

Review

A Systematic Review of Climate Change Implications on Building Energy Consumption: Impacts and Adaptation Measures in Hot Urban Desert Climates

Najeeba Abdulla Kutty, Dua Barakat, Abeer Othman Darsaleh and Young Ki Kim *

Department of Architectural Engineering, United Arab Emirates University, Al Ain 15551, United Arab Emirates; 202090186@uaeu.ac.ae (N.A.K.); 202190024@uaeu.ac.ae (D.B.); 201870084@uaeu.ac.ae (A.O.D.)

* Correspondence: youngki.kim@uaeu.ac.ae

Abstract: The climate change–built environment nexus is complex and intertwined. Recognizing the rising air temperatures and solar radiations owing to climate-induced global warming, it is critical to manage the increased building energy and cooling loads in the Middle East Gulf states’ hot desert climates (Bwh). One of the top climate priorities is to promote climate resilience by reducing risks and enhancing adaptation options. This study aims to systematically review the existing literature to document building energy performances in and the associated adaptation measures of the Middle East Gulf states, regarding the implications of climate change. It is accomplished by answering the following questions: ‘How well do we understand the effects of climate change on building energy use in hot urban deserts?’ and ‘What are the most appropriate adaptation strategies to reduce energy use in hot urban deserts?’. Using the Preferred Reporting Items for Systematic review and Meta-Analysis protocols (PRISMA), 17 studies on the influence of present and future weather scenarios on building performance are examined, considering variations in typology, methods, and input variables. Finally, the paper identifies the preferred methods and input variables for modelling building energy performance under predicted climatic changes. Passive design considerations are considered highly effective in mitigating and adapting to climate change implications. Thermal insulation and efficient window glazing are identified as the best-performing strategies, while the use of solar Photovoltaic (PV) is considered efficient in meeting the primary energy demands. The study’s findings can assist planners and designers in projecting future climatic influences on the energy usage of existing buildings.

Keywords: climate change; energy consumption; hot urban desert climate; adaptation measures; Middle East Gulf states; UAE



Citation: Kutty, N.A.; Barakat, D.; Darsaleh, A.O.; Kim, Y.K. A Systematic Review of Climate Change Implications on Building Energy Consumption: Impacts and Adaptation Measures in Hot Urban Desert Climates. *Buildings* **2024**, *14*, 13. <https://doi.org/10.3390/buildings14010013>

Academic Editors: Szu-Cheng Chien, Aung Myat and Tzen-Ying Ling

Received: 8 November 2023

Revised: 9 December 2023

Accepted: 14 December 2023

Published: 20 December 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The potential risks that climate change and global warming pose to people and ecosystems have garnered increasing attention throughout the last several decades. The increased atmosphere temperatures, the subsequent ocean warming and extensive melting of the polar caps, and the resulting rise in sea and ocean levels verify the implications of climate change [1]. One of the most notable implications is extreme outdoor heatwaves caused by increased greenhouse gas (GHG) emissions, which result in a significant increase in building energy demands [2]. Reports suggest that the building and construction sector accounts for about 36% of the final energy use, while accounting for 39% of energy-related GHG emissions [3]. Clearly, the built environment is susceptible to climate change.

The impact of changing climatic conditions on the built environment is rather complex and intertwined. Potential implications on the built environment include impacts on building structures, building construction performance, building materials’ life cycles, and building energy consumption [4]. Characterized by extreme hot climates and fossil fuel dependency, the Middle East Gulf states—Bahrain, Kuwait, Oman, Qatar, Saudi Arabia,

and the United Arab Emirates (UAE)—are more at risk from the implications of climate change on energy consumption [2]. Previous studies show a reciprocal relationship, focusing on the climate change–energy use nexus in the buildings. Under these climates, gradual changes in weather patterns significantly influence the built environment’s energy consumption and associated energy systems [5,6]. Moreover, experimental studies conducted on existing building stock in these regions indicate promising results, with a potential reduction of up to 35% in GHG emissions and energy savings reaching as high as 42% [7]. Consequently, studies show that climate change has extremely important consequences for the construction industry, which has the largest adaptability capacity among other sectors [8].

The implications of climate change on building energy use may be both short-term and long-term. The short-term impacts involve extreme environmental calamities, while the long-term impacts include rising sea levels due to outdoor temperature increases [9]. Considering the UAE’s geographic location on the Middle Eastern Peninsula, the long-term impacts of frequent and long-duration heat waves pose a higher regional risk level [1]. Within the building sector, the outdoor temperature in summer months reach over 40 °C, while the indoor temperatures remain within the range of 18–20 °C in these Gulf states. Accounting for this substantial difference in the indoor thermal comfort and outdoor temperatures, the cooling energy demand occupies a large share of the energy end-uses. Furthermore, studies imply that the cooling system’s energy usage accounts for 80% of the overall energy consumption in buildings [10]. It is worth noting that these states are facing occasional grid burnouts and power outages due to current climatic circumstances, demonstrating their ever-increasing difficulties to satisfy their energy demands throughout the summer months [9]. Within the context of climate change-driven heat waves, the future implications of such events may be more frequent over longer durations. Furthermore, these climate change-driven energy stresses will have environmental, social, and economic impacts [11].

The National Climate Action Plan 2050 predicts an increase in annual mean air temperature from 4.1 to 5.3 °C by 2100 for the UAE, with negligible decreases in the humidity and global solar radiation levels. Indeed, the combined effect of high outdoor temperatures with high solar radiation and humidity levels poses significant challenges in achieving low energy demands. With a shift in the local and global efforts towards low energy or green building credentials in the UAE, Shanks and Nezamifar [12] highlight the ineffectiveness of the existing building stock to purposefully minimize the extreme effects of climate change. When aiming towards sustainable development, along with local climatic changes, it is necessary to evaluate how climate change affects the cooling energy demand in existing building typologies. This will not only help in identifying the adaptation measures needed, but also enhance the building’s resilience toward future climate change and an increased cooling energy demand [13,14]. One of the key climate change action priority objectives includes promoting climate resilience by minimizing the risks and increasing the mitigation and adaptation strategies. Hence, strategies to mitigate and adapt the built environment may be considered as a viable opportunity to address the implications of climate change [15].

The UAE is considered as one of the Gulf states to be exposed to climate change’s consequences; however, it is often treated unjustly in energy-efficient policies [2]. This may be attributed to the fact that the government’s efforts in crafting policies and strategies that promote energy efficiency in the building sector lack strength in their inception phase. Supporting this, the World Economic Forum analysed the risks associated with a persistent increase in the cooling energy demand with an overall growth in energy consumption [16]. As the world struggles to reduce this risk, lessons may be gleaned from the Paris Climate Agreement, which was agreed at the 2015 COP21 in Paris. Signatories are committed to adopting and implementing the ‘national climate action plans’ to meet the global warming target of 1.5 °C while attaining carbon neutrality by 2050. One of the key climate priority objectives includes promoting climate resilience by minimizing the risks and increasing

climate adaptation strategies. For instance, the UAE has committed to meeting the climate and clean energy targets by 2050. These strategies aim at improving the total energy mix by up to 50% while reducing the carbon footprint by 70%, with simultaneous savings of AED 700 billion by 2050 [17]. Further, the climate action policies in the UAE intend to generate 24% of electricity from clean energy sources, thereby reducing its GHG emissions by 23.5% in 2030. Therefore, improving energy efficiency through proper adaptation measures is critical to meeting the problem of energy sustainability. Nonetheless, the climate action tracker classifies the UAE as “highly insufficient” in implementing climate action plans.

Nakicenovic et al. [3] and Guan [18] reviewed the energy implications of climate change on buildings categorized by the diversity in the methodological approaches. Further, detailed discussions by Li et al. [19], and Yassaghi & Hoque [20] debated the performances, responses, and uncertainties with minimal examination of the adaptation strategies or associated policies. Recently, a meta-analysis was presented by Campagna & Fiorito [21] on the energy consumption variations due to the diversity of input variables throughout all continents. In addition to the above reviews, previous studies on this topic reveal that differences in the predicted energy demand or projected future scenarios exist among studies due to variations in the geographic contexts or investigated climate zones [22]. Although these are affected by climate changes, further uncertainties are also observed due to building typologies, methodological approaches, energy model predictions, and input variables that significantly affect energy predictions [23]. Now considering the geographic contexts and climate zones, most of the studies addressed all climate zones. In contrast, certain studies limited their discussion to selected zones based on criteria such as developing countries [6] or specific continents (such as the European Union, and Australia) [18]. Furthermore, these constraints limit the comparison of findings. Hence, to the best of our knowledge, relatively scarce literature can be found examining the climate adaptation strategies associated with mitigating the implications of climate change on energy use in the Middle East Gulf states.

To address this gap, this study meticulously examined the effects of climate change on building energy performance whilst considering alternatives for adaptation in hot urban desert climates. This purpose was attained by addressing the following study questions:

- (1) How well do we understand the effects of climate change on building energy use in hot urban deserts?
- (2) What are the most appropriate adaptation strategies to reduce energy use due to the adverse effects of climate change in hot urban deserts?
- (3) What are the research gaps and challenges informing academia and practice in addressing the impact of climate change on energy demand?

Using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [24] p-review protocol, the study progressed by selecting and systematically reporting existing articles concerning the impact of climate effects on building performance, considering both the current and future weather scenarios. Accordingly, the objectives provided guidance in evaluating and structuring the study to answer the above questions. These include:

- (1) To determine the impacts of climate change on the energy usage of the built environment in the hot urban desert climate, considering predicted energy needs and input variables.
- (2) To assess the efficacy and success variability of the implemented building adaptation solutions for mitigating the effects of climate change on energy.
- (3) To identify possible research gaps and recommend future research initiatives.

The paper is structured as follows: The second section provides an overview of the existing literature on climate change dynamics and global adaptation practices in the energy sector. The third section reports the systematic review protocol covering the literature search and selection steps, screening using inclusion and exclusion criteria, data extraction, synthesis, and reporting. The fourth section discusses the current state-of-the-art knowledge based on the elements extracted from the reviewed studies. Next, the fifth and sixth sections, respectively, summarise the impacts and adaptation strategies adopted in

hot urban deserts. Finally, the study concludes by recapping the main findings and research gaps, along with future work suggestions.

2. Climate Change Dynamics and Energy Consumption in the UAE

2.1. Geography and Climate Zones

The UAE (23.4241° N, 53.8478° E) is in the southwest part of the Asian continent, oriented towards the southeast of the Arabian Peninsula. Represented as a triangular region, UAE borders the Arabian Gulf waters in the north and northwest, with eastern coastline extensions with the Gulf of Oman. Geographically, the region shares land borders with Saudi Arabia along the south and sea borders with the Sultanate of Oman towards the southeast. The UAE's total land surface may be characterized under four main climate zones as identified by M. Sherif et al. [25]: "east coast"; "mountains"; "gravel plain", and "desert foreland".

The hot desert climate characterizes the UAE region as having two seasons: winter and summer [26]. Winter exists between October and March with average temperatures of about 26 °C during the daytime and 15 °C during the nighttime, considered as generally warm and dry. However, cooler weather conditions exist due to the eastern mountains of Al Hajar, where the average temperatures drop to a minimum of 10 °C through 14 °C in January through February. On the other hand, summers stretch from April to September with an average temperature of 48 °C and relative humidity as high as 90% in the coastal cities. The southern desert regions experience even higher temperatures of nearly 50 °C with very low humidity [27,28]. Considering precipitation, rainfall is generally scarce and much of it occurs during the winter months of February through March with an average annual precipitation measure of 140–200 mm per year [29]. During the summer months, very low rain gauge measures are observed along the coasts, while higher rainfall is received in the mountainous and southeastern parts of the country [27]. Sometimes, years pass by without any rainfall [30].

2.2. Potential Effects of Climate Change in the UAE

The UAE currently has a population of 9.5 million people. Approximately 83% of the UAE's population and 90% of its infrastructure are located within a few meters of low-lying coastlines [30]. This rapid expansion in population was followed by an increase in energy use (10,133 KWh per capita, particularly for air conditioning in the summer), resulting in greater GHG emissions (27.14 kt/capita) [31]. In 2011, the UAE was rated 14th among the 21 nations with the highest consumption per capita in the world.

The UAE has been classified as one of the most susceptible countries to climate change, with considerable impact on the country's infrastructure, natural environment, and population health [32]. These effects are massive on energy generation, water, and natural resources, influencing a wide range of development sectors, policies, and the environment. Furthermore, the economic boom and population expansion have resulted in increasing demand for energy generation, thereby contributing to GHG emissions and climate change [33]. Hence, climate change is already having an impact on the UAE's coastal and geographical areas, projected to cause warmer weather, less precipitation, droughts, and rising sea levels.

The UAE is not immune to climate change and high carbon emissions, with predictions of a 2–3 °C increase in temperature and a 10% increase in humidity by 2050 [32]. As a result, energy consumption will rise by 11%, with the electricity necessary to supply this demand equalling the output of 18 solar power plants. Furthermore, the area will face the danger of longer droughts as well as more intense and varied rainfall events, increasing the likelihood of desertification and floods [32] (see Table 1).

Table 1. Climate change and related factors relevant to UAE, source: [32].

Climate Factor	Change	Potential Effects
Temperature	Positive	Increased temperature level by 2–3 °C; increased energy consumption by 11%
Humidity	Positive	Increase humidity level by 10%
Global sea level	Positive	Increased 0.18–0.23 cm per year; inundation and displacement of lowlands; coastal erosion; increased storm flooding and damage; salinization; rising water tables
Seawater temperature	Positive	Increased coral bleaching; increased algal blooms; northerly migration of coastal species
Precipitation intensity	Negative/Positive	Increased risk of extremities of desertification and flooding
Wave climate	Positive	Increased flooding; erosion; decay of groundwater quality
Storm frequency	Positive	Waves storms will reach inland
Atmospheric CO ₂	Positive	Increased productivity in coastal ecosystems

Climate change will cause the sea level to increase by 0.18 to 0.23 cm per year, endangering coastal regions in all the emirates, particularly those located one kilometre or less from the coast, where more than 17,000 people live [33]. Furthermore, Dubai and Ajman will be the most vulnerable emirates due to rising sea levels; it is projected that 75% of Ajman's and 36% of Dubai's coastline regions will be highly exposed areas due to their economies' reliance on coastal developments [33]. This rise in sea level will cause more tides, waves, and storms to hit land, increasing the risk of floods, erosion, and groundwater quality degradation.

Due to its proximity to the Arabian Gulf and the Gulf of Oman, the UAE is also subject to increased seawater temperatures, by which the seawater absorbs most of the excess heat from greenhouse gas emissions, leading to rising seawater temperatures [27]. As a result, marine species and ecosystems suffer, resulting in greater coral bleaching, algal blooms, and species migration [30].

3. Methodology: A Systematic Review Protocol

Using the PRISMA-p protocol [34], this study systematically collected, synthesized, and reported both quantitative and qualitative data from the preliminary studies executed using a four-step process proposed by Xiao & Watson: (1) Literature search and study selection; (2) Screening—Inclusion and exclusion criteria; (3) Data extraction and synthesis; and (4) Data reporting (Figure 1).

3.1. Literature Search and Study Sample Selection

The quality of a review is highly dependent on the literature and its associated search procedure. The initial step of the search process aimed to generate a list of primary studies believed to be relevant in answering the research question(s). The electronic databases of Elsevier's Scopus served as the channel to locate the relevant peer-reviewed publications. Filters were applied to the publication and source type (such as journal articles and conference proceedings), while the search was restricted to the date of publication (from 2015 to March 2022).

An in-depth sampling strategy using a combination of query strings with possible keywords in the titles and abstracts of indexed articles was used to summarize the studies. A specific combination of keywords highlighting the study fields proved responsive enough to extract relevant primary studies: ("Climate change" OR "Energy consumption" OR "Hot climate" AND "Middle East" OR "UAE"). Towards the end, the resultant search yielded 95 articles for this initial identification phase (Figure 1).

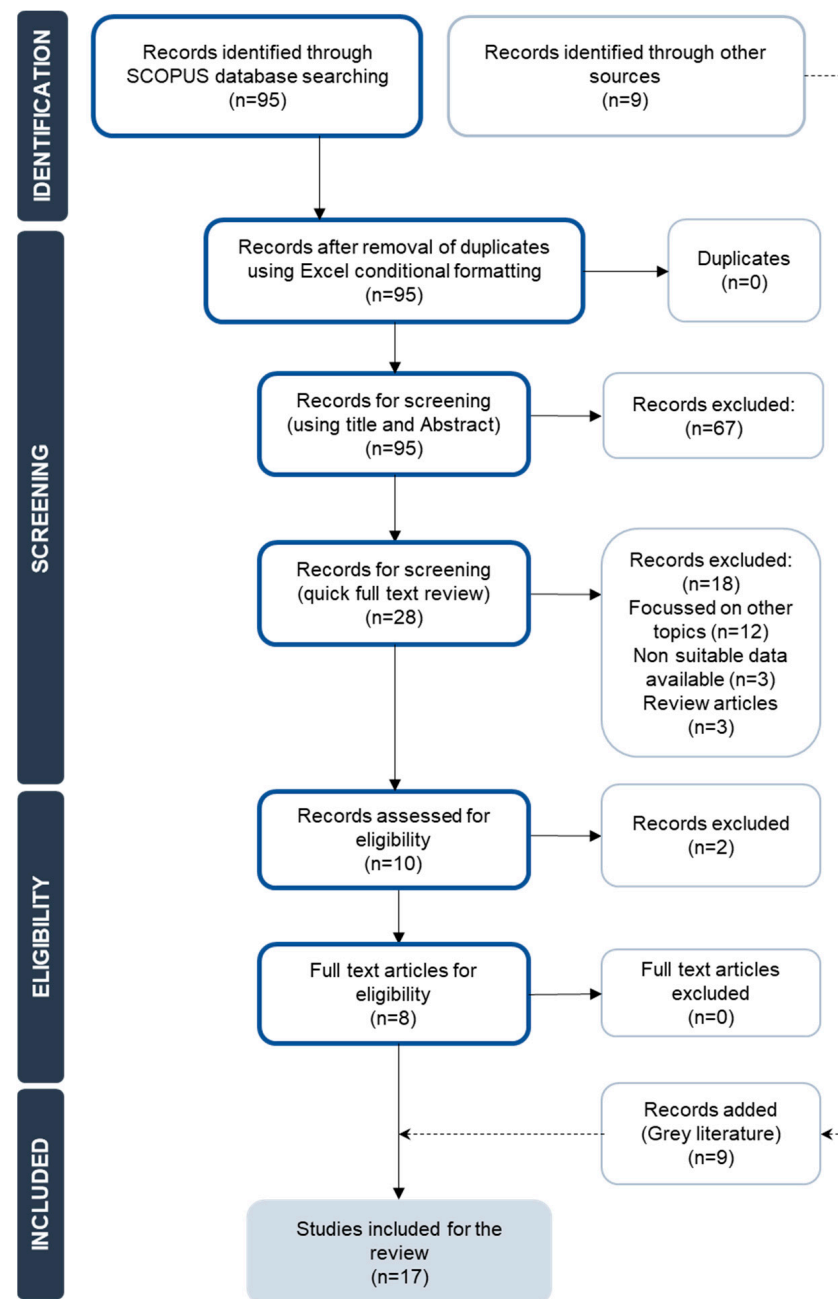


Figure 1. PRISMA-p flowchart showing the process of literature search and screening.

3.2. Screening—Inclusion and Exclusion Criteria

The sample dataset ($n = 95$) obtained was then screened for duplicates using an automated command in Microsoft Excel 2019 (Conditional Formatting > Highlight Cells Rules > Duplicate Values). The compiled list of references was then screened based on a two-stage procedure to exclude the articles not related to the research question(s) or the established criteria in the absence of duplicates. The first stage included articles based on the review of both the title and abstract through a coarse sieve. The above step excluded documents that did not meet the general eligibility criteria of (1) informing or investigating climate change's impact on energy consumption and (2) experimental studies on the effectiveness of mitigation/adaptation strategies. After excluding 67 documents, the second stage excluded 18 more documents by skimming through the full text (without in-depth understanding). The following exclusion criteria were used to arrive at ten eligible documents for this study.

- (1) Focussed on other topics ($n = 12$);
- (2) Non-suitable data available ($n = 3$);
- (3) Review articles ($n = 3$).

Further, while assessing the full-text articles, those studies not relevant ($n = 2$) were excluded to arrive at the full-text articles eligible for the study ($n = 8$). Finally, studies relevant to the research questions were found from the other sources and added as grey literature, including technical reports and peer-reviewed articles ($n = 9$) based on the previous inclusion criteria. Hence, based on the eligibility screening, 17 eligible documents were identified for this review.

3.3. Data Extraction and Synthesis Strategies

In addition to the proper selection of the studies, the extraction of data relevant to the research questions is a crucial point informing the current state of knowledge and discussion of findings. The authors carried out further manual data extraction from the selected documents and this was further verified by another author.

Based on the framework synthesis method [35,36], a tool for extracting, reporting, and discussing the climate change energy impact and the required mitigation/adaptation measures was proposed based on the four main steps adopted in existing experimental studies. These steps include identifying the context through building stock profiling, predicting future weather data through climate change modelling, building energy performance through dynamic simulation modelling, comparing the reference time period with future time slices, data interpretation methods, and implementing mitigation/adaptation strategies. Accordingly, the review documents are categorized to inform the following variables (see Table 2).

Table 2. The review documents' categories and information and contexts.

Categorized Variables	Information and Contexts
(1) Geographical context	- The reference city within the studies' Middle East Gulf states
(2) Building typologies	- The function type of the building
(3) Climate zone	- The hot desert urban climate (Bwh) from the Koppen Geiger classification system, along with hot arid or hot humid distinction
(4) Targeted study outcome	- The study's primary effects of climate change on energy use (cooling/energy demand)
(5) Future climate weather file	- The predicted weather data file used for future climate simulations
(6) Emission scenarios	- The type of pathway used for the prediction of future climate conditions (Representation concentration pathways (RCPs), IPCC Emission scenarios (A1, A2, B1 and B2))
(7) Downscaling technique	- The method employed to generate the future weather file types
(8) Reference time period	- The weather file depicting the current climatic conditions to be modified for future weather data file type
(9) Energy simulation models	- The tool used to generate the 3D energy building model
(10) Data interpretation technique	- Percentage variations in the current condition's cooling and total energy consumption from the considered future scenarios
(11) Passive adaptation measure	- The measures and actions implemented in the studies to improve climate change adaptation without technological interventions
(12) Active adaptation measure	- The measures and actions implemented in the studies to improve climate change adaptation without technological interventions
(13) Renewable Energy (RE) potential consideration	- The measures and actions implemented in the studies to improve climate change adaptation with the implementation of renewable energy technologies (such as Photovoltaics (PV) on roofs, Building-integrated photovoltaics (BIPV), wind towers)

3.4. Data Reporting Strategies

The results are discussed based on two main debates addressed in the selected documents. These include the (1) impacts of climate change on building energy performance and environmental implications (variations in the cooling/total energy performance, thermal performance); and (2) effectiveness of the mitigation and adaptation strategies for energy-efficient buildings (active, passive, and RE potential considerations). Due to the diversity in comprehending the absolute effects of climate change–energy usage implications, the authors attempt to qualitatively present the results across the review studies.

4. Data Extraction Results

As inferred from the 17 reviewed studies, the relation between climate change and building performance in the hot urban desert climates (Bwh) addresses five main targets (Appendix A):

- (1) Impact of climate change on building energy consumption;
- (2) Effective adaptation and mitigation design considerations for buildings against climate change effects (passive, active, and renewable energy systems) [9,13,37–46];
- (3) Building retrofitting and renovation strategies to adapt to climate change [46,47];
- (4) Robustness of the methods-uncertainty of the future climate projection models and variations in building performance predictions [37,38];
- (5) Environmental, economic, or social implications of climate change on the building performance [9,42–44,46,48–50].

Using a synergy between five methodological frameworks, the impact of climate change implications on building energy consumption is assessed in all the reviewed studies [9]. Once the study context and building typology are identified, then the five approaches are executed, including the prediction of future weather files through regional climate change modelling techniques, building energy and thermal modelling, impact assessment and interpretation of meteorological and energy use relationships, selection of mitigation and adaptation strategies, and implementation. These frameworks include predicting the future weather files based on an emission scenario, downscaling technique, study period, weather file types, and global climate models (GCMs). The successive steps involve the prediction of space conditioning and total energy consumption using dynamic building simulations and their appropriate validations. Some of the studies address both the thermal performance and potential mitigation or adaptation strategies towards cooling and total energy use reduction in the future time slices. Each series of steps comes with uncertainties, thus making it necessary to evaluate each step in quantifying the interactions between the built environment and external climate. Accordingly, the data extraction shows the current state of knowledge on the impact of climate change on building energy consumption through three sections: building stock profiling trends; methodology phases and input variables; and mitigation and adaptation measures implementation.

4.1. Building Stock Profiling Trends

4.1.1. Geographical Context

According to Köppen, climates are divided into five groups based on seasonal precipitation patterns and temperature patterns. The five main groups are A (tropical), B (dry), C (temperate), D (continental), and E (polar). All the investigations in this study are based on the hot urban desert climate (Bwh) along the coastal plains of the Persian Gulf between 30 N and 31 N, encompassing G08, G09, and G10 [51].

Despite their differences in geographic context, all the selected papers in this review deal with the same climate zone (Bwh) (see Figure 2). Figure 3 illustrates the geographic distribution of the studies covered in this paper. Most of the studies are in Qatar (29%) and Iran (29%), while a fair share is observed in the UAE (18%), KSA (12%), Bahrain (6%), and Egypt (6%).



Figure 2. Bwh climate zone in the Köppen–Geiger climate classification map. Source [52].



Figure 3. Overview of the building typologies and geographic context of the study selections.

4.1.2. Building Typology

Although building typology has a major impact on heating and cooling energy consumption [1], most studies base their forecasts on only one or two building types. Two of the seventeen studies analysed are reviews of a specific building typology. It is worth mentioning that residential structures receive the most attention, accounting for 67% of the studies, followed by commercial typology, which receives 17% of the attention. The least attention is directed towards other building typologies, namely offices (11%) and educational institutions (5%), as shown in Figure 3.

4.2. Methodology Phases and Input Variables

4.2.1. Climate Change Modelling

Despite the five-step technique, the prediction of future climate forecasts is crucial in evaluating building energy and thermal performance, and the accuracy of the climate projections enhances the chance of a more robust method [9]. As highlighted by Nik [14], this synergy process is inclusive of the following parameters: forecasting tool/software, reference input file and output simulation file data types, downscaling techniques, emission scenarios, reference, and future time slices. The framework consists of global climate models (GCMs) containing the atmospheric, ocean and land surface data for generating the future climates based on boundary conditions, assumptions, and constraints. Due to the building performance assessments, the resolution of the GCMs (range 100–300 km²) is made suitable for a smaller scale by being converted to the regional climate models (RCMs). Weather data for a specific location are projected using a downscaling technique using validated tools such as the CCWorldWeatherGen, Météonorm 7, or MAG-ICC through the input of reference data (.epw) and output simulation files for the IPCC

scenarios from the HadCM3 Atmosphere-Ocean Global Circulation Models (AOGCMs). Finally, the .epw file serves as the input for building energy simulation (BES). The climate change modelling input variables, parameters, and the frequency of usage in the reviewed papers is tabulated in Table 3.

Table 3. Overview of the climate change data modelling input variables, parameters, and choice frequency.

No.	Input Variable	Parameters	Frequency (No. and %)	
1	Emission scenarios	IPCC SRES A2 scenario	10	67%
		IPCC SRES A1B scenario	2	13%
		IPCC SRES A1F1 scenario	1	7%
		IPCC SRES B1 scenario	1	7%
		Other scenarios (P50—av. of SRES)	2	13%
		NA	2 (out of 15)	
2	Downscaling technique	Stochastic method	2	20%
		Imposed offset method	3	30%
		Recorded data	2	20%
		Dynamical	4	40%
		NA	7 (out of 10)	
3	Future climate weather file generators	CCWorldWeatherGen	9	56%
		Meteonorm 7	6	38%
		MAGICC	1	6%
		NA	1 (out of 16)	
4	Weather Data type (reference period)	IWEC TMY	9	53%
		IWEC TMY2	3	18%
		Monthly measured weather data	3	18%
		SCENGEN	1	6%
		US DOE	1	6%
5	Reference time period	1961–1990 (<1992)	6	35%
		1992–2005 (>1992)	2	12%
		2005–2019 (<2019)	7	41%
		2020	1	6%
6	Future time period	2020 (–25)	9	56%
		2050	10	63%
		2080 (–75)	12	75%
		2100	2	13%
		NA	1 (out of 16)	

Abbreviations: IPCC SRES: International Panel on Climate Change Special Report on Emissions Scenarios; NA: Not available; IWEC TMY: International Weather for Energy Calculation Typical Meteorological Year; US DOE: US Department of Energy.

- Climate change models

Climate scientists use two models to predict future climate; namely, GCM and Regional Climate Models (RCMs). These models represent the simulated physical processes within the atmosphere, land surface, oceans, and the cryosphere [53]. For building simulations, an RCM, typically nested within a GCM, focuses at higher spatial and temporal resolution. Hence, RCM downscale the GCMs. Referred to as Couple Modelled Intercomparison Projects (CMIP), a standardised set of forcing scenarios is used. These forcing scenarios include either one of the scenarios: International Panel on Climate Change Special Report on Emissions Scenarios (IPCC SRES), Representative Concentration Pathways (RCPs) [1] or the Shared Socioeconomic Pathway (SSPs) [54].

- Emission scenarios

The IPCC outlines four different narratives to be used as storylines for the GCMs. The scenarios are divided into four families, each exploring a combination of demographic change, social and economic development, and overall technological developments, corresponding to the four families (A1, A2, B1, B2), each with an illustrative “marker” sce-

nario [55]. The first scenario is the A1 scenario describing a future world with rapid economic growth, a global population that peaks mid-century and decreases after that, and the quick introduction of new and more efficient technologies. Under this scenario, there are three groups. The three A1 groups are recognized by the technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B). Balanced is defined as not relying too heavily on one energy source, assuming that similar improvement rates apply to all energy supply and end-use technologies. On the other hand, the A2 scenario describes a very heterogeneous world. The underlying theme is self-reliance and the preservation of local identities. Population patterns across regions converge very slowly, increasing the global population. Economic development is primarily regionally oriented.

The B1 scenario depicts a converging world with the same worldwide population as the A1 scenario, but with rapid shifts in financial structures toward a service-based and data-driven economy, with reduced material intensity and the advent of clean and resource-efficient technology. The B2 scenario depicts a society where localized approaches to all dimensions of sustainability are prioritized. It depicts a future with a slower pace of global population growth than A2, intermediate degrees of economic prosperity, and slower and more diversified technical advancement than the B1 and A1 scenarios. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

While the IPCC scenarios were useful at the time, it soon became evident that the SRES were out of date, and a new technique was implemented to update the emission projections [56]. The IPCC agreed in the Fifth Assessment Report (AR5) [57] to offer information on the trajectories of the key forcing agents for the near and distant future. RCP2.6, RCP4.5, RCP6.0, and RCP8.5 were used to do this. The RCPs include geographically detailed data on greenhouse gas concentrations, air pollutants, and land-use change. The linked numbers represent the approximate radiative (W/m^2) change by 2100 in comparison to pre-industrial levels.

Adopted as an input forcing scenario for the RCMs, SRES emission scenarios are used by 87% of the studies (Table 2). None of the studies within the GCC adopted other forcing scenarios such as the RCPs or SSPs. The A2 scenario is employed in 67% of the papers, trailed by the A1B scenario in 13%. Notably, equal importance was directed to the A1F1 and B1 scenarios, each involved in 7% of the studies. Hence, the IPCC-prescribed SRES scenarios are widely used for future climate modelling as forcing scenarios.

- Downscaling technique

Downscaling is used to bridge the gap between the scale of global climate models (GCMs) and the required resolution for practical applications at a regional scale. It is a method that derives local- to regional-scale information from larger-scale models. Three main approaches and sub-approaches are distinguished as the change factor method, dynamical downscaling, statistical downscaling: imposed offset method, and stochastic method [58].

The easiest way to downscale is by using the change factor approach, which involves applying past climate data that are pertinent to the application of a forecast change from the GCM (such as a temperature change) [59]. It is sometimes referred to as simple scaling, delta, or perturbation.

The statistical downscaling approach is based on actual correlations between local-scale variables (predictands) and large-scale atmospheric variables (predictors) [24,60,61]. Statistical downscaling adds value to change factor approaches due to its greater ability to replicate physically believable change. Downscaling using this approach is classified into three types: regression techniques, weather typing systems, and weather generators [62]. As the first strategy of statistical downscaling, stochastic downscaling has the advantage of creating future weather data in the absence of prior data [63]. This computationally demanding approach can mimic a wide spectrum of severe climate conditions [3]. Unlike the prior technique, the imposed offset method requires few compu-

tations to project prior weather data [3]. This technique is hampered by the fact that it ignores the climatic factors of solar insolation and windspeed. However, new circumstances may be developed and evaluated [64]. Another extrapolated statistical approach is the degree-day method, which uses prior weather data projection to anticipate future weather patterns.

The term “dynamic downscaling” describes the use of a numerical climate model that runs at a higher resolution than the GCM. Dynamical downscaling is based on the RCMs, which generate finer resolution output based on atmospheric data over a region using GCM fields as boundary conditions [57]. The dynamic downscaling projections are valuable in areas of heterogeneous topography, coastline, and regions with significant differences in land surface processes [65–67].

With the introduction of artificial intelligence and machine learning methodologies, Chakraborty et al. [68] created and proposed a data-driven explainable Artificial Intelligence (XAI) model to remove the inadequacies in estimating energy consumption using SSPs. Additionally, to decrease the correlation bias, techniques have been developed using machine learning to enhance the weather files for building energy simulations (BESs) [69].

In accordance with the literature, there is a heterogeneous use of the downscaling methods, including the change factor method and dynamical and statistical techniques. The statistical techniques are adopted through the imposed offset method and stochastic methods. Considering the downscaling techniques, the dynamical model operating on a finer resolution of RGM is adopted by 40% of the reviewed studies. Apart from downscaling techniques, one of the studies uses direct recorded data from weather stations to carry out the energy simulations. Among these, the stochastic method is the least preferred, included by only two studies. The imposed offset approach was used by three studies to forecast future weather data by adding the yearly rise in air temperature to historical reference year data. In contrast, Radhi [37] utilizes recorded weather data to demonstrate the uncertainty caused by using previous year weather data in energy and thermal performance estimates. To obtain finer resolutions, four of the studies use dynamical approaches to investigate RCMs. Surprisingly, much of the research reviewed is based on a GCM that has been downscaled to smaller resolutions. Hence, the dynamical downscaling technique is the most widely adopted to convert the GCMs to RCMs with finer resolution (Table 3).

- Input data weather files—current and future scenarios

The building energy simulation used to analyse the effects of climate change on energy use requires two types of meteorological weather data. These include the following weather files: current weather files and future weather files. The current weather files, also referred to as the reference weather data file, are generated based on the current climatic conditions or recorded data as the baseline for assessing the actual energy consumption and the cooling loads. The future weather data files represent conditions reflecting the possible future energy consumption. From the reviewed studies, about 35% of the studies use weather data within the time range of 1961–1992, representative of the TMY (71% of the studies) weather data file. However, more recent climate files are being used by a number of studies (41%), based on the 2005–2019 reference period representative of the data beyond 2005. One of the papers uses a climate data file based on the 2020 reference period, representing climate files involving very recent data representative of the ‘US DOE’ file type (Table 2; Figure 4).

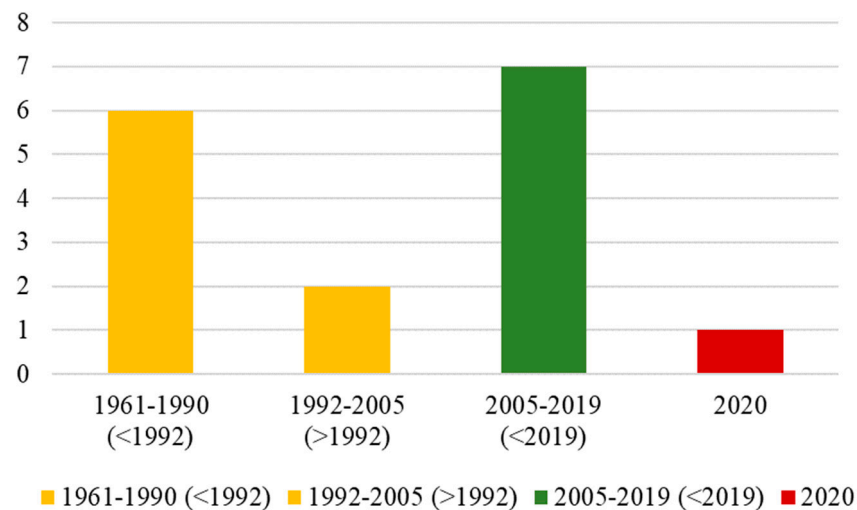


Figure 4. Overview of the input reference time period (current weather data ranges).

- Reference time period

To assess the future climate scenarios, the reviewed studies use four time zones: 2020 (−25) (56%), 2050 (63%), 2080 (−75) (75%), and 2100 (13%). Hence, the studies have a target to achieve the benchmarks related to energy consumption and thermal performance by 2080. Among these studies, the most common weather file format is the IWEC TMY. These file formats are readily downloaded from websites such as Energy-Plus weather and the US Department of Energy (DOE). Obtaining future weather data files is not easy and specific weather generator tools are used; namely, Climate Change World Weather File Generator (CCWorldWeatherGen), Meteonorm 7, and MAGICC. The most adopted CCWorldWeatherGen tool (56%) is a customised spreadsheet (Microsoft Excel 2019) that transforms the weather file format from .epw to TMY2 for future predictions. Followed by the Meteonorm (38%) tool, the TMY and historical weather data file types are provided through a unique combination of calculation tools and data sources (Table 2; Figure 5).

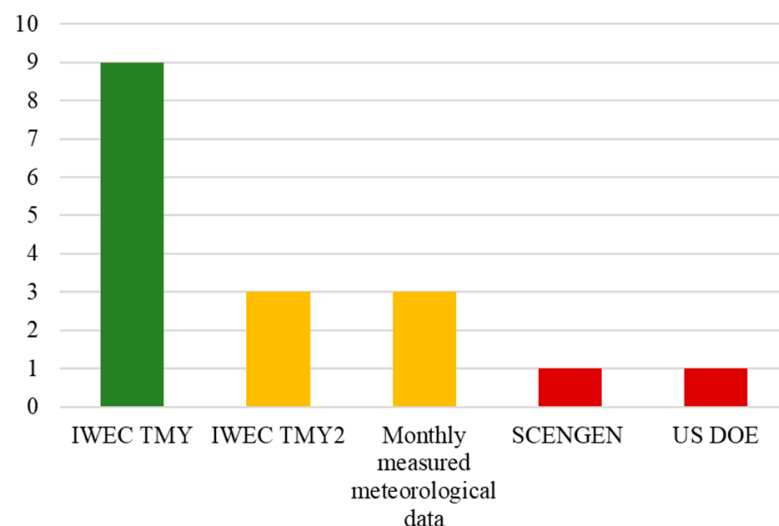


Figure 5. Overview of the input data weather files—current and future scenarios.

4.2.2. Dynamic Building Energy/Thermal Performance Modelling

- Energy and thermal performance simulation models

The building performance simulation (BPS) is a critical tool for estimating building energy consumption and indoor environmental quality. Weather data in various forms are utilized in building modelling, but they normally comprise air temperature, humidity, solar radiation, and wind speed and direction at an hourly temporal resolution at a minimum. A meteorologist traditionally uses a set of ranking criteria to specific months of a continuous 20-to-30-year historically observed data collection and compiles a year of 12 typical months to construct a weather file [70]. The number of years needed to compile a weather file is flexible, although 30 years is commonly chosen because it corresponds to the climatic standard normal period [29].

Building energy modelling is carried out mainly through two approaches: dynamic energy simulation modelling (94%) and regression modelling (6%) (Figure 6). Using the regression models, a linear relationship is established between energy demand and the climate change impacts. It is evident that 15 of the reviewed studies adopted dynamic energy simulation techniques to predict energy consumption in the current and future weather scenarios. Many simulation software includes EnergyPlus (<https://energyplus.net/>, accessed on 7 November 2023) with the graphical user interface of DesignBuilder (nine studies), IES-VE (three studies), and the Visual DOE program (two studies). To evaluate the accuracy of the simulated energy consumption values, validations are employed in comparison to the original electricity bill, the uncertainty variation between which is compared to the ASHRAE-14 guidelines.

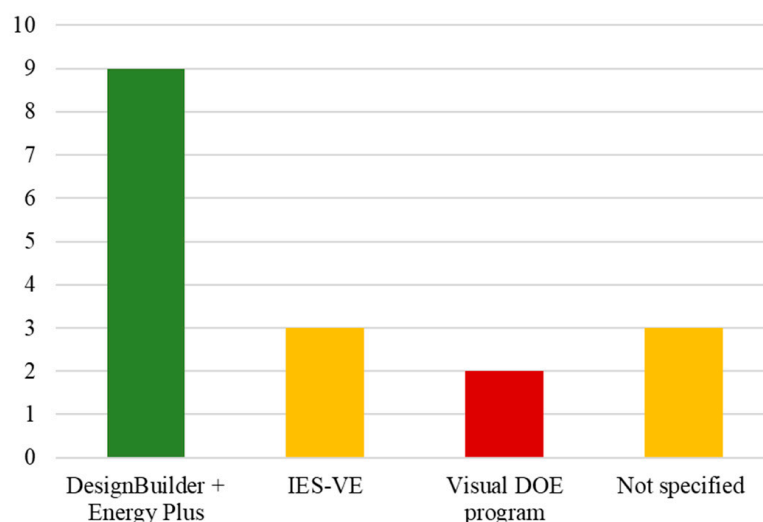


Figure 6. Overview of the building energy simulation modelers.

4.3. Mitigation and Adaptation Measures Implementation

A total of 19 mitigation and adaptation measures are reviewed in this study, where the individual and combined influence of these categories is considered. Passive design considerations alone are considered by 50% of the papers, active and passive considerations are together considered by 29% of scholars, while an integration of renewable energy sources is studied by only 14% of the scholars. Looking at the total mitigation and adaptation measures adopted by the reviewed studies, ten passive design considerations (53% of all measures) are examined against the five active (26%) and four renewable energy (21%) design considerations, respectively (Figure 7).

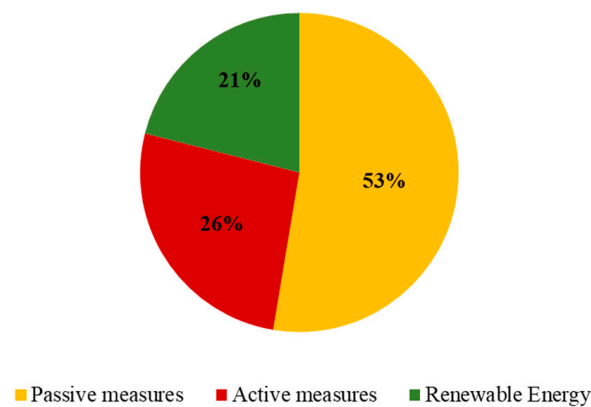


Figure 7. Overview of the active passive and renewable energy design considerations.

4.3.1. Passive Design Considerations

Passive design considerations are systems or buildings that employ natural resources directly to achieve an objective without the need for electricity or fuel [71]. This section covers 10 passive measures: airtightness and permeability indicated by infiltration rate; activated thermal mass; greening elements like green roof, green walls, and roof ponds; high-performance window types and glazing types; WWR%; thermal insulation of building envelope components through appropriate type and thickness adopted in the external wall, roof assembly, and ground slab construction.

Among these passive design strategies, 11 studies achieved the highest energy reduction through the thermal insulation of the building envelope, while natural ventilation, green roof, and green walls showed the least performance as highlighted by 5% (Figure 8).

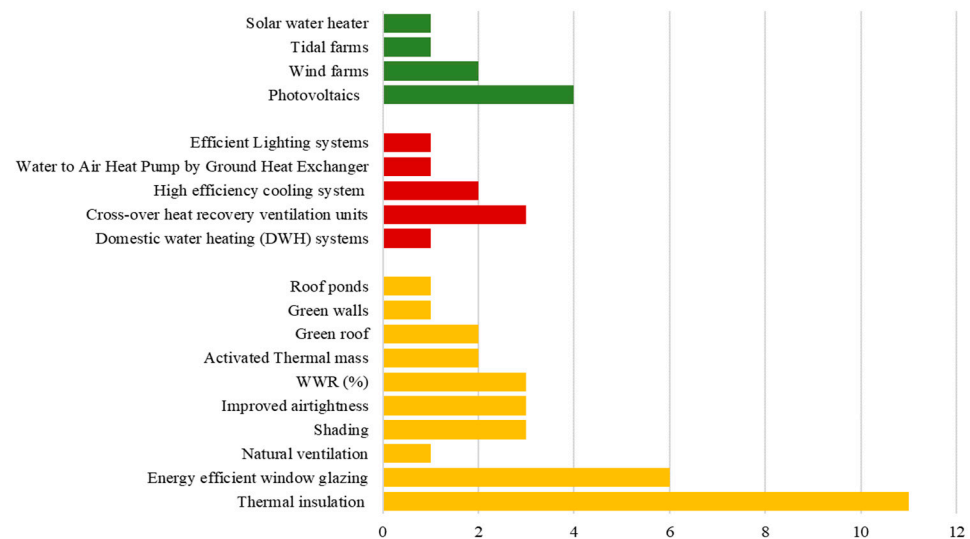


Figure 8. Overview of active, passive, and renewable energy design considerations used in studies.

4.3.2. Active Design Consideration

Active design considerations are systems or devices that use or produce energy. These design considerations include but are not limited to mechanical ventilation strategies, mixed mode ventilation, Variable Air Volume (VAV) reheat, sensible cross-over heat recovery units, air-cooled chillers, efficient heating and cooling systems connected to the grid (district heating and cooling systems), and water to air heat pump by ground heat exchanger [71]. Cross-over heat recovery ventilation units were found to be extremely efficient (16%), while others showed comparable behaviour (Figure 8).

4.3.3. RE Potential Considerations

Renewable energy (RE) is defined as clean energy that comes from natural sources or processes that are constantly replenished. RE designs include solar panels, wind turbines, and photovoltaic (PV) panels. The Middle East has high potential for collecting solar radiation; installing photovoltaic systems in buildings is one option for producing electricity, lowering air conditioning loads, and improving energy efficiency [72]. Building-Integrated Photovoltaics (BIPV) is another approach, which consists of installing photovoltaic cells on the building facade [73] to transform facades into components that collect solar energy [74]. Solar photovoltaics were regarded as the most efficient RE source by 21% of the research (Figure 8).

5. Impacts of Climate Change on Building Energy Use and Thermal Performance

5.1. Impacts of Climate Change on Building Energy Use

Among the papers evaluated, Radhi 2009 [38] analysed how global warming may affect air conditioning energy use in hot countries. Using Visual DOE and Meteo Norm software, simulation studies were performed under various climatic scenarios to assess the monthly energy consumption of buildings and the most efficient energy conservation methods to deal with climate change scenarios. His findings suggested that global warming will have a considerable influence on the built environment and the energy consumed for building air conditioning. According to the energy consumption analysis for 2050 and 2100, rising air temperatures will have a major impact on future power demand and CO₂ emissions [38]. Another qualitative study was undertaken in three major locations of the Emirate of Abu Dhabi (Abu Dhabi city, Al-Ain city, and Al Dhafra) to evaluate the social impact triggered by increased energy usage. Societal implications gave way to economic significance, suggested by the preference of half of those surveyed to shift to a different city due to rising energy prices [49].

The research methodology conducted by Radhi [37,38] in Al Ain was applied to Manama in Bahrain to assess the impact of current and historical climate files on climate change variability, building energy consumption, and thermal performance. The importance of this study was not in determining the effects of future climate change on building performance but in understanding the robustness of predictive methods in specifying appropriate mitigation design strategies. The findings of this study advocate utilizing more recent weather data to estimate building performance rather than historical weather data to develop future climate change scenarios. Simulations based on historical weather data reveal a 14.5% variance in energy consumption from the actual value, making it impossible to assure the trustworthiness of energy estimates based on future weather data. It was also found that the accuracy of cooling loads based on past weather data was incorrectly expressed by about 5.9% to 8.9%. However, when compared with the actual energy consumption based on recently updated weather data, it was estimated that there was a difference of only 1.4%. Radhi, H. [38] shows that global warming would increase the energy needed to cool buildings by 23.5% if Al-Ain city warms by 5.9 °C. Accordingly, air conditioning demands in typical residential villas were projected to increase by 10–35% by 2050, depending on the future emissions scenario of carbon dioxide used. Using another study, Radhi, H [37] indicated that active systems such as HVAC consumed the highest amount of energy, corresponding to 45–67%, in the residential buildings for meeting the cooling loads. A comparison of cooling degree days (CDDs) using meteorological information in the two simulated houses showed a difference of 4.4–5.5%, whereas heating degree days (HDDs) only varied by 0.7%. This impact of misinterpreted variations is highly evident during the summer months from May to September.

Several studies have been conducted to assess the influence of climate change on energy use in Qatar. In 2020, a quantitative analysis was conducted to assess the influence of climate change and the rise in residential construction stock on the environment and grid stability. The authors report an overall annual energy demand increase of up to 30%, with a steep increase in peak load electricity grids [9].

As a method of energy efficient retrofitting to respond to climate change, a study was conducted on the impact of green roofs and walls on energy consumption of Qatari residences [9,41,42,47,48]. In this study, it was confirmed that most heat gain is achieved by the exterior walls of the building rather than direct solar gain. Through energy simulations, it was confirmed that an increase in energy consumption of 9% to 30% would occur within 60 years [48].

In addition, a study conducted by Lelieveld et al. [50] analysed long-term meteorological data sets as well as regional climate models' projections for the 21st century in the Middle East based on the intermediate IPCC SRES scenario A1B for the 1961–1990 reference period and the 2070–2099 period. This study indicated that cooling energy demands will increase by a significant amount from 2070 to 2099. It includes intense cooling, as measured by the number of days per year that air conditioning is required to achieve a temperature reduction of more than 5 °C to reach a comfortable 25 °C (i.e., cooling degree days, CCD > 5 °C) while reducing the stress caused by heat waves. Studies assessing the performance of residential building envelope codes significantly showed that the application of the energy envelope codes reduced the annual cooling demands in Saudi residential villas substantially. Variations in the applied codes further affected the percentage reduction in the cooling energy demands. In simple terms, code 1 showed a reduction of 38%, while a further reduction of 2% was achieved by applying code 2.

Tahir et al. [47] investigated the potential of PV types with higher energy production under the influence of climate change. The study looked at the efficacy of mono-facial and bifacial PV in predicting PV production based on climate change scenarios. The results of the mathematical modelling and estimates of maximum hourly average thermal output suggested that a bifacial PV increased energy generation by 24.5%. Under the influence of peak hours, the decrease in energy yield of monofacial and bifacial PVs were similar. As air temperature increases from 41.8 °C to 45.7 °C by 2080, the solar irradiance will decrease by 5% and 8% in 2050 and 2080, respectively, and it could be expected to lower the daily energy generated from PVs. This study also showed that solar irradiance positively affects the performance of a PV, while higher ambient temperatures negatively influence cell efficiency. Due to climate change, the cell temperature of a monofacial increases by 1.2 °C, while it is comparatively less in a bifacial PV from 2050 to 2080. Higher windspeeds cool down the cell temperatures, resulting in higher energy outputs. Hence, climate change temperature increase has a lower effect on bifacial PVs due to the transmission of unused radiation owing to its transparency.

Research on energy consumption and thermal comfort in residential structures was conducted for the first time in the GCC area, utilizing the German Passivhaus concept. This research compared the influence of climate change on thermal comfort and energy consumption using existing building standards with the German Passivhaus standards. Energy modelling of the current standard residence showed a 45% increase in total energy demand, while only a 19% increase was observed with the Passivhaus residence based on the climate change scenario. According to this study, the use of energy conservation strategies in both current and future scenarios was found to be beneficial for both homes' thermal comfort, while lowering energy demand growth. In the case of Passivhaus, it was confirmed that it uses only about 50% of the energy of a house applying the current standard. In addition, houses using the current standard were found to be vulnerable to climate change. Hence, an energy efficient or low energy building approach to residential building designs has a significant effect in hot urban deserts. The study by Aram et al. (2022) [46] shows that the best retrofit with a maximum of 86.18% energy reduction in the future is thermal insulation of PVC of 0.1 m thickness with a double clear window glazing of 6 mm/13 mm Air.

Roshan et al. [75] discuss the impact of climate change on the energy demand of the residential building stocks along the northern coasts and the southern Oman Sea in Iran. Considering the stations of Bandarabbas along the coast, a cooling degree days (CDDs) index and thermal energy simulation were used to quantify the energy demand and carbon

dioxide emissions. This study reveals that these specific coastal regions of the Persian Gulf and the Oman Sea are more exposed to the incidence of heat waves compared to other Gulf regions. Based on the increase in CDDs due to climate change, it was confirmed that existing residential stocks require a 95% increase in cooling energy. Additionally, the increase in demand for cooling energy is related to the corresponding amount of CO₂ emissions. During the proposal period, it was confirmed that CO₂ emissions would increase by 700 kg per year.

A recent study by Aram et al. [46] investigates the comparative effectiveness of an energy-optimized Net Zero Energy Building (NZEB) in responding to future climate change. The study explores the possibility of the best performing passive, active, and renewable energy strategies to achieve NZEB both under the current and future weather scenarios in an existing educational building in Iran. Considering the higher energy consumption of educational buildings (2.5 times higher than other countries), Aram et al. (2022) [46] uphold the concept of retrofitting the existing buildings. Using multi-stage optimization, the building is retrofitted with design solutions that meet the current climatic conditions while responding effectively to future climate change. In addition to minimizing the cooling and heating energy loads, cost effectiveness for the present and future weather files and retrofit scenarios is assessed. The results of the optimization suggest that optimized retrofit solutions for the current and future weather files are not the same. Under the current climate, the implementation of the building retrofits reduced the total energy consumption by 43.38% in comparison to the American Society of Heating, Refrigerating and Air-Conditioning Engineers in an American professional association (ASHRAE) baseline model (benchmark or standards), while the energy reduction increased to 52% under future climate change. However, using both the passive and active measures, the total energy consumption of the existing building was reduced by 65.14% with energy efficient retrofits under current conditions, while an increase in the total energy reduction of 86.18% is observed in 2080. With the installation of on-site renewables such as solar roof PVs, the energy consumption is reduced by about 90%.

According to Abuhussain et al. [45], the implementation of retrofits resulted in a reduction in the overall yearly cooling demands. By comparing the application of two varying retrofit codes, the results suggested a 2% difference in the cooling demand. The conclusions drawn from the study highlight the importance of appropriate retrofit selection for a reduced cooling demand.

A study conducted by Shanks et al. [12] investigates the impact that climate change will have on generic drivers, including solar gain, conduction gain, and heat gain, of cooling energy demand in a typical floor of a high-rise office building in the UAE. The finding yields that the annual cooling load increases, with the scale doubling every 30 years from 2020 to 2050 and 2050 to 2080. The year 2013 projected an annual cooling and dehumidification demand of 149.6 kWh/m²·yr. The next period in 2020 resulted in a yearly cooling and dehumidification demand of 165.8 kWh/m²·yr, an increase of +10.8% compared to 2013. The next period in 2050 resulted in a yearly cooling and dehumidification demand of 182.8 kWh/m²·yr, increasing +22.2% compared to 2013. The last year, 2080, resulted in an increased yearly cooling and dehumidification demand of 209.3 kWh/m²·yr, having an increase of +40% compared to 2013. Roshan et al. 2012 [39] in his study showed that the cooling degree day (CDD) index is a weather-based technical index designed to describe the need for the cooling (air conditioning) requirements of buildings.

In terms of energy efficiency, adaptation measures such as thermal insulation, thermal mass, window area, and glazing systems are helpful and useful for residential structures. According to Radhi [38], utilizing various scenarios, these techniques considerably cut energy consumption and CO₂ emissions. However, shading devices have a small impact on reducing CO₂ emissions from buildings, while having little influence on global warming. Like the previous studies, a variation of 1.4 °C was observed in the mean air-temperature, with a peak increase of 2.6 °C during July. While comparing the climate variables of relative humidity and wind speed, the past weather data produced a relatively higher value of 8.2%

compared to the current weather (during the summer months). A drop in the wind speed was observed in the past when compared to the current scenario. The temperature rise was observed at the rate of 1.4 °C per decade, while the relative humidity declined by 8.2% during the same period. Importantly, the direct solar radiation increase is complemented by a drop in the diffuse solar radiation. All these climate factors not only influence the thermal performance but also the potential for PV power predictions. Using a moderate scenario, the summer PV potential decreases by approximately 4% for the Arabian Peninsula.

5.2. Impacts of Climate Change on Thermal Comfort Performance

According to Khalfan and Sharples' [41] analysis of the building envelope's thermal efficiency, the influence of climate change is most noticeable from May to September, when temperatures are at their highest. Appropriately, a dry bulb temperature (DBT) increase towards 2080, with a slight % decrease in relative humidity (RH), was observed. Without mechanical cooling, the predicted indoor temperatures increase from 3 to 5 °C in 2080, affecting the internal thermal environment. The increased internal temperatures (current climate) substantiate the unsatisfactory thermal protection offered by the building's envelope from the external environment without any mitigation strategies. While assessing the people's indoor thermal comfort, an almost negligible difference in the annual Predicted Mean Vote (PMV) suggests that the Passivhaus residences are thermally comfortable throughout the year (winter months—PMV score of 0; summer months—PMV score < 1). However, without mitigation strategies, the standard building shows thermal discomfort hours during the summer as a function of climate change. Furthermore, research employing Schneider's comfort charts indicates that thermal comfort levels in a Passivhaus dwelling remain within the inner thermal comfort zones for both present and future weather situations. In contrast, operating temperatures over 25 °C were maintained for 93% of the next year, implying significant variability in thermal comfort levels beyond the inner and extended comfort zones.

Since thermal comfort is a direct impact of space conditioning needs, Khalfan and Sharples [41] justify that an energy-efficient residence attains the same indoor thermal comfort at a much lower cooling energy load than a standard residence.

Considering the thermal performance, the variations in the outdoor temperature, relative humidity, and wind speeds were assessed by Andric et al. [9] in residential buildings for the current and future climates. This study projected the advent of extremely intense, more frequent, and longer heat waves (45 °C) occurring over 21% (1840 h) of the year in the GCC using regional climate modelling. The number of discomfort hours tripled from 8% during the reference period to 21% during 2080. Although stable comfort hours were detected, 2% discomfort hours were predicted in 2080. As suggested, these intensified heat waves show a five-time depreciation (4%) in the comfort hours from the reference period (1961–1990). In Shanks et al.'s 2013 study [12], the author changed the glazing type and walls' U-value to 0.76 W/m²K and 0.35 W/m²K, respectively.

Assessments using the bioclimatic thresholds and PMV index show that the thermal performance of the residence was assessed based on the pattern of the occurrence of indoor comfort and discomfort days. Considering the mean air temperatures, both the comfort days inside and outside decreased by 196 days in 2060 compared to the reference period. Based on the increase in the warm weather due to the global warming heat wave incidence, 96 days of comfort in the reference period were replaced by 49 days of comfort in the future period. Hence, the study of thermal discomfort showed an upward trend. The study findings by Roshan et al. [75] show that an increase of 2.82 °C was observed in the predicted temperature variations for future decades when compared to the reference period. Relatively, a humidity of 69.93% in 2060 shows only a marginal increase of 10%. Climate modelling shows that a 4 °C increase in temperature is anticipated by 2100, boosting the need for cooling energy in May and June.

Aram et al. [46] used global horizontal sun radiation, relative humidity, and dry bulb temperatures to examine the climatic variables stated in earlier investigations. Evaluating

the indoor thermal comfort under passive retrofits, the indices of the PMV and PPD of a building show 0.52 and 23.41%, respectively. Hence, dissatisfaction in thermal performance is recorded for 717.08 h of the year.

5.3. Environmental, Social, or Economic Implications of Increased Energy Consumption

Only a handful of the papers analysed were concerned with environmental, social, or economic concerns. Dealing with the social effects, the research conducted by Alblooshi et al. [49] explored the energy consumption of various Abu Dhabi housing scenarios to assess the potential impacts of climate change on people's lifestyle, employment, and buildings. Despite the increase in energy usage, society remained unaware of the effects of climate change on their energy and water usage. Choosing to investigate this community-based involvement through consumer behaviour surveys, Ayoub et al. [42] showed a conservation of 13% in energy use by modifying behaviours.

The economic effects of climate adaptations are regarded as extremely important due to their influence on decision makers or individuals' investment towards living in their residences. Studies have focused on energy prices and the economic viability of building energy conservation requirements, as well as associated expenditures ranging from construction to operating expenses. Abuhussain et al. [45] critically examined the financial feasibility of being influenced by climate change. The findings based on implemented Saudi Arabian building rules suggested the importance of considering the initial investment and operating costs of residential building envelopes as the key foci under current and future climates. Similarly, a study by Goudarzi, H. et al. [43] economically evaluated the initial cost of passive technologies, their operation, and maintenance. The life cycle cost (LCC) of passive technologies such as green roofs, roof ponds, and wind catchers examined over a 20-year period on subterranean housing identified the wind catcher and roof pond as the most economically viable solutions. Finally, Aram et al. [46] conducted a holistic study discussing the social, economic, and environmental effects of the retrofit measures. The cost analysis run using the NSGA-II algorithm and the jEPlus tool demonstrated higher energy savings with reduced cooling loads, despite a high investment cost.

Under hot summer circumstances, one of the most addressed environmental concerns is the deterioration of the air quality. On this end, Radhi's [38] analysis provides some environmental specifics, indicating a rise in net CO₂ emissions of 5.4% in the coming few decades. Furthermore, studies predict a hike in maximum daytime temperatures, resulting in prolonged heat waves and an increase in mortality among persons with diseases, the elderly, and children. Lelieveld et al. [50] investigated the environmental effect of climate change while examining cooling energy consumption in both residential and commercial buildings. Apart from air quality, Andric and his colleagues conducted two concurrent studies [5,6] that illustrate the severe environmental impacts of the fossil fuel usage of energy systems on the scarcity/depletion of water resources and marine toxicity. According to the findings, 20g of 1.4-DB released into local marine ecosystems, with an emission of 17.5 tCO₂ and an 8-ton fossil fuel depletion, has a massive impact at national/regional levels.

6. Mitigation and Adaptation Measures for Energy-Efficient Buildings

6.1. Passive Design Considerations

To guarantee that buildings adapt to climate change and mitigate its effects, passive ways to improve the thermo-physical building envelope qualities are offered. In hot climates, thermal insulation, energy-efficient glazing, green walls, and green roofs were deemed the most efficient energy performance techniques. According to Aram et al. [46], the evaluation of optimal combinations of passive, active, and renewable energy retrofits is based on the balance between a minimum cooling and heating demand and a minimum investment cost. The evaluation of minimal cooling load, heating load, and building cost using TOPSIS regarded thermal insulation type and thickness as the most effective passive energy reduction measures. For testing, the authors chose insulation materials

of comparable performance as retrofit based on their cost effectiveness. However, the results proved that efficiency in reducing the annual energy and cooling load with a low investment cost was dependent on the choice of wall insulation material and thickness of the glazing used.

According to Abuhussain et al. [44], who assessed the base case villa's performance against building codes considering both present and projected climatic conditions, passive design considerations have a combined positive impact on energy usage reduction. The author proposed updating the building stock by providing lower thermal insulation for exterior walls and roofs, as well as lowering the window-to-wall ratio to 5% and replacing the windows with low-U-value double glazing. Similarly, Shanks et al. [12] conducted research to mitigate climate change impacts on an office building in the UAE using combined strategies of external wall insulation, double-glazed Low-E coated windows with Krypton gas-filled spacers, and external shading. Using an extra 125 mm of EPS insulation beneath the outside wall panel layer lowered the yearly conduction gain from exterior wall components by 50% over the next years. Improved windows resulted in an enhanced U-value = $0.76 \text{ W/m}^2\text{K}$ and G-value = 27%, reducing the impact on the annual cooling demand in different periods. Fixing external shading above all significant areas of glazing helped to provide shade around the building while simultaneously reducing solar gain proportionally even in the future.

As seen in all the above studies, thermal insulation of the building envelope efficiently reduced indoor temperatures within ranges of -4°C in the present and 6°C in future weather scenarios. Roshan et al. [39] studied the effect of adding extra wall insulation in residences of Bushehr (Iran) to increase the U-value and replace the HVAC systems with passive methods like internal coverings, thermal inertia, or air changes of indoor air. In particular, the authors suggested traditional Iranian architecture approaches for changing indoor air to reduce future energy consumption in combination with the former two methods. Likewise, Fahmy et al. [40] studied the effect of adding wall insulation of precisely 10 and 12 cm GRC-foam insulation. The results indicated that using GCR on a building in Cairo showed a gradual energy consumption reduction over current and future conditions. Significantly, low-energy or Passivhaus houses with defined passive design considerations reduced thermal discomfort during summer overheating periods. As discussed earlier by Khalfan and Sharples [41], the minimal air leakages and thermal bridges adopted through the tight control of the Passivhaus residence mitigate the overheating risk. In addition, Andric, and Al-Ghamdi [9] modified Qatar's existing residential building stock by adding thermal insulation to the building envelope. Progressing to experiment on other passive design considerations, the potential of greening in reducing the energy demand was assessed using green walls and green roofs.

Goudarzi et al. [43] investigated the impacts of four passive systems in an Iranian residential structure, including a green roof, roof pond, wind catcher, and subterranean housing. The results suggested that the wind catcher is the most efficient device for conserving cooling energy, followed by the roof garden, roof pond, and subterranean housing. These passive measures reduced total annual energy loss through the building envelope. On the other hand, the wind catcher is specifically helpful in minimizing the cooling energy demand from May to October. Similarly, Andric et al. [48] proposed four scenarios through the business-as-usual scenario. Each scenario addressed the impact of either a single or more individual passive design consideration. Compared to the integration of greenery, thermal insulation provided higher energy reduction rates throughout the year and seasons. An in-depth study of the analysis suggested that adding 5 cm EPS thermal insulation to the building envelope showed higher performance. Furthermore, these efficiencies show a positive correlation with the outdoor temperature increase. Importantly, this study considered the temporal dimension of seasonal variations in influencing the energy reduction rates. Installing the green walls during the winter months (current weather) exhibited a negative effect due to the shading and evapotranspiration from the green walls. Opposing this, the mitigation potential of green walls improved with the predicted future rise in

winter weather temperatures ($>24\text{ }^{\circ}\text{C}$) in 2080. As a result, green walls do not affect the rise in building energy demand during the winter. However, they prove efficient in future weather scenarios (2080). Thermal insulation proved to be a higher energy reduction driver with long-term projections. Thus, the effectiveness of the mitigation strategies depends on the potential of the design considerations in lowering the increased outdoor temperatures while the heat transfers through the walls and windows.

The building envelope, which comprises the walls, windows, roof, and foundation, serves as the major thermal barrier between the interior and outside environments. Within this context, Ayoub et al. [42] performed research in which they analysed energy conservation measures in Qatari commercial buildings to find potential improvements. On both the demand and supply sides, two sets of scenarios were utilized to investigate energy reduction alternatives for commercial buildings. Substitute building envelope designs, changes in consumer demand, alternative designs, and behaviour adjustment scenarios were among the demand control possibilities. Wood for walls and insulation entirely above deck (IEAD) for roofs were obtained as the best materials for reducing energy consumption. Thus, appropriate design considerations/alternatives of building envelope design standards may be used to reduce energy consumption.

6.2. Active System Strategies and Renewable Energy Potential Considerations

Active design strategies such as a four-pipe fan coil unit (FCU) and air-cooled chiller were efficient in lowering overall energy usage both in the current and future scenarios. Aram et al. [46] proved the effectiveness of these active strategies by achieving a reduction in overall energy demand of 65.14% for current and 86.18% for 2080 conditions. Similarly, Roshan et al. [39] also investigated the technical characteristics of HVAC systems. Thus, the effectiveness of these active measures is based on the measures' ability to meet the Predicted Mean Vote (PMV) criteria.

A lack of integrated mitigation and adaptation design considerations increase residential energy consumption by 9% (2020), 17% (2050), and 30% (2080) as the years progress [48]. Using only passive design considerations, the study by Andric et al. [48] suggest a combination of thermal insulation with highly efficient windows, green roof, and green walls for maximum energy reduction. The best performing passive design considerations provided a 30% energy reduction by thermally insulating the walls with a 5 cm EPS, along with energy efficient triple-glazed windows. The least performing passive design considerations that provided a 3% energy reduction were green walls and a green roof. The study concluded with the notion that mitigation and adaptation to energy-use reduction must consider the current and future weather predictions for innovative renovations.

In response to the environmental impact assessment, studies recommend replacing fossil-fuelled energy production units with energy from renewable sources [9]. These include the use of solar photovoltaics (PVs) in areas of high solar potential and wind and tidal farms along the coastal areas. In addition to analysing the demand and supply sides, Ayoub et al. [42] consider the use of green energies derived from renewable resources. According to the analysis, using 30% renewable energy alternatives can reduce CO_2 emissions by 27%. While passive design considerations reduce the summer energy demands, sustainable energy production using renewable energy systems is proposed by Khalfan & Sharples [41] using roof top-mounted PV arrays. The results of the study suggest a reduction in annual energy consumption by 50% and cooling demand by 33.33% in 2080 with the use of these mitigation measures. An integration of renewable energy systems successfully maintains an operative temperature below $25\text{ }^{\circ}\text{C}$, while ensuring thermal comfort levels throughout the year in both current and future years.

The study by Tahir et al. [47] showed that on an hourly basis, the energy yield of a bifacial PV is higher than a monofacial by 18–48%, while the daily average energy produced is 30% higher than the monofacial PV. Although a decrease in insolation by 5% and 8% over 2050 and 2080 is observed, the bifacial PV due to its dual transparency is least affected. Additionally, higher power output and climate change mitigation make the bifacial PV most

preferred in the market while considering the long-term implications of climate change. The authors determine that thermal insulation is the best performing passive design strategy, while solar PV arrays are the best renewable energy technology system for fulfilling the building's energy needs. To fulfil the primary energy need of a retrofit building, three sections facing south at a 45° angle were equipped with PV panels (1.939 m² each) of 18% efficiency [46]. This system guaranteed an energy production of 90.66% of the total site energy, hence providing an excess of 40% electricity back to the grid.

7. Conclusions

While global warming-induced changes may have multiple effects on the built environment (such as on the building construction, materials, and indoor climate), the building sector offers significant potential for climate change mitigation by reducing building energy consumption, GHG emissions, and raw material extraction. However, the link between climate change and energy consumption is reciprocal.

According to the studies, buildings in hot and humid regions are especially vulnerable to the effects of climate change. An increase in overall demand and a shift in the ratios of heating and cooling demand would have a substantial influence on energy system functioning. The bulk of cooling services are provided via decentralized air conditioning systems in hot and humid climates. Steep increases in demand would put further strain on an already overloaded system, leading to failures and blackouts, which are already a common occurrence (impacting utility profitability and operations, as well as consumer satisfaction). Furthermore, these nations' power generation is completely reliant on fossil fuels, and fossil fuel exports are now the backbone of their economy; consequently, an increase in self-consumption will increase national emissions even more, negatively impacting their economy. If these systems are developed based on present climate conditions, they may become outdated in the future due to being over- or under-powered. Hence, this research presents the most recent information on the effects of climate change on building energy usage and thermal performance in hot urban desert climates.

Using PRISMA, seventeen research papers were reported based on a set of extraction criteria representing the main steps to carry out the building stock profiling, methodology and input variables, building thermal and energy modelling, and implementation of the mitigation and adaptation strategies. As a result, the following are the key conclusions of the research, with a more complete summary available in Appendix A:

- (1) The geographical distribution of the research reveals that studies are more concentrated in the state of Qatar and the coastal parts of Iran. For a comparative analysis of energy consumption, all the studies were restricted to cities falling within the hot desert climate zone. Furthermore, to comprehend the implications in the Middle East, all cities inside climatic zone B must be investigated.
- (2) Most of the studies focus on residential typologies (76%), followed by commercial (18%) and then office buildings (12%). Nevertheless, climate change adaptation and mitigation measures are unique to each typology and must be identified to ensure the best performance.
- (3) Many of the studies use weather data files generated using reference data periods of 1961–1990 (35%) that create uncertainty and variations in the future predicted energy consumption. Hence, the reliability of the assessments must be ensured by considering the availability of reference weather files based on recent climate data.
- (4) About 67% of the studies rely on the IPCC SREAS scenarios as the forcing agents to generate GCMs. However, recent studies suggest the usage of RCPs and SSPs as they are more related to the impact assessments of climate change implications.

7.1. Challenges and Opportunities

While adaptation measures offer tremendous promise for mitigating climate change, their large-scale implementation confronts several hurdles. Primarily, national renovation policies should be more clearly stated, less ambiguous, and rigorously enforced. Sug-

gested measures under policies should not be characterized as “one-size-fits-all”, but rather tailored to the characteristics of various building stock sectors. However, such policy formation necessitates an in-depth understanding of the building stock. Previous assumptions and data gathering methods resulted in an underestimation of building energy usage, according to recent results. Abuhussain et al. [44] showed that low consideration was given towards assessing possible passive techniques when proposing residential energy codes (in Saudi Arabia), thereby neutralizing the impacts of comprehending future effects of climate change. Also, Radhi, H. [38] contends that the UAE’s construction authority and energy codes should adjust building regulations to conserve energy and minimize CO₂ emissions. These may be applied alongside the metrics for envelope features, system components, and energy consumption patterns to assure an increase in energy-efficient buildings.

Major efforts should be made to educate homeowners/tenants and provide more information on adaptation measures, as well as to encourage a system-thinking approach among stakeholders and actors participating in the process. The cultural background of house owners/tenants, as well as their daily behaviours, must be considered because these aspects might impact the acceptance of adaptation measures. As shown by Alblooshi et al. [49], despite the modest number of residential units analysed in their study, the results illustrated the necessity to include the impact of occupant behaviour and cultural variables on energy usage.

Given the comparatively low energy costs, the long investment return times (10–15 years), and the fact that the adaptation process consumes additional materials and resources, the economic and environmental performance of the suggested techniques may be called into doubt. However, case studies indicate that most passive and active techniques are both economically and environmentally sustainable.

7.2. Research Gaps and Future Directions

Climate change has tangible consequences on human life, such as uncomfortable severe heatwaves, greenhouse gas (GHG) emissions, and increasing energy usage [76]. To alleviate the environmental implications of these techniques, new regional environmental policies must be devised. Decision makers must consider the economic, environmental, and social ramifications of climate change on the energy and thermal performance of buildings.

Accordingly, more research into the synergistic impacts of linked concerns like water supply and air pollution is necessary. Future studies should focus on the consequences for human health, the development of vector-borne illnesses, the availability of fresh water, agriculture, and energy systems. The necessity to investigate the impacts of social and cultural contexts on climate-induced energy usage is one of the significant research needs prompted by the examined literature. In addition, most of the studies analysed employ a single building typology. However, the study sample should be broadened to include more than one form of residential or commercial structure.

When analysing the environmental impact assessment, the energy and thermal performances of the building are considered. Yet, few studies from the research have looked at the additional repercussions of climate change, such as urban heat islands, worsened IEQ, and health effects on people.

Author Contributions: Conceptualization, Y.K.K.; methodology, Y.K.K. and N.A.K.; software, D.B., A.O.D. and N.A.K.; validation, Y.K.K. and N.A.K.; formal analysis, N.A.K.; investigation, Y.K.K.; resources, N.A.K. and A.O.D.; data curation, N.A.K. and D.B.; writing—original draft preparation, N.A.K., D.B. and A.O.D.; writing—review and editing, Y.K.K.; visualization, N.A.K.; supervision, Y.K.K.; project administration, Y.K.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Summary of This Study and Included Two Tables

Table A1. Summary of the review studies with details of study context, building typology, and adopted methodologies.

No.	Author/ Year	Study Context	Building Typology	Climate Zone	Method Adopted					
					Reference Period Future Period(s)	Emission Scenarios	Downscaling Technique	Future Weather Files RF/FP	Energy Modelling Thermal Comfort Modelling	Temporal Dimension
1	Radhi, H. (2009) [37]	AlAin city—UAE	Residential	Bwh	RF: 1961–1990 FP: 2050, 2100	+1.6 °C, +2.9 °C, +2.3 °C, +5.9 °C Recorded data	Offset method	RF: MeteoNorm 6.1 software	BM: Visual DOE program EM: Visual DOE program	H, C, Fans, Electricity Monthly
2	Radhi, H. (2009) [38]	Manama—Kingdom of Bahrain	Office (low rise); commercial (high rise)	Bwh	RF1: 1961–1990 (<1992); RF2: 1992–2005 (>1992) FP: 2020	IPCC SRES A2	-	FP: MeteoNorm DT: Actual measured monthly meteorological data Solar DT: Actual measured monthly solar data	BM: Visual DOE program EM: Visual DOE program Validation: A <i>t</i> -test, benchmarked energy utilisation indices (EUIs)	Monthly and annual profile of electricity and cooling load
3	Lelieveld, J. et al. (2012) [50]	Eastern Mediterranean and the Middle East	Residential; commercial	Bwh and other climate zones	RF: 1961–1990 FP: 2070–2099	IPCC SRES A1B	RCM	Climatic Research Unit (CRU) TS3.0	PRECIS (Providing Regional Climates for Impact Studies/ multivariate calibration/proxy data land-based meteorological data (CRU TS3.0)	Yearly
4	Roshan, G. et al. (2012) [39]	Iran	Residential	Bwh	RF: 2005 FP: 2025, 2050, 2075	P50 which is the average of SRES scenarios	-	FP: MAGICC/ EP: SCENGEN software, version 5.	-	DDIs
5	Shanks, K. et al. (2013) [12]	Dubai—UAE	Office (high-rise tower)	Bwh	RF: 2013 FP: 2020, 2050, 2080	IPCC SRES A2	Dynamical	FP: CCWorldWeatherGen	BM: IES-VE version EM: IES-VE + EnergyPlus	Annual temperature
6	Fahmy, M. et al. (2014) [40]	Cairo—Egypt	Residential	Bwh	RF: - FP: 2020, 2050, 2080	IPCC SRES A1FI	Statistical	FP: CCWorldWeatherGen Present day climate conditions: USDOE website	BM: DesignBuilder (V.3.0.0.105) EM: DesignBuilder (V.3.0.0.105) + EnergyPlus	Monthly
7	Khalfan M. et al. (2016) [41]	Al Wakrah—State of Qatar	Residential: test (PHV); base model (STV)	Bwh	RF: 1961–1990 FP: 2080	IPCC SRES A2	Morphing (statistical method)	RF: Meteonorm 7 FP: CCWorldWeatherGen DT: IWECC TMY	BM: IES-VE version EM: IES-VE version Validation: HOBO loggers, real-time physical data TC: ASHRAE seven-point scale and Schneider’s comfort chart IES VistaPro application Validation: ASHRAE 140, USGBC and BEST TEST, on-site measurements—energy meters in the houses.	Annual hourly operative temperatures and relative humidity
8	Ayoub, N et al. (2017) [42]	Doha—State of Qatar	Commercial	Bwh	RF: 2014	-	CBECS 1980–2004	Weather data of Qatar	BM: EnergyPlus simulator EM: EnergyPlus simulator	Yearly

Table A1. Cont.

No.	Author/ Year	Study Context	Building Typology	Climate Zone	Method Adopted					
					Reference Period Future Period(s)	Emission Scenarios	Downscaling Technique	Future Weather Files RF/FP	Energy Modelling Thermal Comfort Modelling	Temporal Dimension
9	Goudarzi, H. et al. (2017) [43]	Kerman—Iran	Residential	Bwh	RF: 2017 FP: 2037	-	-	Daily weather data of Kerman's synoptic stations	EM: Numerical evaluation	Monthly
10	Abuhussain, M.A. et al. (2018) [44]	Jeddah—KSA	Residential	Bwh	FP: 2010, 2050, 2080	IPCC SRES A2	-	RF: Meteonorm 7 FP: CCWorldWeatherGen	BM: DesignBuilder EM: DesignBuilder + EnergyPlus Validation: Real-time collection temperature using data/buttlloggers (DS1921H-F5 Thermochron) & DS1923-F5# Hygrochron), comparison of utility bills consumption and DesignBuilder.	Monthly and hourly temperatures
11	Abuhussain, M.A. et al. (2019) [45]	Jeddah—KSA	Residential	Bwh	RF: 2017 FP: 2010, 2050, 2080	IPCC SRES A2, A1B, and B1	-	RF: Meteonorm 7	BM: DesignBuilder EM: DesignBuilder + EnergyPlus	Annual temperature
12	Roshan, G. et al. (2019) [75]	Bandarabbas—Iran	Residential	Bwh	RF: 1961 FP: 2020, 2040, 2060	IPCC SRES A2	Statistical	RF: Meteonorm 7	BM: DesignBuilder EM: DesignBuilder + EnergyPlus	Annual temperature Monthly average temperature
13	Al Blooshi, L.S. et al. (2020) [49]	Abu Dhabi city, Al-Ain City, and AlDhafra—UAE	Residential	Bwh	-	-	-	-	-	-
14	Andric, I. & Al-Ghamdi, S.G. (2020) [9]	Doha—State of Qatar	Residential	Bwh	RF: 1961–1990 FP: 2020, 2050 and 2080	IPCC SRES A2	-	FP: CCWorldWeatherGen DT: IWEC TMY	BM: DesignBuilder (v.5.4) EM: DesignBuilder (v.5.4) + EnergyPlus (v.8.6)	Annual temperature
15	Andric, I. et al. (2020) [48]	Doha—State of Qatar	Residential	Bwh	RF: 1961–1990 FP: 2020, 2050, and 2080	IPCC SRES A2	Statistical morphing	FP: CCWorldWeatherGen DT: IWEC TMY	BM: DesignBuilder (v.5.4) EM: DesignBuilder (v.5.4) + EnergyPlus (v.8.6) Validation: Average percentage difference (Δ [%]), standard deviation, reference energy consumption	Annual, hourly basis on summer and winter day
16	Tahir et al. (2021) [47]	Doha—State of Qatar	Residential: monofacial solar PV; bifacial solar PV	Bwh	RF: 2020 FP: 2050, 2080	IPCC SRES A1B	-	FP: CCWorldWeatherGen DT: Hourly measured meteorological data Solar DT: Hourly measured solar data	-	Hourly solar irradiance, cell efficiency, albedo radiation, and energy consumption

Table A1. Cont.

No.	Author/ Year	Study Context	Building Typology	Climate Zone	Method Adopted					
					Reference Period Future Period(s)	Emission Scenarios	Downscaling Technique	Future Weather Files RF/FP	Energy Modelling Thermal Comfort Modelling	Temporal Dimension
17	Aram et al. (2022) [46]	Bushehr—Iran	Educational	Bwh	RF: 1961–1990 FP: 2080	IPCC SRES A2	Hadley Centre’s HadCM3	FP: CCWorldWeatherGen Solar FP: MeteoNorm 8.0.4 DT: IWECC TMY2	EM: Design Builder (v.7.0.0.116) EM: DesignBuilder (v.7.0.0.116) + EnergyPlus Solar: Validation: Monthly energy cost (bills) survey data Calibration: ASHRAE guideline 14-2014 (i) MBE—4.1% (<5%) (ii) RMSE—14.27% (<15%) Cost analysis: Optimization: NSGA-II algorithm; jEPlus +EA tool Retrofit measure selection: MCDM using TOPSIS method	Annual energy consumption and cooling load

Abbreviations: Change Special Report on Emissions Scenarios. RF: Reference time period; FP: Future time period; BM: Building modelling; EM: Energy modelling; DT: Data type; PHV: Passivhaus villa; STV: Standard villa; RF1: Reference time period 1 (past decades); RF2: Reference time period 2 (past decades); IPCC SRES: IPCC SRES: International Panel on Climate.

Table A2. Summary of the target, building energy consumption, cooling energy demand, thermal performance, environmental implications, mitigation strategies, and the findings from the reviewed papers.

No.	Author Year	Study Context	Building Typology	Target and Findings		Mitigation and Adaptation Strategies			
				Target	Main Findings	Passive	Active	Renewable Energy	
1	Radhi, H. (2009) [37]	AlAin city–UAE	Residential	(i) Investigate the energy consumption of buildings and the most effective measures to cope with this impact under different climate scenarios	CD: Maximum cooling reduction of 19.9%. Strategies: Shading devices—maximum reduction about 3.7% under the baseline; glazing type (single to double) fall of energy consumption of 10.5%; WWR decrease by 9%.	-	Thermal insulation, thermal mass, shading devices, glazing system, glazing area WWR 0.06, glazing area WWR 0.2	-	-
2	Radhi, H. (2009) [38]	Manama–Kingdom of Bahrain	Office (low rise); commercial (high rise)	(i) Evaluating the impact of current and past weather files on the energy and thermal performance (ii) Understanding the robustness of the prediction method in specifying the appropriate mitigation design strategies	CD and TE: CDD variation of 4.4–5.5%; HDD variation of 0.7%. TH: 1.4 C with a peak increase of 2.6 C in temperature; RH declined by 8.2%; PV potential decreased by 4%	-	-	Lighting and HVAC loads and electricity	-

Table A2. Cont.

No.	Author Year	Study Context	Building Typology	Target and Findings			Mitigation and Adaptation Strategies		
				Target	Main Findings		Passive	Active	Renewable Energy
3	Lelieveld, J. et al. (2012) [50]	Eastern Mediterranean and the Middle East	Residential; commercial	(i) Analysing a long-term meteorological dataset along with regional climate model projections for the 21st century, based on the intermediate IPCC SRES scenario A1B	ED: Increased air conditioning energy use with water deficits; distresses energy production for sea water desalination; increased competition with other sectors in need of water. CD: Increased cooling to achieve a temperature reduction of >5 °C to reach a comfortable 25 °C (i.e., cooling degree days, CCD > 5 °C); projected mid-century increase in CCD > 5 °C relative to the 1961–1990 control period is about 1–2 month	Soc: Excess mortality: sensitive groups of people suffering from sickness, elderly, children’s level of discomfort influenced by very high summer temperatures. Env: Hot summer to be the norm by the middle and the end of 21st C; poor air quality; extended heat waves	-	-	-
4	Roshan, G. et al. (2012) [39]	Iran	Residential	(i) Simulate the impact of climate changes on the need for energy consumption in household cooling and heating systems using degree day index	EC: 684 degree days of energy required for cooling by 1980; 982 degree days by 2025; 982 CDDs by 2050; 1148 degree days by 2075. CD: 214 degree days of energy is required for cooling by 1980; 222 degree days by 2025, 299 degree days by 2075	-	HVAC system with passive methods internal coverings, thermal inertia, or air changes of indoor air (traditional Iranian architecture)	Technical characteristics of HVAC systems	-
5	Shanks, K. et al. (2013) [12]	Dubai—UAE	Office (high-rise tower)	(i) Impact climate change will have on drivers of cooling demand	CD: 11% by 2020; 22.2% increase in cooling demand by 2050 and 40% by 2080	-	Low window to wall ratio—5%, double-glazed windows and relatively low U-Values for external walls and roofs.	-	-
6	Fahmy, M. et al. (2014) [40]	Cairo—Egypt	Residential	(i) Evaluate the usage of GRC walls as a new construction method in the housing industry in building envelopes under the future climate change conditions in comparison to using traditional brick wall materials.	EC: Decrease of 28% with the addition of 10 cm GCR to walls; a drop of 31.6% with the addition of 15 cm GCR.	-	Adding 10 cm GRC insulation for walls	-	-

Table A2. Cont.

No.	Author Year	Study Context	Building Typology	Target and Findings		Mitigation and Adaptation Strategies			
				Target	Main Findings	Passive	Active	Renewable Energy	
7	Khalfan M. et al. (2016) [41]	Al Wakrah–State of Qatar	Residential: Test (PHV); base model (STV)	(i) Evaluate the application of Passivhaus concepts for energy and thermal performance under climate change scenarios. (ii) Measure the indoor thermal comfort and moderate energy use for comparative assessment of Passivhaus and standard residences for current and future scenarios.	EC: 45% increase by 2080 (STV); 19% increase by 2080 (PHV) annual; reduction in energy demand of 50% CD: 1/3rd energy for cooling for PHV than STH; 33.33% reduction in 2080 cooling IT: 1 C to 3 C increase (RP); 3 C to 5 C increase (FP) TH: PMV, thermally comfortable (winter months—PMV score of 0; summer months—PMV score < 1) (PHV) Comfort charts: inner thermal zones; OT: >25 °C	-	Thermal insulation of the building	-	Photovoltaics (PV)
8	Ayoub, N et al. (2017) [42]	Doha–State of Qatar	Commercial	(i) Studying the potential of energy conservation in commercial buildings in Qatar by identifying the current energy conservation practices (ii) Assess the possible development of conservation practices	EC: Energy conservation savings about 7.5%; behaviour change about 2.74% and 15.80%; behaviour change + best design alternative -saving of 24.12% of total energy	Soc: Behaviour change conservation	Wood for walls, IEAD for roof, and fixed windows for glazing.	-	Photovoltaic (PV); on-site wind farms
9	Goudarzi, H. et al. (2017) [43]	Kerman–Iran	Residential	(i) Assessed the efficiency of four passive techniques, including green roof, roof pond, wind catcher, and underground house in reducing mean daily energy loss through building envelopes and cooling energy saving	CD: Most energy efficient: wind catcher > roof garden> roof pond > underground house	Eco: The life cycle cost (LCC) for 20 years using four passive systems; the Economic evaluation including (1) Initial cost of passive techniques; (2) Operation cost of passive techniques; (3) Maintenance cost of passive techniques. Most economic approaches—wind catcher and roof pond	Green roof, roof pond, wind catcher, and underground house	-	-

Table A2. Cont.

No.	Author Year	Study Context	Building Typology	Target and Findings		Mitigation and Adaptation Strategies		
				Target	Main Findings	Passive	Active	Renewable Energy
10	Abuhussain, M.A. et al. (2018) [44]	Jeddah—KSA	Residential	(i) Examining the capacity of the Saudi residential energy codes to cope with future climate change	CD: Reduction in the total annual cooling demands at respective rates of 38% and 40% applying code 1 and 2.	-	Low window to wall ratio of 5%, double-glazed windows, and relatively low U-Values for external walls and roofs.	-
11	Abuhussain, M.A. et al. (2019) [45]	Jeddah—KSA	Residential	(i) Assess the capability of existing air-conditioned houses to perform under the current and the future climate change (ii) Examine how financially feasible the codes are under climate change impact.	CD: Reduction in the total annual cooling demands at respective rates of 38% and 40% applying code 1 and 2.	Economic: The cumulative saving flow of the retrofitted house shows that the payback time from electricity bill of the standard of code 2 will be 7–8 years or 11–12 years depending on the house type.	Low window to wall ratio of 5%, double-glazed windows, and relatively low U-Values for external walls and roof.	-
12	Roshan, G. et al. (2019) [75]	Bandarabbas—Iran	Residential	(i) Discuss the implications of climate change on the energy demand of the building stocks along the northern coasts and the southern Oman sea. (ii) Using a degree day index to quantify the energy demand and carbon dioxide emissions	CD: 95% of energy demand towards meeting the cooling loads. CO ₂ : Increased by 700 kg/year TH: increase of 2.82 °C in temperature; RH increase by 10%; 4 °C increase in temperature in 2100.	-	-	-
13	Al Blooshi, L. S. et al. (2020) [49]	Abu Dhabi city, Al-Ain City, and AlDhafra—UAE	Residential	(i) Explore the environmental and socioeconomic impact of climate change on the energy consumption of a stratified random sample of the residents of three main regions in the Emirates of Abu Dhabi and (ii) Investigate residents' awareness of this change.	EC: 88% of the Emiratis believe that weather and climate change are affecting their energy and water consumption	Social: Energy consumption influenced by the climate change; residents unaware of implications of climate change on the energy and water consumption	-	-
14	Andric, I. & Al-Ghamdi, S. G. (2020) [9]	Doha—State of Qatar	Residential	(i) Quantify the building environmental impacts and grid stability implications of increased cooling demand (ii) Assess environmental impacts (iii) Mitigation measures based on environmental impact assessment	EC: Annual energy demand increased to 30%. Increase in energy demand by 9% in 2020; 17% in 2050; and 30% in 2080.	Env: Increase in energy demand: 17.5 tCO ₂ eq. emission, 8 toe fossil fuel depletion, 3551 m ³ of water consumption, 20 g of 1.4-DB released to marine ecosystem	Thermal insulation	Photovoltaics (PVs)—solar radiation, wind and tidal farms—coastal areas

Table A2. Cont.

No.	Author Year	Study Context	Building Typology	Target and Findings		Mitigation and Adaptation Strategies		
				Target	Main Findings	Passive	Active	Renewable Energy
15	Andric, I. et al. (2020) [48]	Doha–State of Qatar	Residential	(i) Assess the potential of energy demand reduction through building renovation—green roofs and walls. (ii) Compare the building energy consumption for renovation scenarios. (iii) Quantify the impact of uncertainties and assumptions through sensitivity study	EC: Annual energy demand increased to 30%. Increase in energy demand of 9% in 2020; 17% in 2050; and 30% in 2080. MM: Majority of heat gains caused by the heat transfer through envelope rather than solar gains. BS: Thermal insulation	Env: Increase in energy demand: 17.5 tCO ₂ eq. emission, 8 toe fossil fuel depletion, 3551 m ³ of water consumption, 20 g of 1.4-DB released to marine ecosystem	Thermal insulation; energy-efficient glazing; green walls; green roofs	-
16	Tahir et al. (2021) [47]	Doha–State of Qatar	Residential: Monofacial solar PV; Bifacial solar PV	(i) Mathematical modelling and simulation to explore the potential of PV types offering more energy yield under the impact of climatic change (ii) Assess the performance of monofacial and bifacial PV in predicted climate change scenarios based on the PV output.	EO: A bifacial PV yields higher energy output than a monofacial of 18–48%, a decrease in insolation of 5% (2050) and 8% (2080)	-	Solar bifacial PV: Higher power output and climate change mitigation make the bifacial PV most preferred in the market when considering the long-term implications of climate change	-
17	Aram et al. (2022) [46]	Bushehr–Iran	Educational	(i) Investigate the comparative effectiveness of an energy optimized NZEB in responding to future climate change. (ii) Examine the retrofit strategies to achieve n-NZEB considering the climate change	EC: reduced by 65.14% (RF); EC: reduced by 86.18% if (FP); n-NZEB meet 90% of its own energy demands. CD: 11.83% reduction in cooling load. TE: A 247% reduction (with retrofits); Energy saving retrofit: DbIClrArg, Rockwool; a 52% reduction in the future and a 49% reduction in the present	Eco: Cost analysis showing higher energy savings with a 40.4% reduction in the total cooling load	Thermal insulation material (rock wool; PVC), window glazing (DbIClrArg; DbIClrAir), insulation thickness (0.1 m), natural ventilation, shading	FCU 4-pipe, Air-cooled; Chiller District Heating and Cooling FCU 4-pipe; Zone Water to Air Heat Pump by Ground Heat Exchanger; VAV Reheat, Air-cooled Chiller

Abbreviations: EC: Annual energy consumption/demand; CD: Cooling energy demand; IT: Indoor temperature; EO: Renewable sources energy output; TE: Total energy (space conditioning + others); PHV: Passivhaus villa; STV: Standard villa; PV: Photovoltaics; Env: Environmental impact; Soc: Social impact; Eco: Economic impact; CDD: Cooling Degree Days; HDD: Heating Degree Days; TH: Thermal performance; OT: Operative temperature.

References

1. IPCC. Climate Change 2014: Synthesis Report. In *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC: Geneva, Switzerland, 2014.
2. IPCC Summary for Policymakers. Climate Change 2021: The Physical Science Basis. In *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., et al., Eds.; Cambridge University Press: Cambridge, UK, 2021; in press.
3. Nakicenovic, N.; Alcamo, J.; Davis, G.; Vries, B.D.; Fenhann, J.; Gaffin, S.; Gregory, K.; Grübler, A.; Jung, T.Y.; Kram, T.; et al. IPCC: Special Report on Emissions Scenarios. 2000. Available online: <https://www.grida.no/climate/ipcc/emission/index.htm> (accessed on 8 December 2023).
4. Hrabovszky-Horváth, S.; Pálvölgyi, T.; Csoknyai, T.; Talamon, A. Generalized residential building typology for urban climate change mitigation and adaptation strategies: The case of Hungary. *Energy Build.* **2013**, *62*, 475–485. [\[CrossRef\]](#)
5. Andrić, I.; Koc, M.; Al-Ghamdi, S.G. A review of climate change implications for built environment: Impacts, mitigation measures and associated challenges in developed and developing countries. *J. Clean. Prod.* **2019**, *211*, 83–102. [\[CrossRef\]](#)
6. Andric, I.; Le Corre, O.; Lacarrière, B.; Ferrão, P.; Al-Ghamdi, S.G. Initial approximation of the implications for architecture due to climate change. *Adv. Build. Energy Res.* **2019**, *15*, 337–367. [\[CrossRef\]](#)
7. Sierra-Pérez, J.; Rodríguez-Soria, B.; Boschmonart-Rives, J.; Gabarrell, X. Integrated life cycle assessment and thermodynamic simulation of a public building's envelope renovation: Conventional vs. *Passivhaus* proposal. *Appl. Energy* **2018**, *212*, 1510–1521. [\[CrossRef\]](#)
8. Dalla Mora, T.; Peron, F.; Romagnoni, P.; Almeida, M.; Ferreira, M. Tools and procedures to support decision making for cost-effective energy and carbon emissions optimization in building renovation. *Energy Build.* **2018**, *167*, 200–215. [\[CrossRef\]](#)
9. Andric, I.; Al-Ghamdi, S.G. Climate change implications for environmental performance of residential building energy use: The case of Qatar. *Energy Rep.* **2020**, *6*, 587–592. [\[CrossRef\]](#)
10. Dabaieh, M.; Wanas, O.; Hegazy, M.A.; Johansson, E. Reducing cooling demands in a hot dry climate: A simulation study for non-insulated passive cool roof thermal performance in residential buildings. *Energy Build.* **2015**, *89*, 142–152. [\[CrossRef\]](#)
11. Ameer, B.; Krarti, M. Impact of subsidization on high energy performance designs for Kuwaiti residential buildings. *Energy Build.* **2016**, *116*, 249–262. [\[CrossRef\]](#)
12. Shanks, K.; Nezamifar, E. Impacts of climate change on building cooling demands in the UAE. In Proceedings of the SB13 Dubai: Advancing the Green Agenda Technology, Practices and Policies, Dubai, United Arab Emirates, 8–10 December 2013.
13. Huang, K.T.; Hwang, R.L. Future trends of residential building cooling energy and passive adaptation measures to counteract climate change: The case of Taiwan. *Appl. Energy* **2016**, *184*, 1230–1240. [\[CrossRef\]](#)
14. Nik, V.M.; Mata, E.; Kalagasidis, A.S.; Scartezini, J.L. Effective and robust energy retrofitting measures for future climatic conditions—Reduced heating demand of Swedish households. *Energy Build.* **2016**, *121*, 176–187. [\[CrossRef\]](#)
15. United Nations Framework Convention on Climate Change (UNFCCC). *Paris Agreement*; United Nations: Paris, France, 2015; pp. 1–27.
16. Global Risk Report 2021. World Economic Forum. 2021. Available online: <https://www.weforum.org/reports/the-global-risks-report-2021> (accessed on 8 December 2023).
17. UAE Energy Strategy 2020. 2021. Available online: <https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/environment-and-energy/uae-energy-strategy-2050> (accessed on 8 December 2023).
18. Lisa, G. Preparation of future weather data to study the impact of climate change on buildings. *Build. Environ.* **2009**, *44*, 793–800. [\[CrossRef\]](#)
19. Li, Y.; Wang, W.; Wang, Y.; Xin, Y.; He, T.; Zhao, G. A review of studies involving the effects of climate change on the energy consumption for building heating and cooling. *Int. J. Environ. Res. Public Health* **2021**, *18*, 40. [\[CrossRef\]](#) [\[PubMed\]](#)
20. Yassaghi, H.; Hoque, S. An overview of climate change and building energy: Performance, responses and uncertainties. *Buildings* **2019**, *9*, 166. [\[CrossRef\]](#)
21. Campagna, L.M.; Fiorito, F. On the Impact of Climate Change on Building Energy Consumptions: A Meta-Analysis. *Energies* **2022**, *15*, 354. [\[CrossRef\]](#)
22. Konstantin, V.; Montserrat, Z.; Manuel, C. Effects of climate change on variations in climatic zones and heating energy consumption of residential buildings in the southern Chile. *Energy Build.* **2020**, *215*, 109874. [\[CrossRef\]](#)
23. Pérez-Lombard, L.; Ortiz, J.; Pout, C. A review on buildings energy consumption information. *Energy Build.* **2008**, *40*, 394–398. [\[CrossRef\]](#)
24. Mehrotra, R.; Sharma, A. A multisite stochastic downscaling model of daily rainfall occurrences with long term persistence. In *MODSIM 2007: International Congress on Modelling and Simulation: Land, Water and Environmental Management: Integrated Systems for Sustainability*; University of Canterbury: Christchurch, New Zealand, 2007; pp. 1485–1491.
25. Sherif, M.; Chowdhury, R.; Shetty, A. Rainfall and intensity-duration-frequency (IDF) curves in the United Arab Emirates. In Proceedings of the World Environment Water Resource Congress, Portland, OR, USA, 1–5 May 2014; pp. 2316–2325.
26. Kottek, M.; Grieser, J.; Beck, C.; Rudolf, B.; Rubel, F. World Map of the Köppen-Geiger Climate Classification Updated. *Meteorologische Z.* **2006**, *15*, 259–263. [\[CrossRef\]](#)
27. UAE Second National Communication. 2010. Available online: <https://unfccc.int/resource/docs/natc/arenc2.pdf> (accessed on 8 December 2023).

28. Fitzpatrick, M. *Assessment of Climate Change Impacts on Key Terrestrial Ecosystems and Species in the Arabian Gulf Countries, Technical Concept Note Prepared for the Phase II Work Program on Climate Change Vulnerability and Adaptation*; Abu Dhabi Environment Agency (EAD): Abu Dhabi, United Arab Emirates, 2012.
29. World Meteorological Organization. WMO Guidelines on the Calculation of Climate Normals. 2017. Available online: <https://library.wmo.int/records/item/55797-wmo-guidelines-on-the-calculation-of-climate-normals> (accessed on 8 December 2023).
30. Fencel, A.; Swartz, C.; Yates, D. Climate Change Impacts, Vulnerability, and Adaptation. Prepared for the Environment Agency of Abu Dhabi. Available online: <https://www.sei.org/publications/climate-change-impacts-vulnerability-adaptation/> (accessed on 8 December 2023).
31. Juaidi, A.; Montoya, F.G.; Gázquez, J.A.; Manzano-Agugliaro, F. An overview of energy balance compared to sustainable energy in United Arab Emirates. *Renew. Sustain. Energy Rev.* **2016**, *55*, 1195–1209. [\[CrossRef\]](#)
32. Mfarrej, M.F.B. Climate change patterns in the UAE: A qualitative research and review. *Nat. Environ. Pollut. Technol.* **2019**, *18*, 261–268.
33. AlRustamani, Z.A. Impacts of Climate Change on Urban Development in the Uae: The Case of Dubai. Master's Thesis, United Arab Emirates University, Abu Dhabi, United Arab Emirates, 2014.
34. Moher, D.; Shamseer, L.; Clarke, M.; Ghersi, D.; Liberati, A.; Petticrew, M.; Shekelle, P.; Stewart, L.A.; PRISMA-P Group. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst. Rev.* **2015**, *4*, 1. [\[CrossRef\]](#)
35. Dixon-Woods, M. Using framework-based synthesis for conducting reviews of qualitative studies. *BMC Med.* **2011**, *9*, 39. [\[CrossRef\]](#)
36. Carroll, C.; Booth, A.; Leaviss, J.; Rick, J. “Best fit” framework synthesis: Refining the method. *BMC Med. Res. Methodol.* **2013**, *13*, 37. [\[CrossRef\]](#)
37. Radhi, H. A comparison of the accuracy of building energy analysis in Bahrain using data from different weather periods. *Renew. Energy* **2009**, *34*, 869–875. [\[CrossRef\]](#)
38. Radhi, H. Evaluating the potential impact of global warming on the UAE residential buildings—A contribution to reduce the CO₂ emissions. *Build. Environ.* **2009**, *44*, 2451–2462. [\[CrossRef\]](#)
39. Roshan, G.R.; Orosa, J.A.; Nasrabadi, T. Simulation of climate change impact on energy consumption in buildings, case study of Iran. *Energy Policy* **2012**, *49*, 731–739. [\[CrossRef\]](#)
40. Fahmy, M.; Mahdy, M.M.; Nikolopoulou, M. Prediction of future energy consumption reduction using GRC envelope optimization for residential buildings in Egypt. *Energy Build.* **2014**, *70*, 186–193. [\[CrossRef\]](#)
41. Khalfan, M.; Sharples, S. The present and future energy performance of the first Passivhaus project in the Gulf region. *Sustainability* **2016**, *8*, 139. [\[CrossRef\]](#)
42. Ayoub, N.; Musharavati, F.; Pokharell, S.; Gabbar, H.A. Energy consumption and conservation practices in Qatar—A case study of a hotel building. *Energy Build.* **2014**, *84*, 55–69. [\[CrossRef\]](#)
43. Goudarzi, H.; Mostafaiepour, A. Energy saving evaluation of passive systems for residential buildings in hot and dry regions. *Renew. Sustain. Energy Rev.* **2017**, *68*, 432–446. [\[CrossRef\]](#)
44. Abuhussain, M.A.; Chow, D.H.C.; Sharples, S. Assessing the Adaptability of the Saudi Residential Building's Energy Code for Future Climate Change Scenarios. In *Smart Healthy Within Two-Degree Limit (Plea 2018)*; Passive and Low Energy Architecture (PLEA): Hong Kong, 2018; Volume 1, pp. 74–79.
45. Abuhussain, M.A.; Chow, D.H.C.; Sharples, S. Sensitivity energy analysis for the Saudi residential buildings envelope codes under future climate change scenarios: The case for the hot and humid region in Jeddah. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2019; Volume 329, p. 012039.
46. Aram, K.; Taherkhani, R.; Šimelytė, A. Multistage Optimization toward a Nearly Net Zero Energy Building Due to Climate Change. *Energies* **2022**, *15*, 983. [\[CrossRef\]](#)
47. Tahir, F.; Baloch, A.A.; Al-Ghamdi, S.G. Impact of climate change on solar monofacial and bifacial Photovoltaics (PV) potential in Qatar. *Energy Rep.* **2022**, *8*, 518–522. [\[CrossRef\]](#)
48. Andric, I.; Kamal, A.; Al-Ghamdi, S.G. Efficiency of green roofs and green walls as climate change mitigation measures in extremely hot and dry climate: Case study of Qatar. *Energy Rep.* **2020**, *6*, 2476–2489. [\[CrossRef\]](#)
49. Al Blooshi, L.S.; Ksikisi, T.S.; Gargoum, A.S.; Aboelenein, M. Climate Change and Environmental Awareness: A Study of Energy Consumption among the Residents of Abu Dhabi, UAE. *Perspect. Glob. Dev. Technol.* **2020**, *18*, 564–582. [\[CrossRef\]](#)
50. Lelieveld, J.; Hadjinicolaou, P.; Kostopoulou, E.; Chenoweth, J.; El Maayar, M.; Giannakopoulos, C.; Xoplaki, E. Climate change and impacts in the Eastern Mediterranean and the Middle East. *Clim. Chang.* **2012**, *114*, 667–687. [\[CrossRef\]](#)
51. Beck, H.E.; Zimmermann, N.E.; McVicar, T.R.; Vergopolan, N.; Berg, A.; Wood, E.F. Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Sci. Data* **2018**, *5*, 180214. [\[CrossRef\]](#)
52. Köppen Climate Classification System. Available online: <https://education.nationalgeographic.org/resource/koppen-climate-classification-system/> (accessed on 8 December 2023).
53. Nielsen, C.N.; Kolarik, J. Utilization of Climate Files Predicting Future Weather in Dynamic Building Performance Simulation—A review. *J. Phys. Conf. Ser.* **2021**, *2069*, 012070. [\[CrossRef\]](#)
54. O'Neill, B.C.; Tebaldi, C.; Van Vuuren, D.P.; Eyring, V.; Friedlingstein, P.; Hurtt, G.; Sanderson, B.M. The scenario model intercomparison project (ScenarioMIP) for CMIP6. *Geosci. Model Dev.* **2016**, *9*, 3461–3482. [\[CrossRef\]](#)
55. Höök, M.; Tang, X. Depletion of fossil fuels and anthropogenic climate change—A review. *Energy Policy* **2013**, *52*, 797–809. [\[CrossRef\]](#)

56. Moss, R.H.; Edmonds, J.A.; Hibbard, K.A.; Manning, M.R.; Rose, S.K.; Van Vuuren, D.P.; Wilbanks, T.J. The next generation of scenarios for climate change research and assessment. *Nature* **2010**, *463*, 747–756. [\[CrossRef\]](#)
57. Stocker, T. (Ed.) *Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2014.
58. Bhuvandas, N.; Timbadiya, P.V.; Patel, P.L.; Porey, P.D. Review of downscaling methods in climate change and their role in hydrological studies. *World Acad. Sci. Eng. Technol.* **2014**, *8*, 660–665.
59. New, M.; Lopez, A.; Dessai, S.; Wilby, R. Challenges in using probabilistic climate change information for impact assessments: An example from the water sector. *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* **2007**, *365*, 2117–2131. [\[CrossRef\]](#)
60. Cannon, A.J. Negative ridge regression parameters for improving the covariance structure of multivariate linear downscaling models. *Int. J. Climatol. A J. R. Meteorol. Soc.* **2009**, *29*, 761–769. [\[CrossRef\]](#)
61. Charles, S.P.; Bates, B.C.; Smith, I.N.; Hughes, J.P. Statistical downscaling of daily precipitation from observed and modelled atmospheric fields. *Hydrol. Process.* **2004**, *18*, 1373–1394. [\[CrossRef\]](#)
62. Fowler, H.J.; Blenkinsop, S.; Tebaldi, C. Linking climate change modelling to impacts studies: Recent advances in downscaling techniques for hydrological modelling. *Int. J. Climatol. A J. R. Meteorol. Soc.* **2007**, *27*, 1547–1578. [\[CrossRef\]](#)
63. Berardi, U.; Jafarpur, P. Assessing the impact of climate change on building heating and cooling energy demand in Canada. *Renew. Sustain. Energy Rev.* **2020**, *121*, 109681. [\[CrossRef\]](#)
64. Trzaska, S.; Schnarr, E. *A Review of Downscaling Methods for Climate Change Projections*; United States Agency for International Development by Tetra Tech ARD: Washington, DC, USA, 2014; pp. 1–42.
65. Feser, F.; Rockel, B.; von Storch, H.; Winterfeldt, J.; Zahn, M. Regional climate models add value to global model data: A review and selected examples. *Bull. Am. Meteorol. Soc.* **2011**, *92*, 1181–1192. [\[CrossRef\]](#)
66. Déqué, M.; Jones, R.G.; Wild, M.; Giorgi, F.; Christensen, J.H.; Hassell, D.C.; Hurk, B.V.D. Global high resolution versus Limited Area Model climate change projections over Europe: Quantifying confidence level from prudence results. *Clim. Dyn.* **2005**, *25*, 653–670. [\[CrossRef\]](#)
67. Colette, A.; Vautard, R.; Vrac, M. Regional climate downscaling with prior statistical correction of the global climate forcing. *Geophys. Res. Lett.* **2012**, *39*. [\[CrossRef\]](#)
68. Chakraborty, D.; Alam, A.; Chaudhuri, S.; Başağaoğlu, H.; Sulbaran, T.; Langar, S. Scenario-based prediction of climate change impacts on building cooling energy consumption with explainable artificial intelligence. *Appl. Energy* **2021**, *291*, 116807. [\[CrossRef\]](#)
69. Hosseini, M.; Bigtashi, A.; Lee, B. Generating future weather files under climate change scenarios to support building energy simulation—A machine learning approach. *Energy Build.* **2021**, *230*, 110543. [\[CrossRef\]](#)
70. Herrera, M.; Natarajan, S.; Coley, D.A.; Kershaw, T.; Ramallo-González, A.P.; Eames, M.; Wood, M. A review of current and future weather data for building simulation. *Build. Serv. Eng. Res. Technol.* **2017**, *38*, 602–627. [\[CrossRef\]](#)
71. Fereidani, N.A.; Rodrigues, E.; Gaspar, A.R. A review of the energy implications of passive building design and active measures under climate change in the Middle East. *J. Clean. Prod.* **2021**, *305*, 127152. [\[CrossRef\]](#)
72. Weber, W.; Yannas, S. (Eds.) *Lessons from Vernacular Architecture*; Routledge: London, UK, 2014; Volume 2.
73. Mujeebu, M.A. A review of solar energy exploration and utilization in Saudi buildings. *Int. J. Adv. Thermofluid Res.* **2015**, *1*, 70–85.
74. Conde, M.G.S.; Shanks, K. Evaluation of Available Building Integrated Photovoltaic (BIPV) Systems and their Impact when Used in Commercial Buildings in the United Arab Emirates. *Int. J. Sustain. Energy Dev. (IJSED)* **2019**, *7*, 344–356. [\[CrossRef\]](#)
75. Roshan, G.; Arab, M.; Klimenko, V. Modeling the impact of climate change on energy consumption and carbon dioxide emissions of buildings in Iran. *J. Environ. Health Sci. Eng.* **2019**, *17*, 889–906. [\[CrossRef\]](#)
76. Met Office—Meteorological Office, Weather and Climate Change. 2016. Available online: <http://www.metoffice.gov.uk/news/releases/archive/2016/2015-global-temperature> (accessed on 8 December 2023).

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.