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Design of Sustainable Building by Considering Green Materials – Case Study in Salalah/Oman

Ahmed Al kathiri[1], Omer Damdelen[2]

[1*] Cyprus International University, Faculty of Engineering, Nicosia, North Cyprus, 22012337@student.ciu.edu.tr
[2] Cyprus International University, Faculty of Engineering, Nicosia, North Cyprus, odamdelen@ciu.edu.tr

Abstract. The present study is based on analyzing the sustainable approaches toward adaptation of green building , materials and technology. The implemented standards to reduce resource and energy usage is applied to improve the living standards of people and society. The study is focused on construction industry of Oman and consider fiver case studies from Salalah based on designing green building in Dhofar region. The green building and construction is rated according to standards provided by LEED organization. The study compare the case studies and develop model for sustainable building. The simulation results indicates the improtance of green building in saving energy and resources such as Eco-house.

Keywords: Sustainable building, Oman, Modelling, Construction.

1. Introduction

The green building practices are environment friendly that encourage cost-effective solutions. At present, the global construction industry is moving toward sustainable building construction. Several environmental issues are originating due to larger urbanization activities. Construction and urbanization require huge quantity of energy and materials that increase the carbon content in atmosphere causing pollution (TRC., 2022). Development of technologies also contribute to consumption of energy that directly or indirectly influencing the environment. The only solution to reduce environmental pollution is to adopt sustainable green building construction (Xinzheng, 2009). Effecient use of materials and reuse of materials water preservation, and exploration of untapped sources. The green materials are used in construction to enhance the energy efficiency (AJAR. 2022). The environmental performance of green buidling is evaluted and encourage to change the market directions toward sustainable design (Zhi Liu, 2020). The benefits of designing green building include energy efficient, cost effective lifespan, better lightening, better indoor air quality, better learning for educational institutes, day-lit buildings, and increased slaes for stores and markets (Xinzheng, 2009). The present study is aimed to promote green building by anlayzing the case study of Salalah, through model investigation, the concept of sustainablility and construction material in life cycle of buidling project s in relation to standards developed by different bodies including LEED. The study examine the sustainability level rating system of a building project, identify the green practices and materials used in building, analyze Simple Model for simulation energy usage over time, and emphasize the role of building standardization and energy utilization sustainability thourough out the construction projects (Afolabi & Dania, 2013).

Salalah is the third largest city in the Sultanate Oman and it is one of the highly developing city in term of construction and building. The development of green buildings within Salalah is supported by several private contractors, building councils, groups, and government projects (ADEC Innovation, 2022). According to WGBC, green building has high performance criteria in term of water utilization and efficiency in energy, utilized environmental resources, highly maintained interior air quality and consumed environment-friendly materials in sustainable way (WMO Region 2, 2021). According to LEED, 2022 criteria, green building is demonstrated by site planning, indoor environmental quality, energy, material use and water management. Fig 1 demonstrate the green house definition developed by LEED. The green construction is directly associated with energy requirements of the building and increase the overall performance of the building (ADEC Innovation, 2022).

Figure 1: LEED: A Green House's Definition (WGBC, n.d.)

Leadership in Energy and Environmental Design (LEED) is a globally known rating system define by the United States Green Building Council (USGBC). LEED system require to educate the clients and members about the sustainable construction practises. The system provide awareness to the clients about benefits of building green like increased productivity, reduced cost and capacity to sell the building structure in future (GreenSource. 2008). LEED, 2022 standards are aimed to influence market by encourging and promoting construction transformation toward sustainablility. Environment friendly construction of buildings and deverlopment of strategies for sustainable construction are significantly promoted by LEED (Rizqa, 2016). LEED certification for a project involve evaluation of performance of the building with respect to the environment. LEED define different types of buildings including homes, neighborhood development, commercial interiors, core and shell, new construction, and school, retail, healthcare. To evaluate each type of building, LEED provide different rating system programs with different set of criteria. A building that fulfill all the standards for a specific type of building is certified (LEED, 2022). There are 6 categories that could be considered while evaluating a construction program including water efficiency, sustainable sites, energy and environment, indoor environment quality, materials and resources, and innovation and design process (Rizqa, 2016). Meeting the conditions for each specific category result point score for the project. For example, sustainable sites has eight credits with one requiorement. İt is mendatory to meet the requirement and iut does not earn any point for the project. According to the scored points, the Eco-house grading system of LEED determine a project as certified, silver, gold and platinum. A certified project score between 45-49 points on core elements (WGBC), silver project scores between 50-59 points, a gold project scores between 60-79 points, and platinum project scores above 80 points (Subhes, 2019).

Sustainable construction involve the process that restores or maintain equlibrium between natural and artificial ecosystems and support fairness in economic life of humans (Song & Zhang, 2018). According to research conducted by Harvard green building sustainability, the goal of green building is to influence the behavior of tenants, firms, and local governments to implement the environment friendly building and development practices. Building materials plays an important role in determning the energy consumption and envirnomental consequences of the building (WMO Region 2, 2021). The material used in construction site preparation include recycled concrete, geo synthetics, inorganic fibrous material and insulation materials (Song & Zhang, 2018). The challenges faced by the sustainable bulding methods are to be recognized in order to adapt, promote, and implement the sustainable development within construction industry. The major challenges include cultural challenges, financial challenges and steering challanges (WMO Region 2, 2021).

2. Material and Method

2.1. Problem Statement

The area of concern for the present study is associated with lack of experienced engineers, designers and contractors within construction industry that are not compliance with green building standards. The conventional building have increased negative influence on the environment as the construction industry is expanding.

2.2. Methodology

The present study is based on analyzing four case studies of green building in Oman under the LEED certification standards. The data formulated from each case indicates the key points that are required to meet the standards set by LEED. The oppertunities toward improvement of energy and atmosphere (EA) are explored in the study. EA rating of a constructed home is defined by LEED and has a sub-criteria called building-level energy matering for energy management that is demonstrate any possible chances to further save the energy by monitoring the energy use of the building. The building efficiency is important to quantify and the building design is directly associated with energy model. The energy model,selection of materials and preparing home design is made by using Energy Simulation software packages named Open Studio, Energy Plus and Sketch Up. The cooling and heating load under local weather conditions is measured through simulation results.

2.3. Requirements and Tools

The present research include two major requirements including the software tools for modeling and simulation, and the LEED standards.

2.3.1. LEED Standards and Scorecard

The green building and sustainability parameters of a home construction project are analyzed with the help of LEED standards. On the base of completing the certification indicators the building recieves score for the construction. The checklist is reffered by LEED for the green building standards. The LEED levels of certification are defined on the base of points scored by the construction project that involve certified, silver, gold and platinum award for the project. The present study is based on LEED v4.1 Building Design and Construction (BD+C) project types. The table shows requirements and standards according to LEED v4.1. the “New Construction and Major Renovations” is a common category used for the construction projects unless the project is based on special purpose or type.

Table 1: Premises categories according to Latest LEED v4.1 BD+C certification

Building Type	***Code***
New Construction & Major Renovation	*LEED v4. 1 NC*

Core and Shell	*LEED v4. 1 CS*
Schools	*LEED v4. 1 Schools*
Retail	*LEED v4. 1 Retail*
Data Centers	*LEED v4. 1 DS*
Warehouse and Distribution Centers	*LEED v4. 1 WH & DC*
Hospitality	*LEED v4. 1 Hospitality*
Healthcare	*LEED v4. 1 Healthcare*

A building project has different verfication steps throughout the lifecycle of construction process including pre-construction, mid-construction and final construction phases. The LEED contract is adopted during the early planning stage of the project. The project outcomes demonstrate that the project may achieve the desired goals after the complete verification and rated under the LEED cerdit categories. The categories and detailed scores are provided in following tables 2, 3, 4. The categories include Integrative Process (ID), Location and Transportation (LL/LT), Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR), Indoor Environmental Quality is denoted as EQ, Innovation in Design is denoted by IR, and Regional Priority.

Table 2: Integrative Process Score (LEED, 2022)

Y	***?***	***N***			
			Credit	*Integrative Process*	***1***

Table 3: Location and Transportation Scores Distribution (LEED, 2022)

0	***0***	***0***	***Location and Transportation***		***16***
			Credit	*LEED for Neighborhood Development Location*	*16*
			Credit	*Sensitive Land Protection*	*1*
			Credit	*High Priority Site and Equitable Development*	*2*
			Credit	*Surrounding Density and Diverse Uses*	*5*
			Credit	*Access to Quality Transit*	*5*
			Credit	*Bicycle Facilities*	*1*
			Credit	*Reduced Parking Footprint*	*1*
			Credit	*Electric Vehicles*	*1*

Table 4: Sustainable Sites Scores Distribution (LEED, 2022)

0	0	0	Sustainable Sites		10
Y			Prereq	Construction Activity Pollution Prevention	Required
			Credit	Site Assessment	1
			Credit	Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1

Table 5: Water Efficiency Score Distribution (LEED, 2022)

0	0	0	Water Efficiency		11
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	6
			Credit	Optimize Process Water Use	2
			Credit	Water Metering	1

Table 6: Energy and Atmosphere Scores Distribution (LEED, 2022)

0	0	0	Energy and Atmosphere		33
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6

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			Credit	Optimize Energy Performance	18
			Credit	Advanced Energy Metering	1
			Credit	Grid Harmonization	2
			Credit	Renewable Energy	5
			Credit	Enhanced Refrigerant Management	1

Table 7: Materials and Resources Scores Distribution (LEED, 2022)

0	**0**	**0**	**Materials and Resources**		**13**
Y			Prereq	Storage and Collection of Recyclables	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Environmental Product Declarations	2
			Credit	Sourcing of Raw Materials	2
			Credit	Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2

Table 8: Indoor Environment Quality Scores Distribution (LEED, 2022)

0	**0**	**0**	**Indoor Environmental Quality**		**16**
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1
			Credit	Acoustic Performance	1

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Table 9: Innovation Scores Distribution (LEED, 2022)

0	***0***	***0***	***Innovation***		***6***
			Credit	*Innovation*	*5*
			Credit	*LEED Accredited Professional*	*1*

Table 10: Regional Priority Scores Distribution (LEED, 2022)

0	***0***	***0***	***Regional Priority***		***4***
			Credit	*Regional Priority: Specific Credit*	*1*
			Credit	*Regional Priority: Specific Credit*	*1*
			Credit	*Regional Priority: Specific Credit*	*1*
			Credit	*Regional Priority: Specific Credit*	*1*

2.3.2. Software Tools for Modeling and Simulation

Before runing a model in Energy Plus, there are several assumptions and stages that need to be followed. The modeling and simulation techniques are established to persue the present research study. Three software programs are used in certain order that include Sketch Up to create the model structure, Open Studio to create areas and conditions, and finally Energy Plus to calculate and display the findings of the study. All the three software are used to develop 3-dimensional drawing of the structure including specification of spacing and area. Geographical and atmospheric conditions are added through Open Studio and the Energy Plus use information and enable the user to get parameters of sustainability like energy demand, temperature profile and window radiations. Following figure 2. demonstrate the usage and methodology of modeling and simulation software.

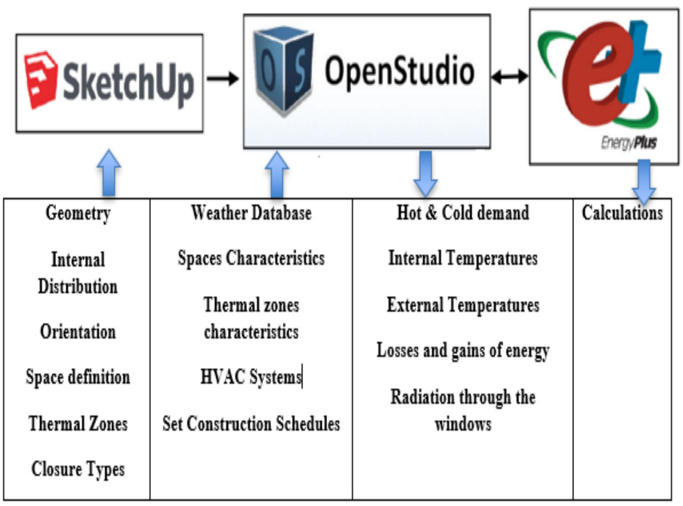

Figure 2: Methodology and Steps of Modelling and Simulation

3. Results and Discussion

3.1. Case Studies

The results advocates that the conventional construction methods can be enhanced by incorporating ecological friendly or green building practices. The main focus of present study is to analyze four LEED certified case studies at Salalah and derive the feature matrix to draw the conclusion for sustainable green construction. Table 11 demonstrate the four different building cases in Oman including Oman Botanic Garden, Khasab Hotel,Jebel Al Akhdar Hotel, Muscat and Salah Airport. The table summarize the cases and first case is used as reference project that is analyzed for the recommendation of obtaining LEED certification.

Table 11: Information of Case-Studies

Case Study No.	Name	Location	Building Type	Area (Sq/m)	LEED Standing	LEED Points (Reported)	LEED Version	Date of Certification
1	**Eco-House Salalah (EHS)**	Salalah, Dhofar Governorate OM	Home	598.00	Un-certified	N/A	LEED v4. 1	N/A
2	**Consolidated Contractors Company Oman (CCC Office Building)**	Salalah, Dhofar Governorate OM	Office	5775.9678	Certified	44/110	LEED NC 2009	March 27, 2017
3	**Mall of Oman (MOO)**	Muscat, Muscat Governorate OM	Retail	390192.768	Platinum	81 /110	LEED CS 2009	May 16, 2021
4	**City Hotel Muscat (CHM)**	Muscat, Muscat Governorate OM	Lodging	37033.75303	Gold	73/110	LEED NC 2009	Feb 18,2020
5	**Alila Jabal Akhdar Resort (AJAR)**	Jabal Al Akhdar, OM	Lodging	17645.91051	Silver Certified	50/110	LEED NC 2009	February, 18, 2015

3.1.1.Case Studies

The first case is about reference design that require LEED certification and it is observed that the uncertified building with a site area of 598 sq/m build for an eco-friendly house project. The illustrations are based on actual drawing made by Eco of Dhofar Team. The materials used in building of eco house are listed in the study. Name of each material is demonstrated along with the purpose and one material could be used for more than one purpose or location.

The LEED certification point scoring for the project is fall under the category of innovation that encompasses innovative techniques that facilitate lighting, cooling, aeration and ventilation. The quality assurance and control involve the planning and meeting the quality standards to gain LEED certification. The design of building include orientation for solar design, planning for durability of design, durability management, heat loss, natural disasters, common pest, and water and moisture factors. Contractor checklist include innovation and design, sustainable sites, pest control, framing order waste factor limit, material and resources, waste management, indoor quality environment, innovation design and durability management verified by third party.

Case study 02, Consolidated Contractors Company Oman (CCC) demonstrate that the builduing consume 53% less water and 28% less energy as compared to convetional building. Case study 03: Mall of Oman (MOO) demonstrates 49% water saving, 28.59% less energy consumption, 82.5% reuse of construction waste, 5% parking for low emission vehicles, over 40% construction material was locally sourced and 23% supplies are recycled materials. Case study 04 City Hotel Muscat (CHM) reduce 24% building thermal performance, 50% diversion of demolition, 40 % reduction in indooor waste, 50% reduction in waste water, 20% construction material was locaaly produced, and 20 % of building content is recycled. Case study 05, Alila Jabal Akhdar Resort (AJAR) demonstrates 24% improvement on baseline building thermal performance, 3% onsite renewable energy, 50% reduction in waste water generation, 35% reduction in indoor water usage, and 20% use of recycled content. Following table demonstrate the analysis of case studies.

Table 12. Highlighted actions for Greener Outcome

Project	**Energy Efficiency**	**Water conservation**	**Material selection**	**Waste reduction**
MOO	28% improvement on baseline building performance rating, 1% onsite renewable energy	40% reduction in baseline indoor water use, 50% reduction in wastewater generation, 100% reduction in potable landscape water use	50% FSC-certified wood products, 20% regionally extracted, harvested, recovered, or manufactured materials	75% diversion of construction and demolition debris, 20% recycled content building materials
CCC	20% improvement on baseline building performance rating	40% reduction in baseline indoor water use, 50% reduction in		

		wastewater generation		
CHM	24% improvement on baseline building performance rating	100% reduction in potable landscape water use, 40% reduction in baseline indoor water use, 50% reduction in wastewater generation	20% regionally extracted, harvested, recovered, or manufactured materials	50% diversion of construction and demolition debris , 20% recycled content building materials
AJAR	24% improvement on baseline building performance rating, 3% onsite renewable energy, 3% onsite renewable energy	100% reduction in potable landscape water use, 35% reduction in baseline indoor water use, 50% reduction in wastewater generation	10% regionally extracted, harvested, recovered, or manufactured materials,	20% recycled content building materials, 75% diversion of construction and demolition debris

According to LEED credit rating system, the rating of all cases is demonstrated in following table in term of LEED scorecard. According to the results the MOO case is rated as platinum, CCC is rated as certified, CHM is rated as gold, and AJAR is rated as silver.

Table 13: LEED rating of case studies

	EHS	**MOO**	**CCC**	**CHM**	**AJAR**
Energy & Atmosphere	29	25/37	9/35	18/35	15/35
Materials and Resources	NA	7/13	0/14	5/14	5/14
Indoor Environmental Quality	NA	9/12	3/15	11/15	7/15

Sustainable Sites	NA	21/28	20/26	22/26	9/26
Water Efficiency	NA	10/10	6/10	10/10	10/10
Innovation in Design	NA	5/6	2/6	5/6	4/6
Regional Priority	NA	4/4	4/4	2/4	0/4
TOTAL POINTS	**NA**	**81/110**	**44/110**	**73/110**	**50/110**

Target area achieved uder LEED v4.1 criteria is summarized for each case participated in water conservation, energy efficiency and material selection toward meeting the criteria of meeting LEED certification. The table demonstrate target areas.

Table 14: LEED v4.1 Target Areas Achieved Summary

S.No.	Project	Energy efficiency	Water conservation	Site selection	Material selection	Day lighting	Waste reduction
1	Consolidated Contractors Company Oman	YES	YES	NO	YES	NO	NO
2	Mall of Oman	YES	YES	NO	YES	NO	YES
3	City Hotel Muscat	YES	YES	NO	YES	NO	NO
4	Alila Jabal Akhdar Resort	YES	YES	NO	YES	NO	YES

The green building practices that are observed and identified in the case studies include passive design, location of the house next to existing roads, grid pattren of simple rectangles, silted house-minimum buildup area, ENERGY STAR trademark lighting, LED lighting, large opening supply to all the interior soaces, photovoltic solar panels, on-grid power distribution, the solar water heaters, use of local materials, use of recycled materials including wooden logs, water saving plumbing fixtures, on-site structures and rain water harvesting system to improve water usage efficiency. The green building structures are powered by solar panels that are connected to on-grid system and provide energy for the other buildings during day time. İt is observed that the bottom up models are required for solar passive building design that are valid for local environment.

The results indicates that the temperature of buildings interior was maintained between 25.4 to 27.2 degree celsius without use of airconditioning. On the other hand, the humidity is inversly proportional to the irradiance. During noon humidity was lowest while the solar radition reached a peak of 900 watt/meter square. The graphs are domonstrated in following figure.

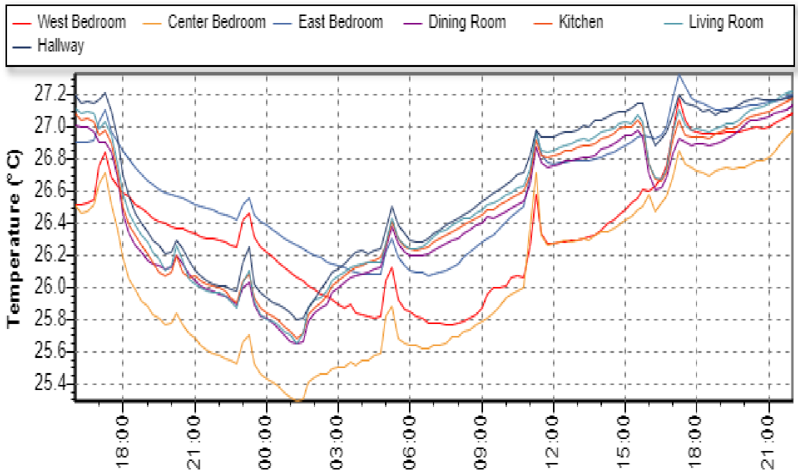

Figure 3 (a): Temperature of different areas of Eco-House (TRC, 2022)

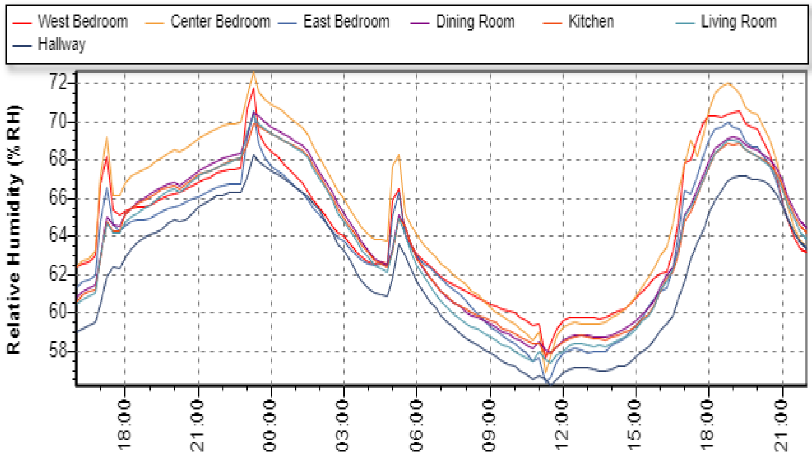

Figure 3 (b): Relative Humidity of different areas of Eco-House (TRC, 2022)

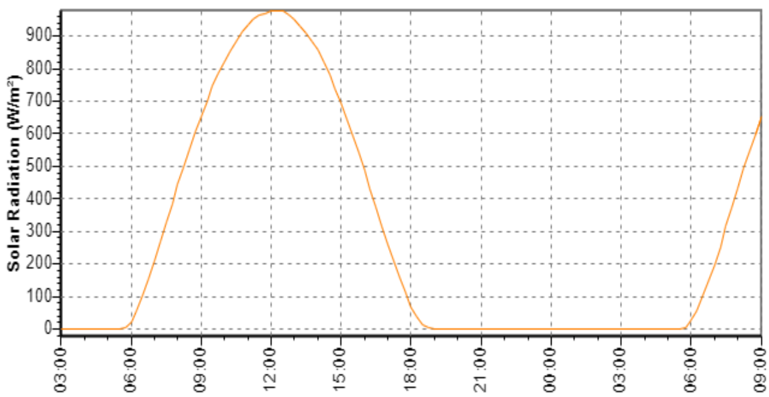

Figure 3 (c): Solar Radiation in W/m2 for the Eco-House Location

After analyzing the case studies, we conclude that for most projects the concept green sustainability refers to greener practices rather than green materials. In this way there is a distinct difference between the two pathways of green buildings in which the projects are executed. It can be concluded that a building construction utilizing greener materials is inherently green and can contribute more effectively to a greener ecosystem. Alternatively, a building construction utilizing conventional building materials that may follow certain building standards may also contribute towards sustainable building practices as verified by the LEED rating and certification framework.

3.2. Setting Up the Model for Oman

Setting up the model for Oman is aimed to sustainable design that provide thermal comfort and ensure high degree of thermal performance to minimize the adverse effect of building and construction. İn modeling for energy new variables are created that is described as mathematical relationship and factorizations. Sketch Up software is used to define the dimensions of the model while Open Studio divide spaces into different energy zones. Energy Plus software has algorithm to perform all the simulations and calculations graphs are plotted for extracted knowledge from vast database. Four scenarios 1,2,3, and 4 are four different instances that offer data needed to verify the objectives of study. Scenario 1 demonstrate the space with all adiabetic walls, scenario 2 depict the space with air-wall on one side, scenario 3 depict the atrium and space that are seperated with adiabetic walls, and scenario 4 depict the atrium and space are seperated with air-wall. Weather files are downliaded from the website available at https://climate.onebuilding.org/ . the data for Oman is collected and best selected location is Salalah Airport. .EPW file is required to set uo the location of the model and it involve setting the longitude and latitude. The modeling is significantly benficial to improve the performance of building and construction with minimum energy and resource consumption.

The model findings include heat load per anum and cooling load per anum for the four scenarios. Results demonstrate the heating and cooling demand throughout the course of year. İt is observed that scenario 1 has a higher heat demand due to absence of insulation. On the other hand, scenario 4 has the least demand of 6MJ per year. Greater cooling is required for scenario 3 due to the reason that atrium store greater energy that is transmitted to the home as there is no insulation between atrium and living space. Scenario 2 require minimum cooling because the insulation prevents the transfer of heat from outside. Following figures shows the annual demands of heating and cooling.

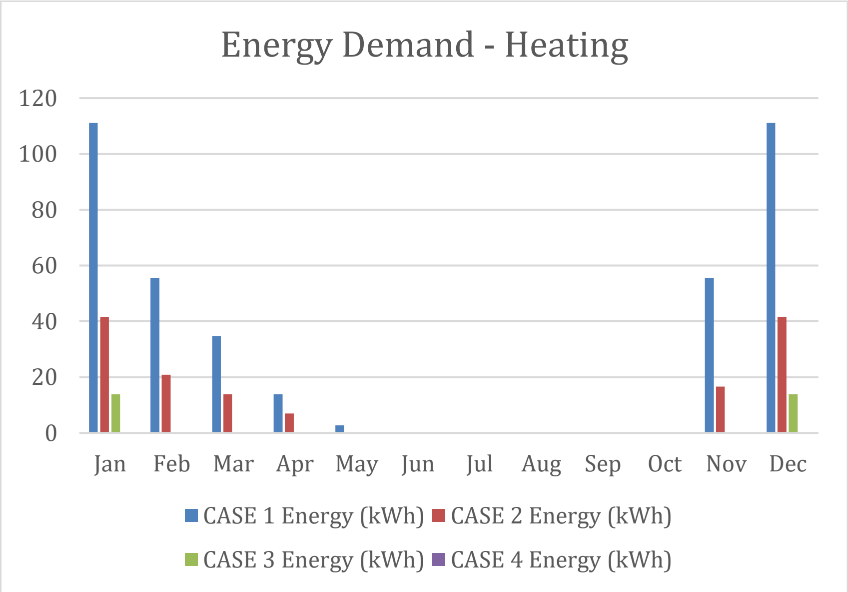

Figure 4 (a): Heat Load per annum for the four scenarios studied

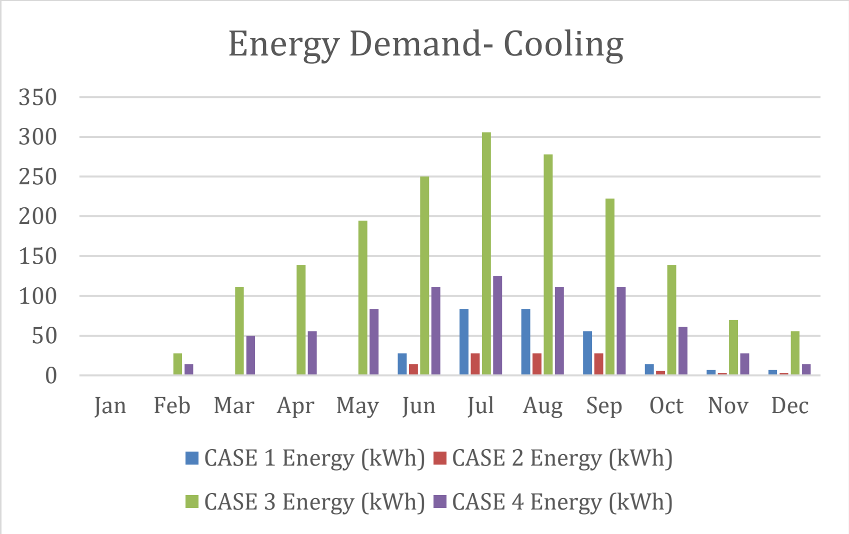

Figure 4 (b): Cooling Load per annum for the four scenarios studied

Table 15: Energy Demand per annum for the four scenarios studied (Montalvo, 2017)

	Atrium	Insulation	Annual Heat Demand (MJ)	Annual Cold Demand (MJ)
Scenario 1	NO	NO	1354.58	907.35
Scenario 2	NO	YES	481.11	327.07
Scenario 3	YES	NO	92.84	6271.25
Scenario 4	YES	YES	6.33	2468.83

The temperature data was collected every 30 minutes and in each case the tempertaure of interior wall is represented by figure 5. it is observed that the temperature transfer between walls is maximum in scenario 1 due to no isulation. On the other hand, the range of temperature at external wall is large and the temperature variation is significantly affected by sun. Wall temperature of different scenarios is demonstrated in following figures.

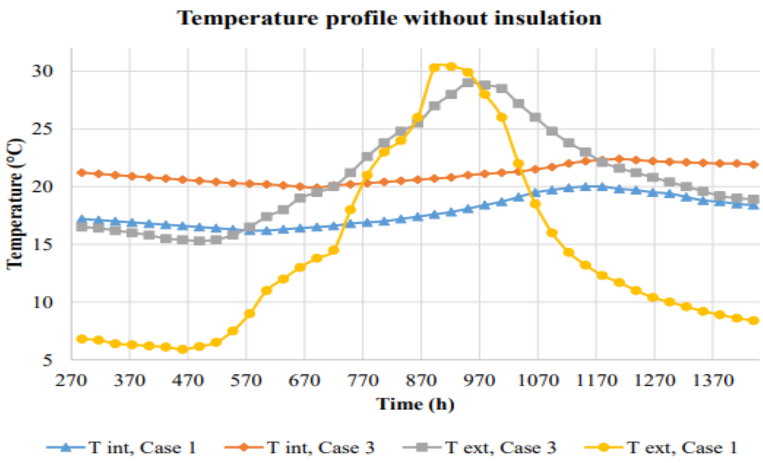

Figure 5 (a): Wall Temperature profile (no insulation) for the Scenario # 1 Scenario # 3 (on first of January) (Montalvo, 2017).

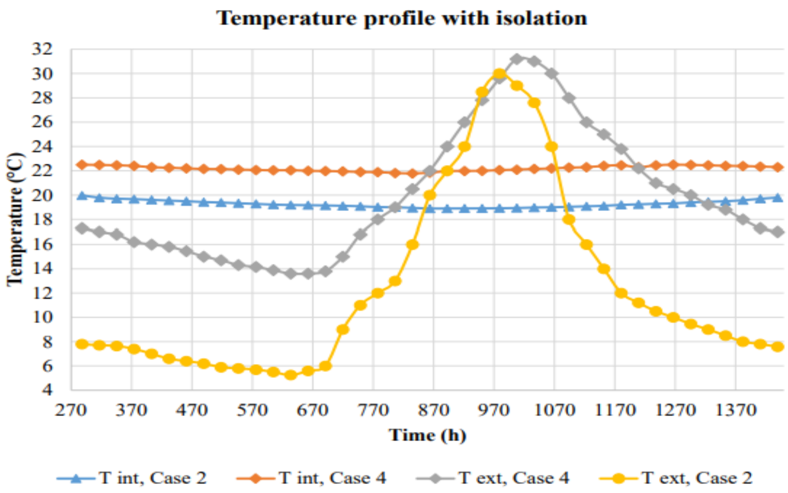

Figure 5 (b): Wall temperature profile (with insulation) for the Scenario # 2 and Scenario # 4 (Data from 1st Jan) (Montalvo, 2017)

The temperature of the air inside the home for each scenario is measured and difference in temperature is illustrated for all the four scenarios. The temperature inside and outside atrium and energy consumption is influenced by the insulating thickness of the wall. İn the case of atrium the energy consumption significantly reduced. As demosntrated in below figure the heat demand without atrium is significantly higher as comaore to heat demand with artrium.

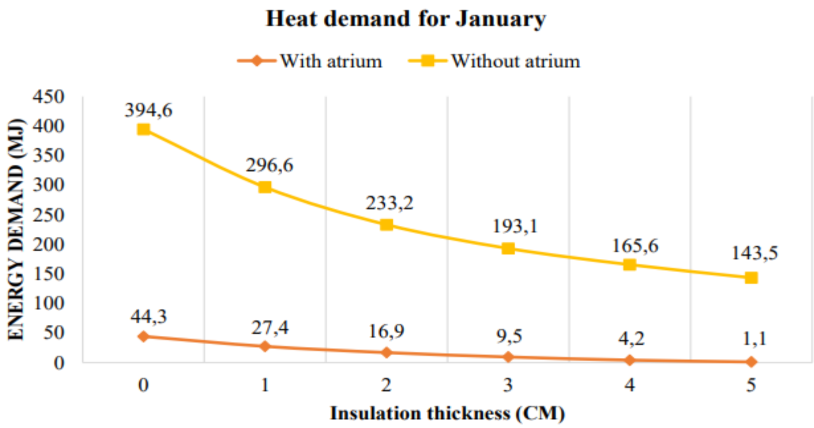

Figure 6: During the month of January, heat demand was calculated based on insulation thickness. (Montalvo, 2017)

The energy model is developed as per DOE formula and average amount of kilowatt hours per squre foot is found to 22.5. it is observed that green building shows 78.6 % saving of enery due to installation of photovoltaic system. Calculations are made from the 3.5 kW energy system available and the time for which the devices were tested for a single run 822 hours (approx.: 34.25 days)

Energy -kWh = Power- kW * time –hrs

Energy – kWh = 3.5 kW * 822 hrs = 2877 kWh

Table 16: Energy Usage per Sq.Feet Area and Energy Savings (%)

	% Reduced Energy Consumption	Area (Sq. Feet)	Energy Usage (22.5kWH /Sq. Feet) kWh	kWh saved	kWh Usage after Savings
EHS	**78.6%**	**598.00**	**13455**	**2,877.6**	**10,577.4**
CCC	28%	5775.9678	129,959	36389	93570.48
MOO	28.59 %	390192.768	8,779,337	2,510,012	6,269,325
CHM	24%	37033.75303	833,259	199982	633,277
AJAR	24%	17645.91051	397,033	95,288	301,745

The Energy Plus simulations yield results of Table 17 Annual Heat and Cold Demands for Four Scenarios, showing that the energy usage of through the heating and cooling load of each modelled scenario and compares that with a single space of the Eco-house model.

Table 17: Annual Heat and Cold Demands for Four Scenarios

	Atrium	Insulation	Annual Heat Demand (MJ)	Annual Cold Demand (MJ)
Scenario 1	NO	NO	1354.58	907.35
Scenario 2	NO	YES	481.11	327.07
Scenario 3	YES	NO	92.84	6271.25
Scenario 4	YES	YES	6.33	2468.83

I. In Scenarios 2 and 4, the yearly thermal energy consumption is lowered by 65%, 93%, and 99%, respectively. In scenario 2, the yearly cooling energy consumption is lowered by 64%, whereas it increases by 590% in Scenario # 3 and 170% in Scenario # 4. In the case of the eco-house, the required cooling energy is the highest.

II. In cold climate, the atrium raises the outside wall temperature by around 10 degrees Celsius, whereas the insulation maintains the temperature of the inner walls constantly. However, a thermal energy source is required to maintain a suitable temperature of 20°C in the residential building. In the absence of any atrium in eco-house there is no assistance from the solar radiations to heat up the inside during winter.

III. In places with high radiation levels, such as Thumrait or Salalah, the model conserves more energy due to the single brick design. Conversely, the study of results of four scenarios indicate that the use of insulation can save more energy than that of atriums in a building within areas of low radiation levels, e.g. cities in northern hemispheres.

IV. The combination of insulation and atrium minimizes energy demand in the four scenarios, but when comparing that with high cooling load of Eco-house, it is concluded that insulation and atrium would have helped to reduce the cooling load which is the highest. The insulation and atrium may reduce heating load due to the amount of radiation. In hot weather (Muscat), the scenarios show that savings might reach up to 99%, while in cold weather (More near to Northern Hemispheres), it may be less than 25%.

V. Using shades to minimize overheating in the summer is an excellent solution. The demand of cooling is reduced by 60-95% depending on the blind's active time periods, according to the four scenarios. For the eco-house, the effects of shading are ignored.

Finally the assigned scores for EHS based on percentage saving of energy. Annual Simulated Heat and Cold Demand (combined) for EHS in KWh, show the simulated thermal load for the EHS in KWh for a year.

Heat Demand in kWh = 135.15 MJ * 0.277778 = 37.54 kWh

Cold Demand in kWh = 52709.52 * 0.277778 = 14641.53 kWh

Estimated Thermal Load of Eco-House = 13455 kWh

Simulated Thermal Load of Eco-House = 37.54+14641.53 = 14679.07 kWh.

4. Conclusions and Recommendations

The present study is based on analyzing sustainable building and construction in Oman and the paper discuss five case studies while keeping the first case as a reference to analyze the LEED certification and impact of green building on energy consumption and sustainablility. The results from modeing and case studies are discussed and compared to establish the trends in sustainable building. The study is mainly focused on Omani construction industry and it is concluded that green building is much cost effective and energy efficient. The percentage saving due to installation of solar panels contribute to low energy requirements of the building. Annual heat and cold demand of EHS is analyzed by developing model for Oman. İt is concluded that annual heat and cold demand is very useful perameters for the estimation of green buildings and simulation model provide oppertunities to improve the construction sector based on sustainable principles of building construction project.

İt is recommended that LEED scores are not clear indicators to determine the energy saved per square foot. The LEED standard is the most renowed standardization body in Middle East region. The Energy and Environment metrics for measuring the thermal performance of the building are its heating and cooling loads and the energy consumed to keep the internal comfort conditions within a specific range.

The buildings in Oman and more specifically in Salalah, are to be looked upon with the perspective of simulated and actual data from sites to find the extent of the Energy and Atmosphere credit category of the LEED standards. For the future study, the scores may be estimated for the remaining credit categories of LEED by following up using forms from LEED (Forms, 2022) with the project's life-cycle or referring to its construction documentations.

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