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Climate implication and adaptation measures for energy use in buildings – a scoping review

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Abstract. The purpose of the study is to investigate data on climate implication and adaptation measures for energy use in buildings. It is based on a scoping literature review, concerned mainly with the main journals operating in the field of climate adaptation of the built environment. Research documents that significant changes are taking place due to the implications of climatic change. Studies concerning climate change impact on energy use in buildings in warm climates represent the majority of the findings. The volume of research within the consequences for the built environment in cold regions is found to be surprisingly low, especially concerning the pecuniary stakes involved. However, significant regional differences are observed. Though further research is of essence, policy/regulatory measures ought already to be taken, based on climate scenarios.

Keywords: Climate change, building, adaptation, impact, energy use

1. Introduction

The global climate is constantly fluctuating to some degree. Data collected over the recent decades, however, show unusually rapid change in a historic context, caused primarily by anthropogenic activities. Increased concentrations of greenhouse gases in the atmosphere causes the global average temperature to rise, with wide-ranging consequences for the atmospheric climate [1]. Among other things, the increased global temperature causes weather patterns to shift and sea level to rise. This will have severe consequences for a built environment designed under the assumption of steady conditions. Representative Concentration Pathway (RCP) describes greenhouse gas concentration in the atmosphere for future climate scenarios, utilized to predict the climate change consequences [2]. The four RCPs used for climate modelling are RCP2.6, RCP4.5, RCP6, RCP8.5, where RCP2.6 represents the lowest, and RCP8.5 the highest concentration projection [3].

In Norway, climate change is expected to manifest itself in the form of higher temperatures and increased levels of precipitation. The national average air temperature has risen by 1 °C between 1900 and 2014, and precipitation has increased by 18 % over the same period [4]. The trends are expected to be prolonged over the next century. This leads to shorter and milder winters as well as more frequent and intense rainfall events. Sea level rise is a relatively minor concern in Norway, as it is largely counteracted by land rise. However, increased precipitation is expected to lead to costly damages to buildings and infrastructure by 2100 [5].

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The amount of energy use in buildings depends on the building's location, outer factors, the building envelope and the intended use of the building [6]. Climate change will have consequences for energy requirements in buildings [7]. Since the winters will be warmer, the heating demand may be reduced. Rising summer temperatures cause higher demand for cooling to assure thermal comfort. Evaluation of adaptation measures for buildings, especially in urban areas, is therefore of high importance [8]. To examine this matter, the following research questions are addressed:

- What is known from existing literature about climate implication and adaptation measures for energy use in buildings?
- What are the most important gaps in the research?

This study is part of a larger literature research which concerns climate implication and adaptation measures for buildings (as a whole). Elements omitted are: policy, sustainability, mitigation, health impact, air quality, design tools and guidelines, overheating, extreme weather impact, precipitation and adaptation of the building envelope.

2. Methodology

This study is based on findings from a scoping literature review, carried out during the period of November-December 2018/January 2019. A scoping study might "aim to map rapidly the key concepts underpinning a research area and the main sources and types of evidence available and can be undertaken as stand-alone projects in their own right" [9]. Thus, the objective for this study was to map the literature available on the subject of climate change impact and adaptation for energy use in buildings, with the purpose of categorize and analyze the findings according to the proposed research questions. The method is based on the framework described in [9]. This involves a six-step procedure; 1) identifying the research question, 2) identifying relevant studies, 3) study selection, 4) charting data, 5) collating, summarizing, and reporting the results, 6) consultation.

The procedure also made it possible to identify the research gaps. In this manner, the study can provide a thorough and valid method for mapping the research area, to discover the measure and the characteristics of the research done in the field [10].

Given the extent of the material identified, certain limitations needed being outlined. The articles investigated concern mainly questions of building physics. Furthermore, as according to the guidelines provided by Arksey & O'Malley we did not assess research quality of the articles included in the review. The practical research procedure can be illustrated in the following figure:

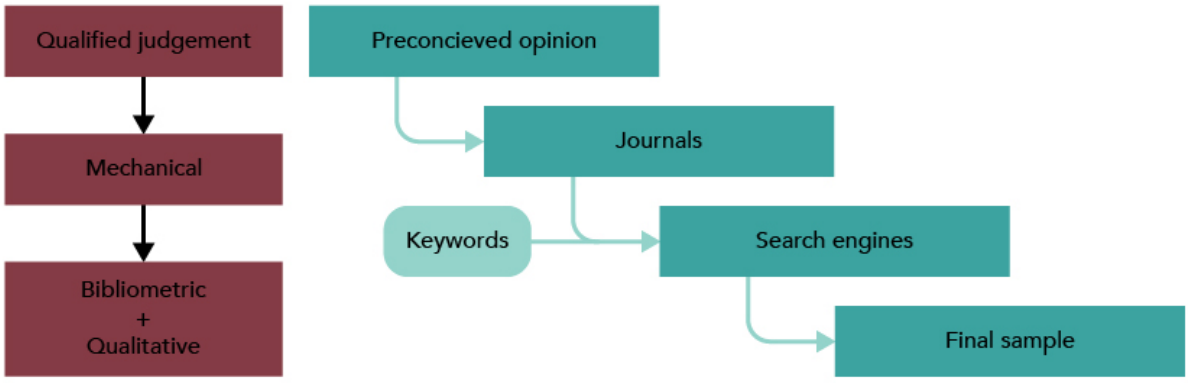


Figure 1. Research procedure

2.1 Identifying and selecting studies

To be as comprehensive as possible identifying studies, searching for research evidence should involve different sources [9]. Given the extensiveness of the field, two main search processes were employed. First, hand-searching of key-journals as described in 2.1.1. Second, a comprehensive search through carefully selected databases and search engines was conducted.

As part of the broader study, over 20 000 article titles and/or abstracts were examined in order to identify studies related to climate implication and adaptation measure for buildings. 163 articles were

identified. To narrowing the scope, this study presents a set of 67 articles that all met inclusion criteria's regarding the topic of implications and measures for energy use in buildings.

2.2 Hand-searching of key-journals

Hand-searching of key-journals was carried out to identify research pertinent to the field of inquiry, as well as obtaining an overview of the content of the key journals within the field. Based on the experience of research co-workers and pre-conceived opinion, 12 journals were selected to examine. This selection consists of Building and Environment, Climate Services, Energy and Buildings, Building Research & Information, Journal of Climate Change, Buildings, Journal of Building & Physics, Climate Sustainable Cities and Society, Energy Policy, International Journal of Climate Change Strategies and Management, and Advances in Energy Building Research. The publications in Construction and Building Materials were examined only for 2018. It was discovered that this journal is very extensive. Since no relevant articles were found among the 40 volumes, the journal was discarded. The articles published in the selected journals are related to building science and/or climate change related issues. Articles newer than five years were selected through qualitative assessment of titles, keywords and abstract. 74 articles were found in this way.

2.2.1 Identification of search words. The search terms were decided based on the keywords in the articles that were found by hand-searching the key-journals. As figure 2 shows, the keywords in the selected articles were listed and counted. The final keywords were selected based on frequency and qualitative judgement. Thus, creating a consistent basis for the final search strategy as described in the following paragraph.

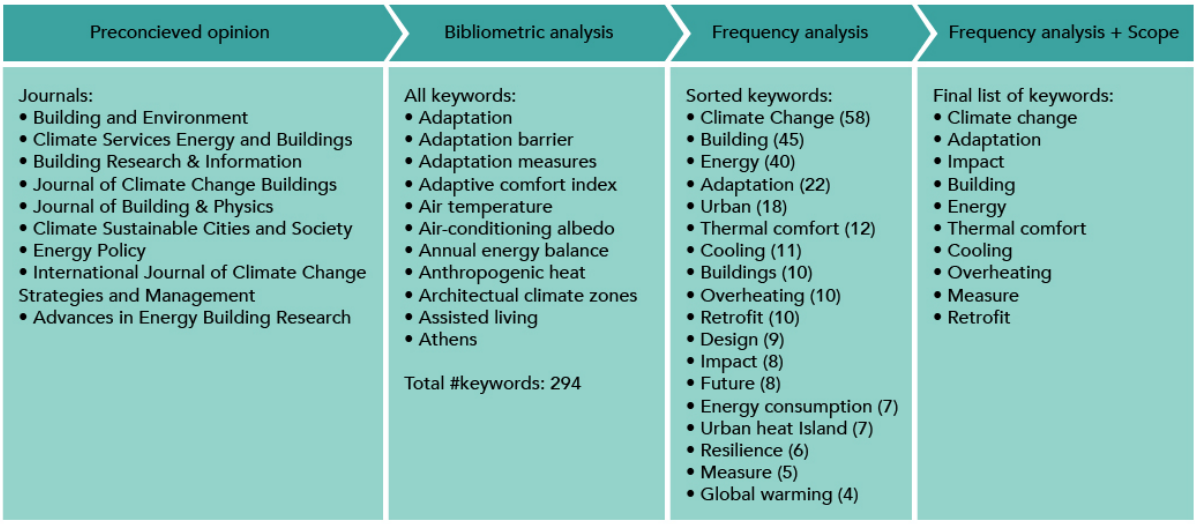


Figure 2: Procedure for identifying search words

2.3 Search through databases and search engines

The systematic search was carried out using combinations of search words identified through the key-journals, showed in figure 2. Three reference databases were then searched through, using the search strategy explained in table 1. The three major electronic databases included Google Scholar, Oria (Norwegian university library search engine), and ScienceDirect. Electronic databases provide several tools for narrowing the search, therefore, the search was limited to English scientific research and review articles, excluding patents and conference papers, published the past five years. Because databases operate with diverse filters and algorithms, some variation in the search strategy were employed for use in each of the databases. Regardless of variations in the structure of databases, all search words and combinations were consistently used in all databases. The filters for each database/search engine, filter explanation and the number of unique and double identified publications

are listed below in table 1. Duplicate publications were later filtered out as from the final sample.

Table 1. Filters used for search through databases and search engines, filter explanation and number of unique identified publications.

Search engine	Filter	Filter explanation	Unique identified publications (doubles)
Google Scholar	Title and topics	All field-search gave an unmanageable number of hits	2 (13)
Oria	Title	All field-search gave an unmanageable number of hits	36 (70)
ScienceDirect	Title, keywords and abstract	Search results could be examined manually	50 (65)

2.4 Sorting of articles

The search-process produced a large number of hits in total, creating the need for an extensive screening. The screening process worked as follows: first, articles with obviously irrelevant titles were excluded. Second, if the title seemed relevant, abstract was examined. Third, if abstract seemed relevant as well, a throughout examination of the article was conducted. The screening was conducted primarily by the main author, but articles that were not irrelevant according to the inclusion criteria's set was discussed in weekly meetings between all of the authors.

2.5 Charting and reporting the results

All articles accepted through the screening process were retained for analysis. This step included "charting" of data, described as "a technique for synthesizing and interpreting qualitative data by sifting, charting and sorting material according to key issue and themes" [9]. As for analyzing the articles, a database was created using spreadsheets. The database collected the article's title, author, keywords, year of publication, study location, purpose, methodology, and highlights from the study. The articles were then categorized, as illustrated in [11]. It must be noted that some of the categories are overlapping. Some articles not included in this study, mentions energy use, without being the primary focus. As for reporting the results, the final sample consisting of 68 articles were divided into nine sub-categories; general aspects, electricity consumption, heat demand, cooling, heating and cooling demand, building envelope, passive adaptation measures, retrofit measures and costs. There is significant overlap between several categories; for instance, heating and cooling loads will be impacted by energy adaptation measures. It was also noted whether each article primarily concerns climate change impact, measures, or both.

The synthesis includes a qualitative analysis of the final sample. The qualitative analysis is primarily descriptive meaning that the results are described according to each category in the results section, mainly focusing on presenting the research purpose of each article. The discussion provides a synthesis of what is known about climate implication and adaptation measures for energy use in buildings and the current knowledge gap in the research.

3. Results

3.1 General overview of the material

Given the magnitude of data obtained, this chapter only reports briefly on each article. Furthermore, the results are organized around the nine sub-categories as described in the methodology. The material includes articles from 26 countries (first author affiliation), spread across all inhabited continents. The studied articles are sorted by categories and impact/measure in figure 3.

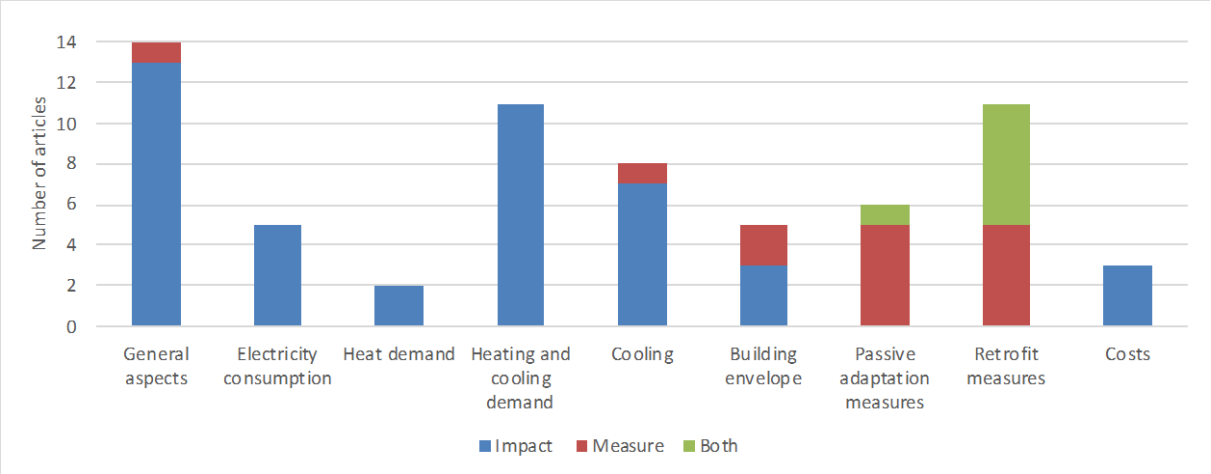


Figure 3. Number of articles sorted by categories and impact/measure.

3.2 General aspects

Variations in energy demand and consumption due to climate change and different impact factors, are investigated by several authors. Zhou et. al [12] investigate the impact of climate change on energy use in the US, using a sensitivity analysis. The results indicate that the impact varies greatly between states and between different energy carriers (i.e. electricity, oil and gas). Similar results are found in a different sensitivity analysis by Huang and Gurney [13], who also evaluate methods for estimating future energy consumption. The same authors [14] quantify how the relationship between climate change and building energy consumption varies across a range of building types in 925 U.S. locations. Changes in annual energy consumption range from −17% to +21%. Even within climate zones, changes in building energy consumption show strong variation. A similar study in the US was done by Dirks et. al [15], who simulated the impact of climate change on peak energy loads as well as annual energy consumption in buildings. It is found that peak demand can increase significantly faster than annual demand.

Shen [16] investigate how building energy use patterns in the US would change in response to climate change in the years of 2040-2069, using case studies in four cities. Future building performance regulations and codes are drafted. The change in annual energy use is predicted to range from −1.64% to 14.07% for residential buildings and from −3.27% to −0.12% for office buildings. Similar work was carried out by Kikumoto et. al [17], who constructed prototype future (2030s) weather data for locations in Japan. Building thermal loads were also simulated using these data, finding a predicted increase in sensible heat load of 15% for a house in Tokyo.

To address climate change issues, Cox et. al [18] investigate if a weather file constructed from a coarse (annual) estimate of future air temperature change can provide useful estimates of future energy demand of a building, if high-resolution data is not available. Future weather files are constructed based on annual, monthly and hourly temperature change estimates. The constructed weather files are found to give similar energy demand as high temporal resolution files. In a literature review, Fazeli et. al [19] analyze models of residential energy demand in response to temperature changes. The potential of the models to evaluate the adaptation responses is discussed. This study can be seen in relation with Pyrgou et. al [20] who compares typical weather files with locally collected weather data for a city in central Italy. Through analysis, a discrepancy between the data sets is identified. This may cause inaccuracies in building energy consumption estimates.

Downscaled future hourly weather data from the Global Climate Models (GCM) is used by Shen and Lior [21] to predict future performance of renewable energy systems for residential zero energy buildings in the U.S. The analysis shows that present systems in half the climate zones will not achieve net zero energy use.

Dodoo and Gustavsson [22] explore to what extent different climate scenarios influence overheating risk, energy use and peak loads for space conditioning of district heated multi-storey buildings in

Sweden. The thermal performance of the buildings changed notably under future climate scenarios, depending on the buildings' energy efficiency level.
A literature review is provided by Jenkins et. al [23], where some of the risks associated with energy use in buildings are discussed in the face of climate change. As climate change will affect the performance of energy systems, as well as building energy demand, it is proposed that climate change is taken into account during the energy assessment of buildings.
The thermal and energy performance of social housing projects in Brazil are investigated in Triana et. al [24], considering climate change. Energy efficiency measures for adaptation to climate change are also assessed.
Guan [25], on the other hand, investigates the influence of internal load densities on energy and thermal performance of office buildings in Australia. It is found through building simulation that reducing internal load densities has a high impact on the energy use of the building, and it is suggested that this could be an effective adaptation strategy in the face of climate change. Also in light of climate change, the impact of urban location on energy use of office buildings in Vienna is studied by Berger et. al [26]. It is shown that buildings in central urban areas yield lowest energy demand because of the urban heat island effect. Despite the lower need for heating, older buildings will still have a high energy demand, and may require cooling devices to remain habitable under certain future climate scenarios. Modern buildings are more robust in the face of climate change. A similar study was carried out by Wang and Chen [27], who found that the effect in energy use depends significantly on geographical location and building type. Natural ventilation availability will be reduced in some cities.

3.3 Electricity consumption

Analysis to relate the electricity consumption with outdoor climate during a 12-year period (2005–2016) is performed by Li [28]. Results show that electricity consumption may increase as much as 47% under the worst climate change scenario. The consumption increase is supported by Santamouris et. al [29], who compared existing studies on the impact of ambient temperature increase on electricity consumption. It was shown that the change in electricity demand per degree of temperature increase varies between 0.5% and 8.5%. In this case a more specific study by Braun et. al [30] is of interest. They investigated possible changes in gas and electricity consumption in supermarkets throughout Great Britain for the 2030s. Changes in temperature are expected to lead to a 2% increase in average electricity consumption and an average drop in the gas usage of 10%. Similar conclusions were shown in a 2014 article by the same authors [31]. A consequence of the increased electricity need is shown by Tarroja et. al [32], who indicate that up to a 31.6% increase in future grid capacity is needed, as heating electrification loads not align with future grid renewable generation.

3.4 Heat demand

The main scope of Andrić et. al [33] is to present a methodology to assess the possible long-term effects of climate change on building heat demand on a large scale. Through building simulation, it was discovered that heat demand density could decrease 22.3-52.4% in 2050. In another study performed by the same authors [34], reduction in heating hours was found to be insignificant in cold climates, while heating hours rate was substantial in warmer climates considered.

3.5 Cooling

A relational study of correlating cooling energy use with local weather station and apartment price in Seoul is presented by Yi and Peng [35], using simple bivariate regression models. The largest predicted increase rate is 96.1% in one city district (year 2047). The result may be seen in line with Li et. al [36] who investigated the climate change impact on cooling energy consumption of office buildings in China. Their building simulations show that cooling energy consumption is affected by different climate factors in different climate conditions but did not rise with rising temperatures in hot climate conditions. It is noted that humidity effect rather than single temperature effect should be fully considered to improve building energy efficiency, and humidity change should be used to predict future energy cooling consumption. Another impact study on office building is given by Yau and Peng [37] who studied the effect of weather variation on air conditioning in a building located in Malaysia.

The overall results show that every 1 °C causes the COP and the total cooling capacity to be lowered by 2%. Impact on residential buildings is given by Hwang et. al [38] who investigates the impact of climate change on current and future residential cooling energy use in central Taiwan, as influenced by the urban heat island (UHI) effect. Further, Arima et. al [39] assess the impact of climate change on energy consumption of a two-story detached house in Tokyo. A bias of the weather data was corrected using the statistical values of observations. The sensible heat load for the house was predicted to increase by 26% and latent heat load increased by 10%. These studies are of interest in the context of the building thermal simulation carried out by Zoras et. al [40]. They estimated the impact of outdoor bioclimatic measures on cooling demand during a summer day over a large city area. The main result of their study was the capability to synchronously evaluate building energy performance due to exterior micro- climate improvement for about 200 buildings.
Another example by Oliveira Panão [41] discusses benchmarks for cooling energy requirements for residential buildings in 30 regions in Portugal. Benchmarks for annual cooling energy needs from 5.5 to 37.6 kWh/m^2 are recommended. Finally, Santamouris [42] discusses a framework which defines the present and future cooling energy consumption of the building sector. The global cooling consumption of the residential sector is expected to increase up to 34% in 2050 and 61% in 2100.

3.6 Heating and cooling demand
Heating and cooling demand has been investigated by several authors and in many different locations in the world. The energy consumption of a university school campus for three typical future years (2039, 2069, 2099) is modeled by Mauree et. al [43]. Simulations predict, there will be a constant decrease in the heating demand in the future, while the cooling demand will increase substantially. This trend was also noted by Kalvelage et. al [44], who pointed out that peak heating load will decrease and the peak cooling load increase. Chen et. al [45] came to the same conclusions after similar investigations on Chinese cities. Similar results were also suggested by Orehounig et. al [46], who used weather data from expected climate change scenarios in Vienna, to evaluate different building design.
Spandagos and Ng [47] used a model building in Hong Kong, Seoul and Tokyo for energy simulations. The study shows an expected increase in energy usage for heating and cooling over the next few decades, even with future stabilization and reduction of GHG emissions (RCP-4.5). An increase in annual energy demand was also proved by Invidata and Ghisi [48], who investigated the impact of climate change on thermal comfort conditions and on heating and cooling energy demand in dwellings in three cities in Brazil. These studies are supported by a literature review performed by Santamouris [49], concerning the impact of the urban heat island effect and global warming on building energy demand. In the period 1970-2010, the average increase of the cooling demand is found to be 23% and the corresponding average reduction of heating demand is 19%. For typical buildings, the average energy consumption for heating and cooling purposes increased by 11% for the same period.
In colder climates, reduction in heating energy demand may be more substantial than the increased need for cooling. Jylhä et. al [50] assessed the energy demand of a typical detached house in Finland under observed recent and anticipated future climatic conditions. It is expected that the increased demand for cooling will be compensated by the high decrease in heating demand, and the net annual energy demand will therefore be reduced. Possible reduction of energy consumption was also found by Shibuya and Croxford [51]. They analyzed the impact of climate change on cooling and heating loads in office buildings in three sites in Japan, and over three periods (1981–2000, 2031–2050, and 2081–2100). Similar results were found by Damm et. al [52], who simulated changes in the heating and cooling electricity demand for 26 European countries, based on +2°C global warming. Electricity demand is found to decrease in most European countries, with the highest relative decrease found in Scandinavia. Similar trends were noted by Berger et. Al [53] who applied data from future climate scenarios in a simulation of office buildings in Vienna, Austria. Older office buildings are found to require less heating, which will slightly counteract the considerable increased need for cooling. Modern buildings, on the other hand, were found to have a higher cooling demand today which will increase further in the future, resulting in a higher net energy demand.

3.7 Building envelope

The influence of façade surfaces on the energy balance in buildings and thermal conditions in urban environments is investigated by Alonso et. al [54]. The findings suggest that the impact of the surface finish is significant. Similarly, Fontanini et. al [55] investigate how different attic forms are impacted by current and predicted future climates in multiple locations across the U.S. Relative changes in cooling, heating, and overall thermal loads are calculated for future climate scenarios. Further, Karimpour et. al [56] analyses both the external wall and roof construction on a case building in Adelaide, Australia. Climate change was found to shift the buildings energy demand from heating to cooling dominated by 2070.

Rubio-Bellido et. al [57] evaluates the impact of different elements of building design on energy demand in office buildings in Chile, under a projected climate change scenario. Energy demand is found to increase in all the 9 investigated climate zones in Chile. Further, Sajjadian et. al [58] presents a method to assess the effect of phase change materials (PCMs) on thermal comfort and energy consumption in UK dwellings in summer months. PCMs are found to be beneficial in current times and in the future, as the impact of climate change on thermal comfort and cooling loads are considerable in the UK.

3.8 Passive adaptation measures

A literature review by Ascione et. al [59] is focusing on renewable technologies for the passive cooling of buildings. Passive adaptation measures that reduce the cooling need and improve thermal comfort during summer include greenery of facades and roofs, phase change materials, solar screens, cool colors, thermal mass, evaporative cooling and natural ventilation. Fahmy et. al [60] explored the use of greenery as a climate change adaptation measure in urban areas in Egypt. Simulations show that the greenery improved the energy efficiency of buildings by as much as 23.8% in 2080, compared to a street without greenery. Another study, Van Hoof et. al [61] analyses the effect of passive climate adaptation measures on the cooling and heating energy demand of a terraced house, under a future climate change scenario. External solar shading and natural ventilation show the best performance in limiting the required cooling energy.

An adaptive comfort model was used in Huang and Hwang [62] to identify the air-conditioning operation status of a residential building to determine cooling energy use, in the past and the 2020s, 2050s, and 2080s. The cooling energy demand was found to increase by 31%, 59%, and 82% respectively. Five passive design strategies for reducing cooling energy demand are discussed.

Pierangioli et. al [63] focuses on the effectiveness of passive adaptation measures in central Italy in the medium (2036–2065) and long term (2066–2095). In the medium term, the reduction of energy needed for heating could be bigger than the increase for cooling in case of poorly insulated buildings. This results in a total annual net energy need decrease; however, in the long term the opposite happens.

Mitigation and adaptation strategies for sample office buildings in Vienna are simulated by Berger et. al [64], applying weather data from future climate scenarios. Internal heat gains are found to influence cooling demand more than climate change. Reduced internal heat gains and additional external insulation minimize cooling and heating demand. It is shown that winter savings due to external insulation will continue to outweigh increased cooling demand even in the future.

3.9 Retrofit measures

The energy performance for residential buildings in Stockholm from 1961-2100 for five climate scenarios is simulated by Nik et. al [65]. A method to assess and quantify the relative robustness of retrofitting measures on long term is presented, taking into account climate variations in different time scales, extreme conditions and uncertainties of climate change. Interesting in this context is also Cao et. al [66] who offers an overview of building energy-consumption situations, relevant energy-saving approaches, and the influence of global climate change. Improvements on building envelope and ventilation are found to play an essential role in reducing space heating and cooling consumption levels. They also provide some suggestions for further developing Zero Energy, while Pagliano et. al [67] discuss a retrofit of a building in Milan (Italy) on the basis of future weather scenarios. The analysis suggests that climate change might require the installation of active cooling systems to

compensate for harsher summer conditions in the long term. However, in the mid-term, passive cooling strategies may still guarantee thermal comfort. Strategies for reducing HVAC demand in US cities presented in Wang et. al [68] builds up on this statement.
Further aspects such as energy poverty and decision making were considered by Flippín et. al [69] who propose retrofit strategies for adapting to a climate change scenario in Argentina. The strategies might be seen in context with the model called CESAR (Combined Energy Simulation And Retrofitting) [70]. This model is used to generate future demand and emission projections of districts, including key economic indicators. Building energy performance under climate change projections is also evaluated by [70], while Waddicor et. al [71] investigate the impact of predicted climate change and building ageing on the energy performance of a library in Turin, Italy. The two phenomena are found to greatly influence the energy demand of the building. Mitigation measures against climate change are assessed.
Energy retrofitting measures for residential buildings in Sweden for five scenarios of future climatic conditions are compared by Nik et. al [72]. Nine energy retrofit measures are compared, as well as four combinations of these. Tuning the indoor set-point temperature to 20 °C can contribute to significant energy savings. A combination of improved thermal insulation of the building envelope with energy efficient windows is found to be the most effective and robust retrofitting measure. However, this seems to be of less importance in Australia. Here Daly et. al [73] have simulated the possible impact of climate change on the energy consumption of an office building in five Australian cities. The impact of climate change is compared to other possible changes to building energy consumption. For the Australian case, climate change is found to be relatively unimportant in selection of optimal retrofit strategies. Pérez-Andreu et. al [74] model a range of passive and active energy improvement measures applied to a typical Mediterranean residential building under various climate-change scenarios. Temperatures are projected under two Global Circulation Models for 2050 and 2100. Heating energy demand decreases significantly and cooling energy demand increases. It is shown that total energy demand is the most affected by thermal insulation and infiltration.

3.10 Costs

Potential future implications of climate change on building energy expenditures around the globe is explored by Clarke et. al [75]. Net expenditures decrease in some regions where heating demands currently dominate. Net expenditures increase the most in areas with higher need for space cooling. Similarly, based on the impacts of climate change on U.S. building energy consumption, Huang and Gurney [76] quantify the financial implications to consumers and suppliers. For the U.S. as a whole, building energy costs decrease by ~7 billion $/year in the residential sector, while costs increase by ~2.2 billion $/year in the commercial sector. For cold-weather states, residential energy savings are expected, while warmer states see increased residential energy costs. The latest is supported by Zachariadis and Hadjinicolaou [77] who assess the cost of additional electricity requirements because of projected climate change in Cyprus by the mid-21st century. Annual electricity demand is projected to rise by 6% by 2050. Additionally, welfare losses of more than 150 million Euros (at 2010 prices) are expected per year.

4. Discussion

In this paper, we set out to address the following research questions: What is known from existing literature about climate implication and adaptation measures for energy use in buildings, and what are the most important gaps in the research? Just from the past five years, there is a substantial body of literature on climate adaptation measures for energy use in buildings. As this scoping review indicates, the literature covers a wide array of topics. To provide clarity, the results are discussed according to the following nine sub-categories: building envelope, cooling, costs, heat demand, heating and cooling demand, passive adaptation measures, retrofit measures, and “others”.
A general theme noted in a majority of the articles is that climate change will manifest in the form of higher temperatures, which will reduce the energy demand for heating and increase the demand for cooling. In warmer climates the overall energy demand for heating and cooling will increase, while it will decrease in colder climates. Highly insulated buildings may experience substantially higher

cooling loads to prevent overheating. Poorly insulated buildings may benefit comparably more from reduced heating demand. However, they will also require more cooling in high temperatures. Peak loads will be affected more than annual consumption.
Adaptation measures can be active or passive. Active measures include more efficient use of heating, ventilation and air-condition (HVAC)- systems, as well as active solar shading. Passive measures include building insulation, greenery of facades and roofs, phase change materials, solar screens, cool colors, thermal mass, evaporative cooling and natural ventilation. Many articles emphasize that use of measures may compensate for increased energy demands from climate change, and even lower energy usage in individual buildings compared to the current practice.
There are notably fewer articles about adaptation measures than the impact of climate change. Few studies examine building energy use in cold climates, although this might be because warming climate will be a more serious challenge in warmer regions. As building designs in colder regions are dominated by the need for heating, a changing climate may have a significant impact on construction practices. For instance, the implications of a reduction of freezing index, including impact on slab-on-ground insulation have not been addressed in the studied literature, Lower demand for heating may lead to a loosening of the stringent insulation requirements in the Norwegian building code.

5. Conclusions

This scoping literature review was first step by the authors toward exploring what is known about climate implication and adaptation measures for energy use in buildings. In sum, it is shown that impact of climate change in energy use in buildings has been thoroughly studied for climate regions all over the globe. The material includes articles from 26 countries, spread across all inhabited continents. However, there is a certain lack of material concerning the implication of climate change and relevant adaptation measures in cold climates. Climate change is expected to manifest in the form of higher temperatures, which will increase cooling demand and reduce heating demand. This has been a focus in the majority of the examined literature.
Further work on the subject will examine the implications of climate change in other fields than energy use, as well as different forms of climate change adaptation measures. Research is required on wider effects of climate change on buildings, including resilience, design guidelines, impacts of extreme weather events and more.

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