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Energy Retrofitting Application Research to Achieve Energy Efficiency in Hot-Arid Climates in Residential Buildings: A Case Study of Saudi Arabia

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Abstract**—**This study aims to present an overview of recent research in building energy-retrofitting strategy applications and analyzing them within the context of hot arid climate regions which is in this case study represented by the Kingdom of Saudi Arabia. The main goal of this research is to do an analytical study of recent research approaches to show where the primary gap in knowledge exists and outline which possible strategies are available that can be applied in future research. Also, the paper focuses on energy retrofitting strategies at a building envelop level. The study is limited to specific measures within the hot arid climate region. Scientific articles were carefully chosen as they met the expression criteria, such as retrofitting, energy-retrofitting, hot-arid, energy efficiency, residential buildings, which helped narrow the research scope. Then the papers were explored through descriptive analysis and justified results within the Saudi context in order to draw an overview of future opportunities from the field of study for the last two decades. The conclusions of the analysis of the recent research confirmed that the field of study had a research shortage on investigating actual applications and testing of newly introduced energy efficiency applications, lack of energy cost feasibility studies and there was also a lack of public awareness. In terms of research methods, it was found that simulation software was a major instrument used in energy retrofitting application research. The main knowledge gaps that were identified included the need for certain research regarding actual application testing; energy retrofitting strategies application feasibility; the lack of research on the importance of how strategies apply first followed by the user acceptance of developed scenarios.

Keywords**—**Energy efficiency, energy retrofitting, hot arid climate, Saudi Arabia.

I. Introduction

In the last decade, energy efficiency has become a hot topic in the Middle East region, especially within the countries who are based in the oil economy. In 2016, the Kingdom of Saudi Arabia (KSA) announced a new vision called (Saudi 2030 Vision) after oil prices dropped. According to Felimban, KSA is burning one-third of its oil production to generate electricity [1]. Buildings being the main consumer of electrical energy represent a major potential contributor to lowering energy consumption in Saudi Arabia [2], [3]. Official sources, such as Saudi Energy Efficiency Centre (SEEC), have stated that buildings consume around 80% of energy in the form of electricity that served the buildings needs while air conditioning used 50% of this consumption [4]. However, the government has established several amendments for the new building codes and regulations while the existing buildings remain, which need energy retrofitting applications.

Building Energy Retrofitting in Hot-Arid Climate Regions

Energy retrofitting has recently been introduced in the Gulf Cooperation Council (GCC) countries after the period when oil prices decreased. Normally, energy retrofitting project applications followed the business model in the context of hot climates due to the low energy tariff prices which impacted the project economic feasibility. Nowadays, the awareness of energy consumption and the CO_2 emissions has started to take place in many new projects after the new building codes were introduced. There has also been research carried out [5] that has shown a remarkable reduction in energy consumption after applying different scenarios of energy retrofitting strategies. However, most of the studies, such as [6]-[8], have focused on simulations rather than actual testing and having been put into practice.

Most of the research approaches such as [5], [8], [9] applied at least one of two saving measures (insulation enhancement, window glazing upgrade) or both in most cases. These studies used simulations regarding the suggested measures and provided a range of savings in energy consumption. A number of recent researches such as [8], [10]-[12] also showed a relationship between the numbers of measures applied to the energy reduction levels. Almost all of the studies used the simulation method as a basic tool to produce quick results which in an actual application might differ and cost analysis also needs to be taken into account.

The solo research used monitoring which was fully supported financially by the Saudi government using actual pricing and timing. The applied measures were not just in the envelope but also used in other modes of savings, such as the HVAC systems efficiency upgrade. However, more actual application research of energy retrofitting is needed, especially in this climate region.

II. Methodology

The study was based on 29 research papers that were carefully selected by searching specific words (energy, retrofitting, efficiency, hot-arid climate, buildings, Saudi Arabia). ScienceDirect.com was the main search engine

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website that was used. 15 papers were excluded since they focused on other climate regions and towards code and regulations levels. 14 papers were scientifically related to the scope, and they mentioned substantial savings in energy consumption. However, the articles were concentrated in saving energy in relation to certain measures that been applied mainly using digital simulations. The articles were analyzed based on the measures that had been used in their research. Also, building types were carefully selected residential or any other related type of buildings such as educational. In the last step, data was analyzed within the context of KSA to illustrate results and future opportunities.

TABLE I
SAVING ENERGY ARTICLES CONSIDERING DIFFERENT MEASURES AND METHODS

Date	Article Name	Building Type	Method	Measures	Outcomes
2003	Retrofitting residential buildings in hot and arid climates[5]	Residential Villa 42,403 old (Existing)	Simulation	3	Savings 3.25 M. MWh in 10 Years, Earn $577 Million
2014	Domestic energy consumption patterns in a hot and humid climate: A multiple-case study analysis[6]	6 Residential buildings: 3 villas, 3 flats	Simulation	4	An energy consumption reduction in a range from 21% to 37%. Regionally replicable
2014	Domestic energy consumption patterns in a hot and arid climate: Multiple-case study analysis [7]	6 Residential buildings: 3 villas, 3 flats	Simulation	4	Energy consumption reductions in the range of 15%-34%.
2014	Energy consumption patterns for domestic buildings in hot climates using Saudi Arabia as Case study field: Multiple case study analysis [8]	Residential	Simulation and interviews	3	A decrease in energy utilization, varying but reaching 37% kWh/m² and Co2 emission
2014	Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U.A.E. buildings [9]	Residential Villa (New, Existing)	Simulation	3	Up to 23.6% reduction on Annual energy
2015	Optimal design of residential building envelope systems in KSA [10]	Residential Villa (New)	Simulation	5	Energy savings of non-subsidized energy cost 47.3%, 41.5%, 43.19%, 41.1% and 26%
2016	Energy retrofit strategies for housing sector in the arid climate [11]	10 Residential Villa (Existing)	monitoring	4	Increasing the energy efficiency by 25.1% in average, savings varies from 14.4% to 47.6% of the total electricity
2016	Establishing domestic low energy consumption reference levels for Saudi Arabia and the wider Middle Eastern region[12]	6 Residential buildings: 3 villas, 3 flats	Simulation	4	Reduction in energy consumption of up to 71.6%, compared with similar houses.
2017	Envelope retrofit in hot arid climates [13]	Residential Apartment block	Simulation	1	It can lead up to 16.5% savings of total energy
2017	Effectiveness and viability of residential building energy retrofits in Dubai [14]	Residential Villa (Existing)	Simulation	3	Reduce summer peak demand by 40%
2017	Retrofitting strategy for building envelopes to achieve energy efficient [15]	Higher educational building	Simulation	4	Reduce energy consumption of an average of 33%.
2018	Displacing air conditioning in KSA: An evaluation of 'fabric first' design integrated with hybrid night radiant and ground pipe cooling systems [16]	Residential	Simulation	4	Passive measures could reduce 37% The hybrid system is predicted to reduce about 43%
2019	Indoor environmental monitoring of residential buildings in Saudi Arabia, Makkah: a case study	Residential Villa	Simulation	2	Reduce cooling load up to 34.5%
2019	Envelope retrofitting strategies for public school buildings in Jordan [17]	Higher educational building	Simulation	2	Envelope retrofitting leads to energy savings of up to 54% with a payback period of 5.5 years.

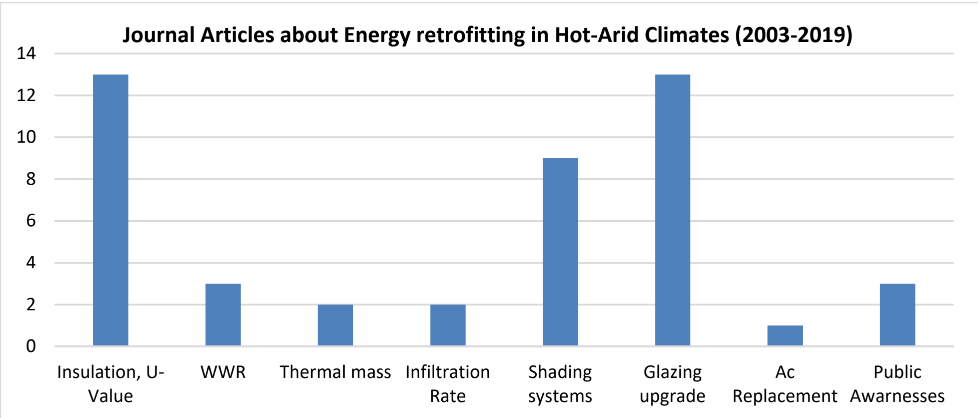

Fig. 1 Compared applied measures between articles

III. LITERATURE

A. Energy Retrofitting State of the Art

The scope of this research was to define which measures had been applied and where the primary research gaps are within recent research. In Table I the measures column represents how many times each measure has been used between the conducted articles. In addition, a research showed energy savings which were applied retrofitting measures that were used in a public building in Egypt which was able to reduce the energy consumption on an average of 33% [15]. Other research suggested several scenarios of energy saving measure applications that were able to reduce energy consumption up to 72.6% compared to similar houses [12].

In general, insulation and double glazing upgrades were commonly used as shown in Fig. 1 in order to enhance the efficiency of the building energy performance. Shading device systems were used by more than half of the researches. Onsite energy was used in just below 40% of the research which was expected to be more in this climate. The rest of the measurements were explored but they showed limitations either due to the costs or they were proven too difficult to be applied in practice. For illustration, the application of reducing the current window to wall ratio (WWR) is not appropriate in existing buildings. In general, energy retrofitting applications in building envelops in hot arid climates needs further research especially regarding actual applications that also include cost analysis.

B. Energy Retrofitting within the KSA Context

In KSA context, retrofitting has been used either to keep historic buildings, to renovate or to fix what has structurally failed. Hence, energy retrofitting is new terminology used in architecture and in constriction due to many reasons such as energy efficiency which has been recently introduced, low energy bills, and public awareness. The Government and businesses started to be more careful about energy consumption after the energy bills increased significantly several times [1].

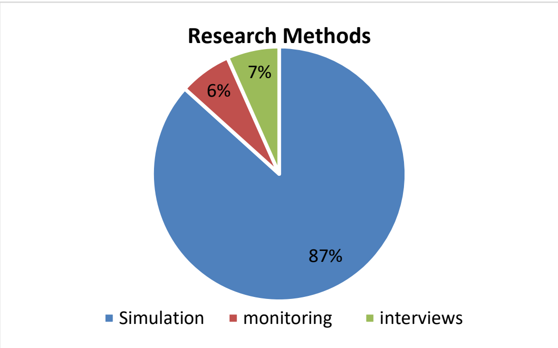

Fig. 2 The percentage of research method application

Until now, there have been no energy retrofitting projects of building envelops that have been done due to the recent changes in energy which started at the beginning of 2018. The Social Development Bank (SDB) defined the restoration (refurbishment) financial support as: "Is a financing program designed for restoration, maintenance, repair of structural and emergency defects, for additions or necessary modifications for private residential houses" which indicated the understanding and the importance of energy within a governmental sector [18]. The government needs to be involved to achieve national savings in energy consumption from buildings in particular. The application of these measures must be levelled based on energy reduction impact and feasibility to have a positive impact in the future.

IV. Outcomes and Opportunities

The recent research has shown a lack of actual application of these measures while there has been a large amount of research using simulations as shown in Fig. 2 whereby positive results were found. Insulation and window double glazing upgrades were pointed out to be essential measures for further energy enhancement. Even with low WWR, shading devices were also recommended due to heat prevention needs. On-site energy generation was also suggested, especially in this hot region coupled with efficient Air Conditioning (AC) systems. Infiltration rate measures were also mentioned, this needs further investigation.

The application of energy savings measures is essential, especially if the KSA wishes to achieve the Saudi 2030 Vision goals. The SDB is willing to provide an opportunity in which they provide up to sixty thousand Saudi Riyal (Sixteen thousand U.S. Dollars) to be paid back in 5 years with no interest, which will be used in retrofitting [18]. The challenge is to decide which measures need to be applied first and followed by which second measure, considering the total national impact and with respect to economic feasibility.

V. Conclusion

This study aimed to present an overview of recent research in building energy-retrofitting strategies applications and analyzing it within the context of hot arid climate regions represented in the KSA. This study presents a broad understanding of an analytical review of recent research applications within the last decade. It also explains where the main knowledge gap is and which are the most applicable strategies that could be applied in future research. The paper conclusion presents the research the discussions of the results after a systematic method has been applied. There was an analysis of the information which was conducted through a review of articles from a well-known database. The study narrowed the searching scope to specific criteria such as energy performance, hot-arid climatic regions, residential buildings and existing buildings. The method provided a general understanding of the current research worldwide while it also provided in-depth examples within the related papers. However, the limitation on this study was on only focusing on one database for the majority of the research while if other databases were researched and interviews carried out in practice this would have added an additional aspect to the study. The content of the results presented a review of existing research and current knowledge regarding energy retrofitting strategies and application for residential buildings application, in order to detect research orientation and define knowledge gaps for research orientation.

Energy retrofitting in residential buildings: This topic is highly relevant and will be in the future of increasing interest. It is relevant to state that energy retrofitting research trends are currently in an active profile which can be seen in the amount of research that has been done in the last six years. This was due to the introduction of energy efficiency. Worldwide, energy retrofitting applications of buildings is slowly being implemented due to the feasibility of retrofitting projects. The KSA programs have taken the initiative to enhance the energy efficiency from electric devices as a first step but they have not yet considered the current buildings. In this aspect, energy retrofitting can be seen as an opportunity for future development with respect to the Saudi 2030 Vision goals.

Research methods: Software simulations were mainly used as a primary tool for saving measure applications, which is a good initial testing tool for assumed results and performance driven developments. However, there is also another research tool used in monitoring which presented valuable information about the actual performance of retrofitting strategies and applications, but this solo trail applied certain measures which limited it for the project economic feasibility.

Energy retrofitting strategies: Passive and Active measures were primarily measured to be applied followed by public awareness. Most of the research was focused on insulation upgrades, double glazing upgrades, shading devices and onsite energy generation. There was significant information in these areas to identify them as particular and distinguished research field.

Knowledge gap: Energy retrofitting Applications in the built environment: Even though there was a slight increase in the amount of energy savings research, there was a need for specific research regarding the possibilities for application of energy retrofitting without ignoring performance matters. This necessity of practical guidelines information is essential for architects and building professionals in order to test the optimum solutions in actual practice.

Technological application in monitoring and simulation methods: An obvious gap was seen in the lack of articles addressing monitoring methods particularly in hot-arid climate regions. Thus the introduced energy efficiency and cost feasibility played a big role in this aspect. Even though these strategies have increased in the last six years, there is a room for growth regarding both performance and application issues. Furthermore, the potential of these applications presents opportunities for future architectural development in residential buildings.

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