League and UEFA Champions League matches. For instance, "Team A" has been regularly participating in either UEFA Europa League or the UEFA Champions League since 2010/2011 or both (when any team is eliminated from the qualifying round and group stage of the UEFA champions league, it can still join UEFA Europa league). This is further supported by the fact that as Bodø/ Glimt football club (users of Aspmyra stadium) qualified for the UEFA Europa League in 2020/2021, the stadium's energy consumption increased from 0 KWh to 400,000KWh in January. Similarly, when Sarpsborg 08 participated in the UEFA Europa League in 2018/2019, the energy consumption was high and it decreased significantly when they were not participating in subsequent seasons. Therefore, although I have not been able to study every instance of usage of the stadium and its heating, the performance of football clubs appears to be more closely related to an increase in energy consumption in winter. Furthermore, the lack of relationship between energy use and temperature in winter is a clear indication that the increased usage is due to increased amount of football being played or training carried out during these months.

The increase in energy use in winter is not limited to the Norwegian league alone, several leagues in Europe are lately witnessing a significant surge in energy consumption during winter (Roberts, 2023). Therefore, smaller clubs and leagues of the English Football Leagues are planning to play the matches earlier to reduce expenses on floodlights, as energy consumption is expected to increase by four times in the winter season (Roberts, 2023). Similarly, the German Football League (DFL), operating the Bundesliga is also discussing moving the starting times of matches to minimize the energy consumption of floodlights (Nestler, 2022). Norway also can save a considerable amount of energy by rescheduling the matches. For example, the Eliteserien league in Norway plays only 8 matches in a week (2 on Saturday, 5 on Sunday, and 1 either on Monday or Friday) and if just two more games are played within a week then the length of the season will be shortened by 6 to 8 week, and season could be started in mid-spring, avoiding the extension of football and making the operation of the stadium more economically sound. Additionally, cutting down the summer vacation in July for players can further shorten the football season.

During spring, energy use is strongly affected by temperature variation, the demand for energy declines as the temperature increases, following a similar pattern as in residential sectors (Bigano et al., 2006; Ang et al., 2017). It is likely due to fewer days of frost when the spring temperature is warmer. With the anticipated temperature rise resulting from future climate change, the demand for energy during the spring season could therefore be expected to decrease. As these months are during the domestic season, they are unaffected by European competition and the extended season. So, referring to this situation, this is advantageous for the Norwegian clubs as they can save energy and money in warmer climates.

4.3 Implications

Due to climate change, spring and autumn season months are expected to be warmer than present in Norway (Hanssen Bauer et al., 2017). As shown by the results, this is likely to result in less demand for energy for the maintenance of artificial pitches during that period. Therefore, football clubs in Norway are likely to benefit economically from climate change in the near future, and future years perhaps the football season could be of the same length as it is now with no energy use on pitch heating. However, the annual average warming rate is uneven: it is lowest on the western coast of Norway (0.2-0.3^{0}C per decade) and highest (0.5^0 C per decade) towards inland and Northwards (Hanssen-Bauer et al., 2000). We can expect low or no snow in spring and autumn in Aspmyra, Sarpsborg, and Fosshaugane Campus before "Stadium A" and other stadiums on the western coast of Norway in the near future. As results suggest that climate change is beneficial to football in Norway, but due to the heterogeneous warming rate, the energy to de-ice the football pitches may still be required on the stadiums of the western coast of Norway, when the energy used to de-ice pitch is none in the stadiums of other parts of Norway.

During winter, the usage of football pitches has been made possible by artificial pitches and underground heating. Changes to football patterns have led to an increase in energy use during winter. Therefore, when it comes to heating the pitches, in the future they are likely to be doing it only in winter in Norway which probably will cost more money and contribute to GHG, offsetting the benefit gained from raising temperatures in spring and autumn. Therefore, Norwegian stadiums need to optimize energy efficiency during winter, following the approach that one of the clubs in the Bundesliga League has adopted by integrating the undersoil heating system with a weather station to lower energy consumption only when necessary (Nestler, 2022). Lately, Guard Automation Company is promoting this approach as the Field Smart solution in Norway (Oldenkotte, 2022). Norwegian clubs and stadiums should step forward and embrace new technology for making the winter use more energy efficient.

4.4 Future work

In this study, only short-term data is utilized to analyze the influence of natural weather variation on energy consumption. Since the rate at which the temperature is increasing per decade has doubled to 0.18^{0}C after 1981 where the rate was 0.08^{0}C since 1880 (*Climate Change: Global Temperature*, 2023), similar kinds of research with longer data sets (at least 3 decades) would help to identify how climate change has impacted the energy consumption in the stadiums. Also, it would provide an idea of how further climate change would affect the energy use pattern. Both stadium owners and policymakers can be benefitted from the information. Stadium owners can focus on energy-efficient systems and policymakers can speculate on future needs for infrastructure and resources and develop effective strategies and regulations accordingly.

4.5 Limitations

The data used in the study during the analysis has discovered the impact of weather variation on energy consumption, but longer data series would have provided insights into the impact of climate change on the energy consumption of the pitch. Furthermore, countries have their own kind of climatic conditions, and the pitches are made accordingly. The method of analysis of this study is applicable globally but, the study is based on Norwegian climatic conditions, so the findings are only applicable to the football pitches in cold climates such as Finland, Sweden, etc. where football is taken as the summer sport. In countries with warmer climates winter normally may not mean a lot of snow and ice, differing in energy use pattern. In addition, the study only considers two factors: usage of pitch and weather variation influencing energy consumption however there are many other meteorological factors (snow depth, humidity) and other technical factors (heating system) that influence the energy consumption that are not considered which could shed light on causal relation of energy consumption that was not covered by the average temperature and usage of pitches. In addition, football clubs don’t keep data long enough to do meaningful studies and do not want to take part in the study, reflecting that they are not taking this matter seriously. Furthermore, due to the absence of usage statistics, extended season and European league explanations are educated guesswork, so further analysis without actual information will be challenging.

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Annexes

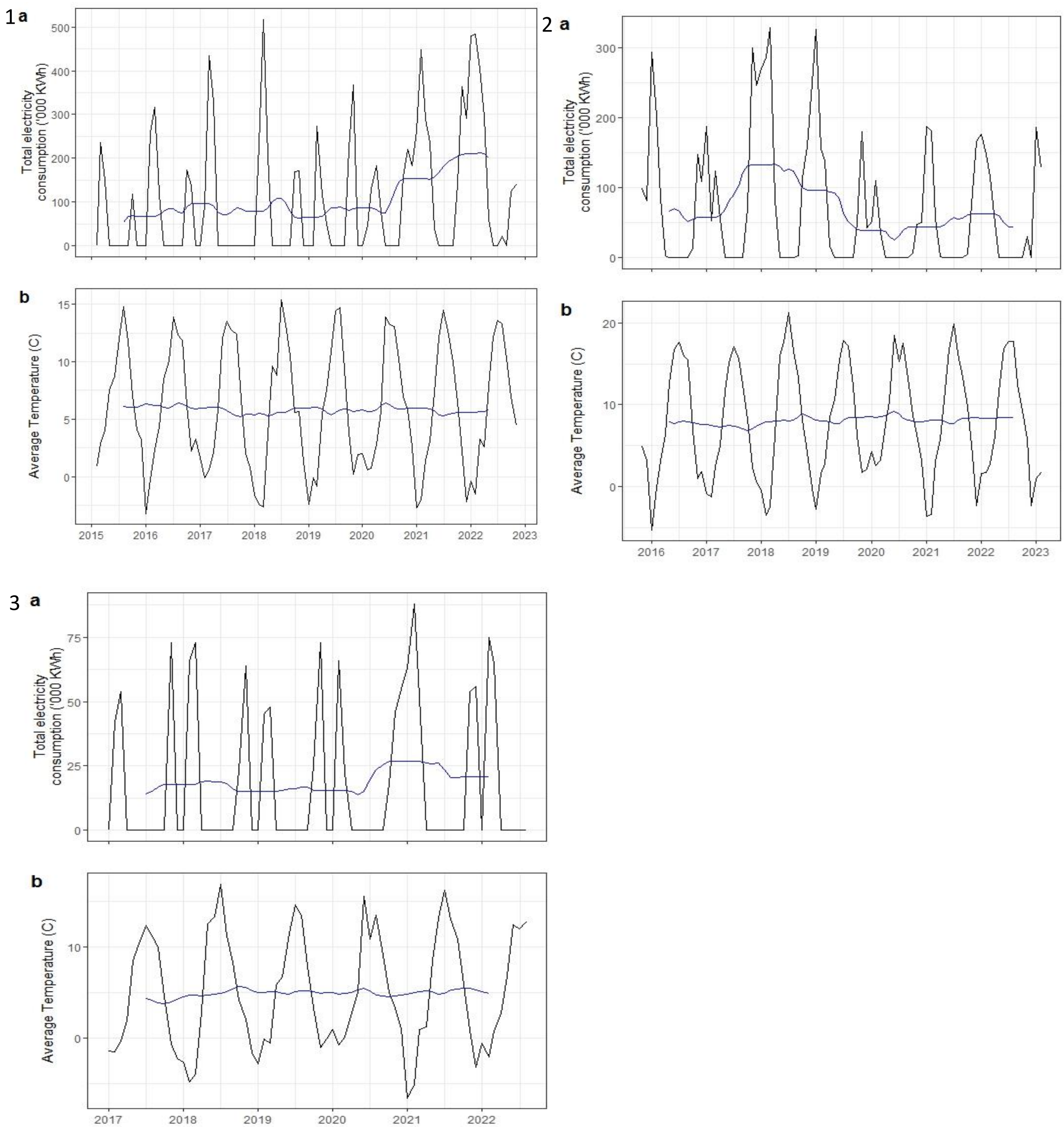


Fig A 1: Time series of a) monthly electricity consumption ('000 KWh) and b) average temperature over time (Black Line) with moving trend (Blue line) of 1) Aspmyra 2)Sarpsborg and 3) Fosshaugane Campus stadium.

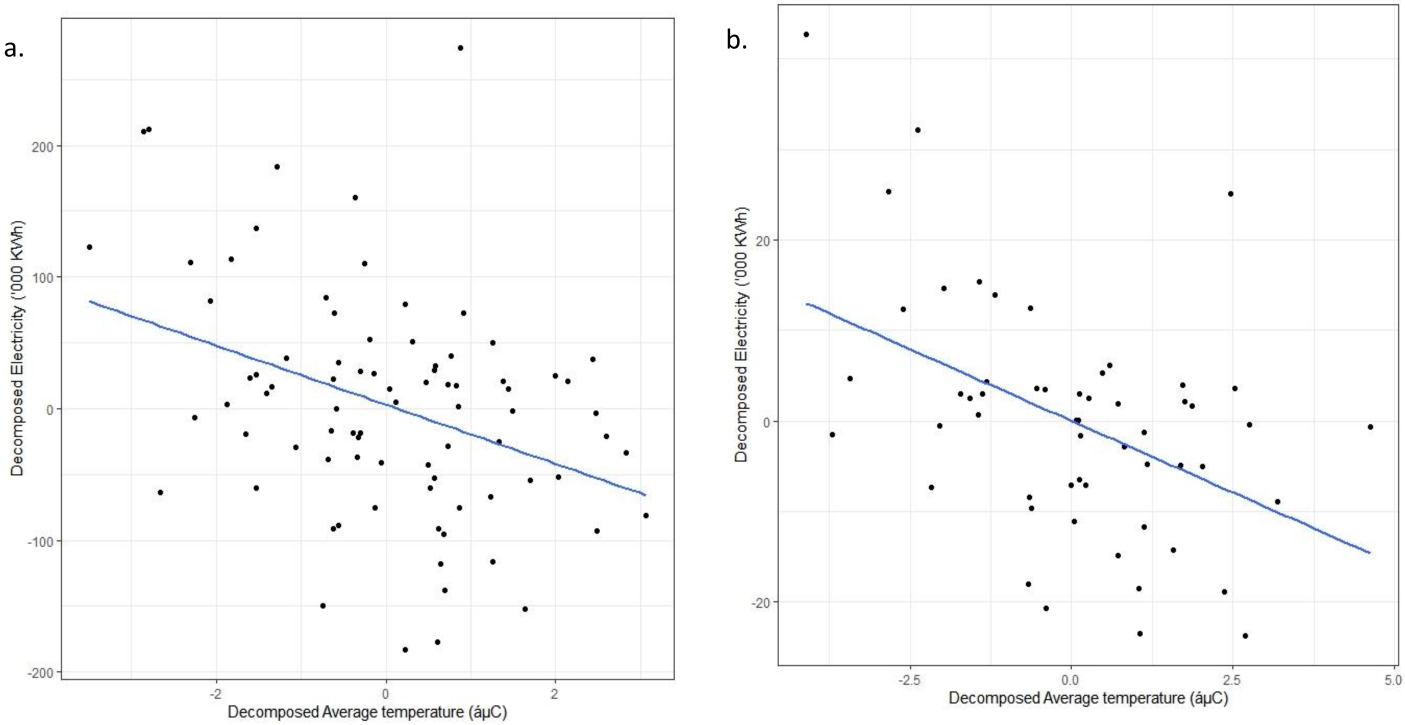


Fig A 2: Scatter plot of decomposed electricity and average temperature in a) Aspmyra and b) Fosshaugane Campus Stadiums. Each points represents a month in the time series from 2015-2020 for "Stadium A" and from 2017-2022 for Sarpsborg.

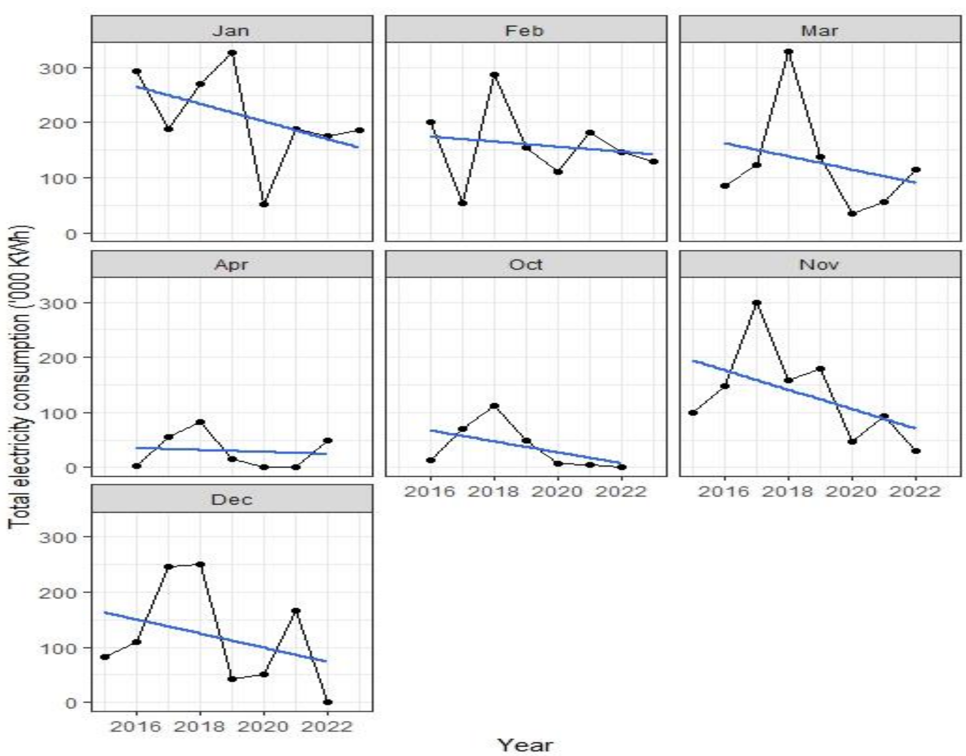


Fig A 3: Monthly electricity consumption (‘000 KWh) trend over time in Sarpsborg stadium. Amount of electricity used (Black line) and regression line (Blue line). Only those months with consumption values above zero are shown.

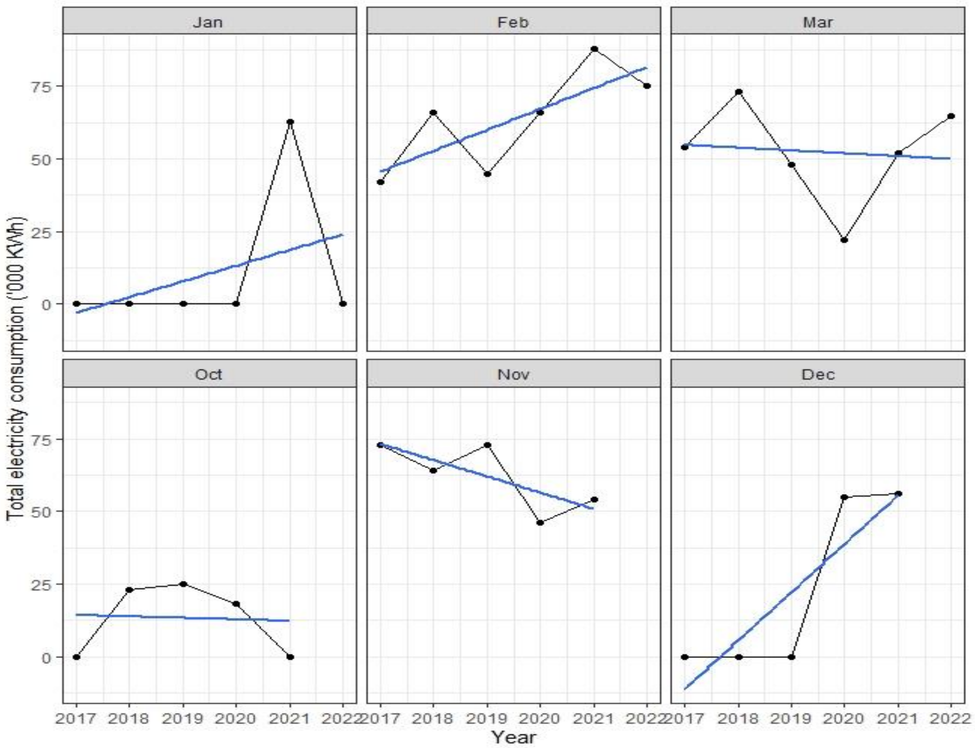
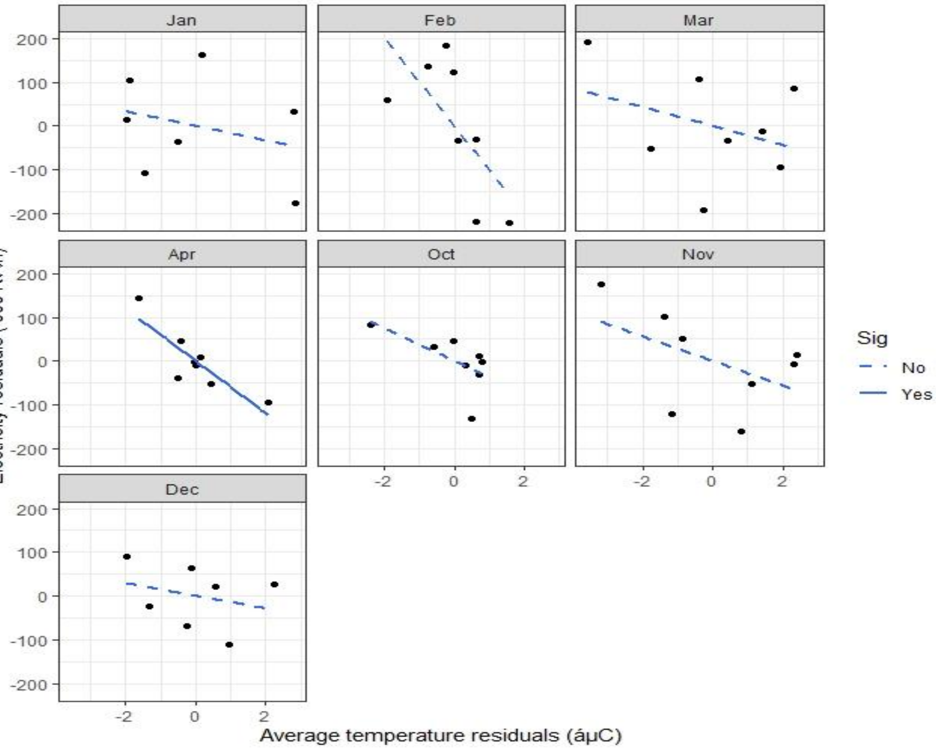
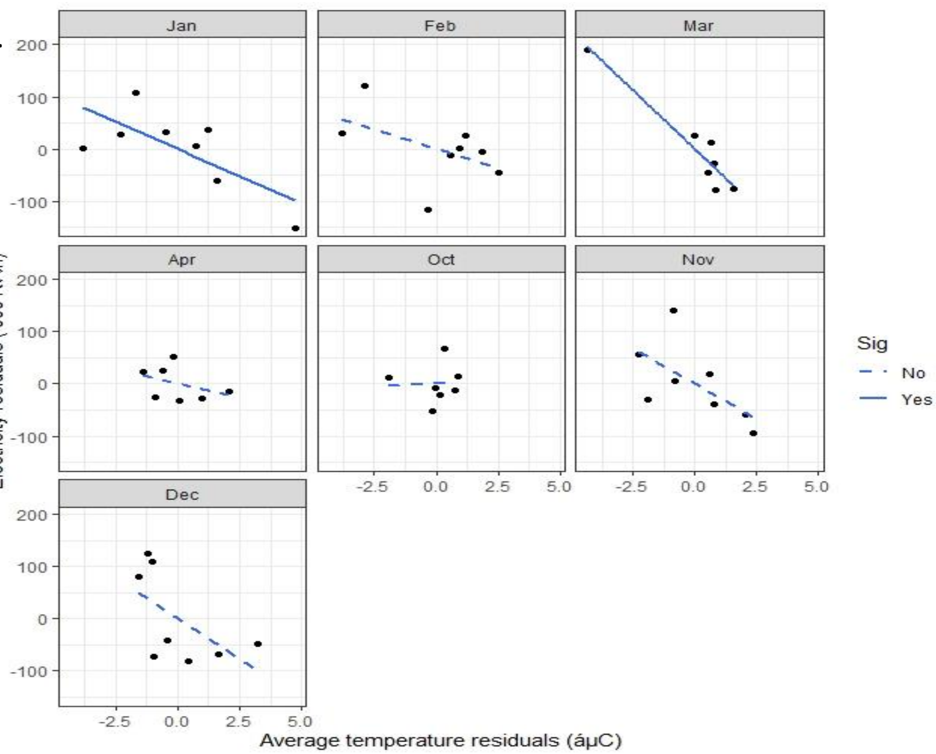


Fig A 4: Monthly electricity consumption (‘000 KWh) trend over time in Fosshaugane campus stadium. Amount of electricity used (Black line) and regression line (Blue line). Only those months with consumption values above zero are shown.

a.


Jan
Feb
Mar
Apr
Oct
Nov
Dec
Electricity residuals ('000 KWh)
Average temperature residuals (áµC)
Sig
No
Yes

b.


Jan
Feb
Mar
Apr
Oct
Nov
Dec
Electricity residuals ('000 KWh)
Average temperature residuals (áµC)
Sig
No
Yes

c.

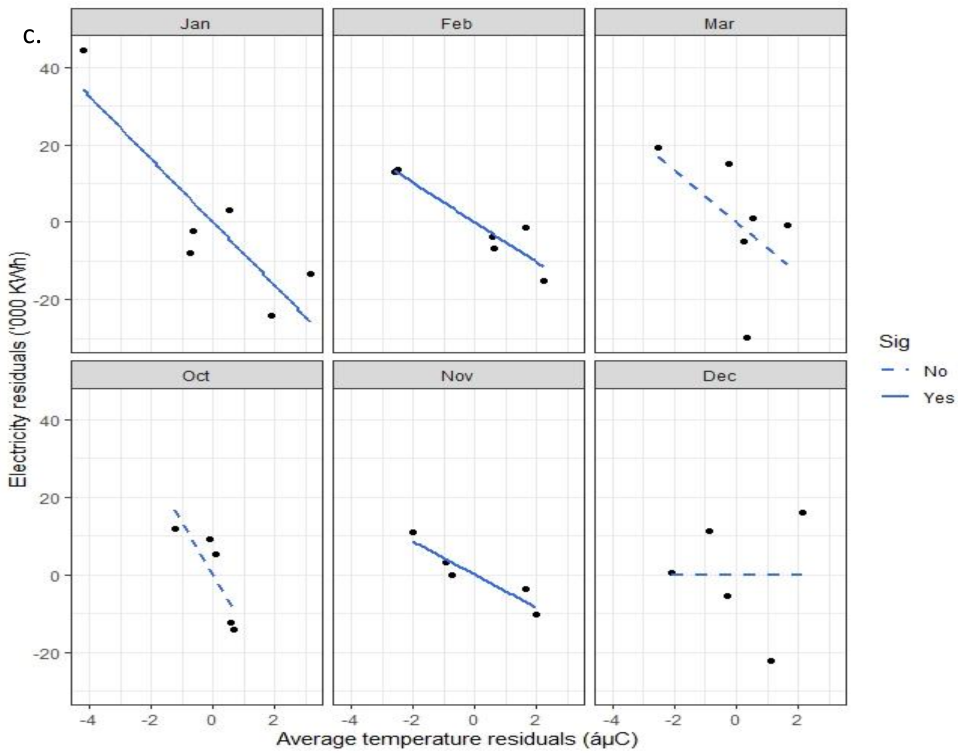


Fig A 5: linear Regression between residuals of average temperature and energy consumed ('000 KWh) in a) Aspmyra, b) Sarpsborg and c) Fosshaugane Campus. (Solid line: there is the significant influence of temperature in energy consumption, Dotted line: there is no influence of temperature in energy consumption)