www.ijbar.org
ISSN 2249-3352 (P) 2278-0505 (E)
Cosmos Impact Factor-5.86

https://doi.org/10.5281/zenodo.14202373

"Enhancing HVAC System Selection with Value Engineering and Life Cycle Cost Models"

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Abstract:

There is a direct correlation between the HVAC system a building chooses and its LCC, making it a very important decision. Considerations such as LCC, HVAC size and weight, buildability, interior and outside building attractiveness, and quality all play a role in the selecting process. There is no universally accepted unit of measurement for these characteristics, making them impossible to quantify. Evaluating the building's performance and functionality to ascertain its HVAC requirements is another difficult aspect of the decision process. At the moment, there is no universally accepted systematic approach, thus the choice is mostly based on the opinions of experts. Using the value engineering (VE) framework, this article seeks to provide a methodical methodology for HVAC system selection. Twelve objective criteria and four subjective criteria were found by the model using a commonly accepted test and a typical assessment, respectively. A mix of AHP, pairwise, FAST, and Monte Carlo methods were used to evaluate these HVAC criteria. So, within the framework of the building information modeling (BIM) environment, a comprehensive model was created to improve the selection process. To verify the model, we surveyed over twenty specialists in the field of heating, ventilation, and air conditioning (HVAC) and spoke with a number of them. Furthermore, the programmed HVAC selection model was used to validate a case study building in Riyadh, Saudi Arabia via its implementation. Designers might find the selecting procedure more easier with the help of the programmed model.

Keywords: value engineering; quality; AHP; FAST; BIM; Monte Carlo; HVAC system; life cycle cost

Introduction

Given that buildings account for almost 40% of the world's energy usage, the crucial procurement process for HVAC&R systems has the potential to annoy decision-makers [1]. On average, heating, ventilation, and air conditioning (HVAC) systems account for half of a building's total energy use [2]. By 2022, experts predict that Saudi Arabia's HVAC solutions business will be worth up to USD 6.36 billion. Nearly two percent of the world's HVAC market is located in Saudi Arabia [3].

Therefore, it is critical to develop sustainable buildings with HVAC systems that are energy efficient [4]. It is already common knowledge that HVAC systems play an important part in engineering. When planning a structure, choosing the right HVAC system is an important step. Defining an HVAC system with many functionality is necessary to meet a company's final standards. Various design needs may be satisfied by choosing from a wide variety of HVAC systems, each with its own unique set of characteristics. Choosing an HVAC system is a challenging and time-consuming task due to the wide variety of options available and the intricate interrelationships among selection criteria. Choosing the optimal HVAC system for a certain building requires a methodical and efficient evaluation process. In order to choose the most efficient HVAC system during building design, this research use value engineering (VE) to examine these factors. When the function always uses the best choice, it gives the most value. The first selection of

any material or design choice with a maximum value index that takes into account the building's functionality rather than its LCC and how to assess the quality of the material. Here is the formula for this relationship:

The formula for value is the product of function and quality divided by cost.

Because there is a wide variety of HVAC systems, it is crucial to take your time during the selection process in order to maximize efficiency while decreasing expenses. Along with cost, the quality criteria must be established and given a weight in order to be measured. Furthermore, the standard definition of VE takes into account maximum quality at the lowest feasible cost, as well as the building functions (needs and performance) when assessing quality requirements.

By comparing and contrasting local and international standards, this research looked at the components and definitions of HVAC systems now in use in Saudi Arabia. Furthermore, in order to arrive at precise quality standards that are compatible with the HVAC function, the study drew on prior research. To get a sense of how much weight each criteria had, we consulted HVAC specialists and employed the function analysis system approach (FAST). A model for predicting the HVAC system's LCC was developed in the research. Last but not least, the method's efficiency in practice relies on its incorporation into building information modeling (BIM) tools, which was achieved by programming the whole system

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using an API for BIM.

In order to validate the suggested approach, this research used a single case study of the endowment building at King Saud University in Riyadh, Saudi Arabia. This case study examined five different HVAC system options: water chillers, air chillers, rooftop packaged, split wall mounted, and variable refrigerant flow (VRF). According to the case study data, the VRF system performed the best. Experts evaluated the study's results and compared them to a real-life building operation and management contract to determine the level of accuracy. In order to double-check everything, we used two surveys: one to outline the whole research process and another to detail the outcomes of using this approach in the case study. Many people were pleased with the results, according to the surveys.

Here are some ways the research added to what is already known: development of a forecast HVAC and LCC model using Monte Carlo techniques; development of an automated model to integrate the proposed model with BIM; designation of fourteen agreed-upon criteria based on the Saudi market, measured using a standard test and quantitative subjective scale; weighting of criteria ranking and importance, based on consultations with several specialist experts; and selection of office buildings as one of thirteen building types. Building owners and designers may benefit from this automated HVAC selection model's guidance when deciding between available HVAC choices.

Review of Relevant Literature

Because it affects building occupancy and energy consumption, HVAC energy and process selection is a heavily researched topic. Following this introduction, you will find a list of research covering each of the topic areas.

Evaluation Procedures for HVAC Systems

When looking at past research, multiple criteria decision-making (MCDM) was the main tool employed. The entropy approach is one of several ways to get the MCDM problem's criterion weights. The entropy approach was used by Milani et al. [6] to evaluate the MCDM criterion weights. The authors have chosen a number of prior research that they believe are significant and applicable to the current study, and Table 1 details their review procedures.

Criteria for Evaluating HVAC Systems

Energy efficiency, thermal comfort, and air quality are the three main criteria that are considered when choosing an HVAC system, according to earlier studies [13]. A look at how the HVAC system is important since it helps maintain suitable indoor air quality while lowering a building's energy usage [14]. Also, think about how vital it is to have a low noise level in the building when selecting an HVAC system [15]. Durability is also a key requirement in the ASHRAE standards. Using fifteen sources spanning 1989–2016, Shahrestani et al. [16] compiled a summary of the quantitative and qualitative assessment techniques used during the selection process. Recent research by Baç et al. [17] synthesised 23 papers on selection strategies that made use of MCDM approaches. Building energy simulation (BES), weighted additive sum product assessment (WASPAS), and modified stepwise weight assessment ratio analysis (SWARA) were also included into the HVAC decision-making process. The building information modeling (BIM) tool was used to gather building plans, HVAC system blueprints, and geographical data, which were then employed to calculate the energy consequences of removing occupant variety [18]. A number of other research have zeroed in on the various HVAC assessment goals. Table 2 provides a comprehensive overview of these works and their significance within the HVAC sector.

The CW was identified in this study using FAST analysis to accomplish the project goal. A shortcoming of many studies is that they overlook the problems involved in calculating CW [33]. They take it for granted that decision-makers are aware of the criteria assessment. The five tasks described below can be used to determine CW in this model.

Step 2: Evaluate the Criteria Weight (CW)

Task 1: Establish the project goal and conduct a functional analysis.

The proposed HVAC systems must achieve the project's primary goal. The main questionnaire establishes scores for each function/subfunction/criterion based on input from design experts. In the VE process, function analysis plays an important role as well. HVAC system criteria cannot be weighted until the function analysis is carried out.

Task 2: Link the criteria to the functions/subfunctions/criteria.

In this task, the FAST and AHP/pairwise methods are integrated. Each criterion has to be relevant to its respective function in order to achieve the integration. Figure 3 depicts the integration of the proposed model. The diagram shows how the criteria are related to the HVAC system's functions. The function analysis with the FAST approach is represented on

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the left side, and the criteria results from step 1 are represented on the right side. The design experts must determine the function analysis and distribution of criteria related to the function/subfunction.

Task 3: On the FAST diagram, assign weights to all functions, subfunctions, and criteria. Some criteria can be applied to many functions. Accordingly, all criteria should be allocated weights using one of the two means described below. According to Zardari, if there are three or fewer criteria being compared on one level, the point allocation technique should be used [33]. The experts used numbers to describe the CW values directly in the point allocation technique. If there were more than three criteria being compared at one level, pairwise comparison was used. Using scale factors ranging from 1 to 9, pairwise comparison uses expert judgment to assess the relative value of each criterion against the others. Each of two criteria has a value of 1 if they are equally important. If one criterion is more significant than the other, a factor of importance degree is assigned on a scale of 2 to
9. This approach then creates a matrix and employs equations to determine the weight of each criterion, as indicated by Bhushan and Rai [69]. All functions/subfunctions/criteria are assigned a weight based on expert input by the end of this task. Tables 14–16 show the pairwise comparison matrix calculations for an office building. In the future, assigning weights for all building types will be required in step 1, task 2.

Task 1: Calculate distributed criteria weights.

The following step determines where the criteria are associated with each function and subfunction. Multiply all weights in Task 3 for each path of the FAST diagram to complete this task. As indicated in Figure 3, each path can contain functions, subfunctions, and criteria. Table 17 explains the calculations of the DCW, which is calculated by Equation (4):

$$DCW_{(\text{Each path})} = W_{(\text{Function})} \times W_{(\text{SubFuction})} \times W_{(\text{Criteria})} \qquad (4)$$

Task 5: Calculate the CW for each criterion.

The DCW values for all system criteria are assigned based on the results of the previous four steps. Because system criteria might be linked to several functions/subfunctions, there is a requirement to include all DCWs that are associated with one criterion, which reflects the CW using Equation (5):

$$CW_{(\text{For Each Criterion})} = \sum DCW_{(\text{For all DCWs relate it to each criterion})} \qquad (5)$$

All CW values for the total system should be equal to 1 (100%) in order to verify the computations. The last column of Table 17 shows that all CWs are equal to DCWs, as all of the criteria are linked with sole functions/subfunctions in the case of the selected criteria.

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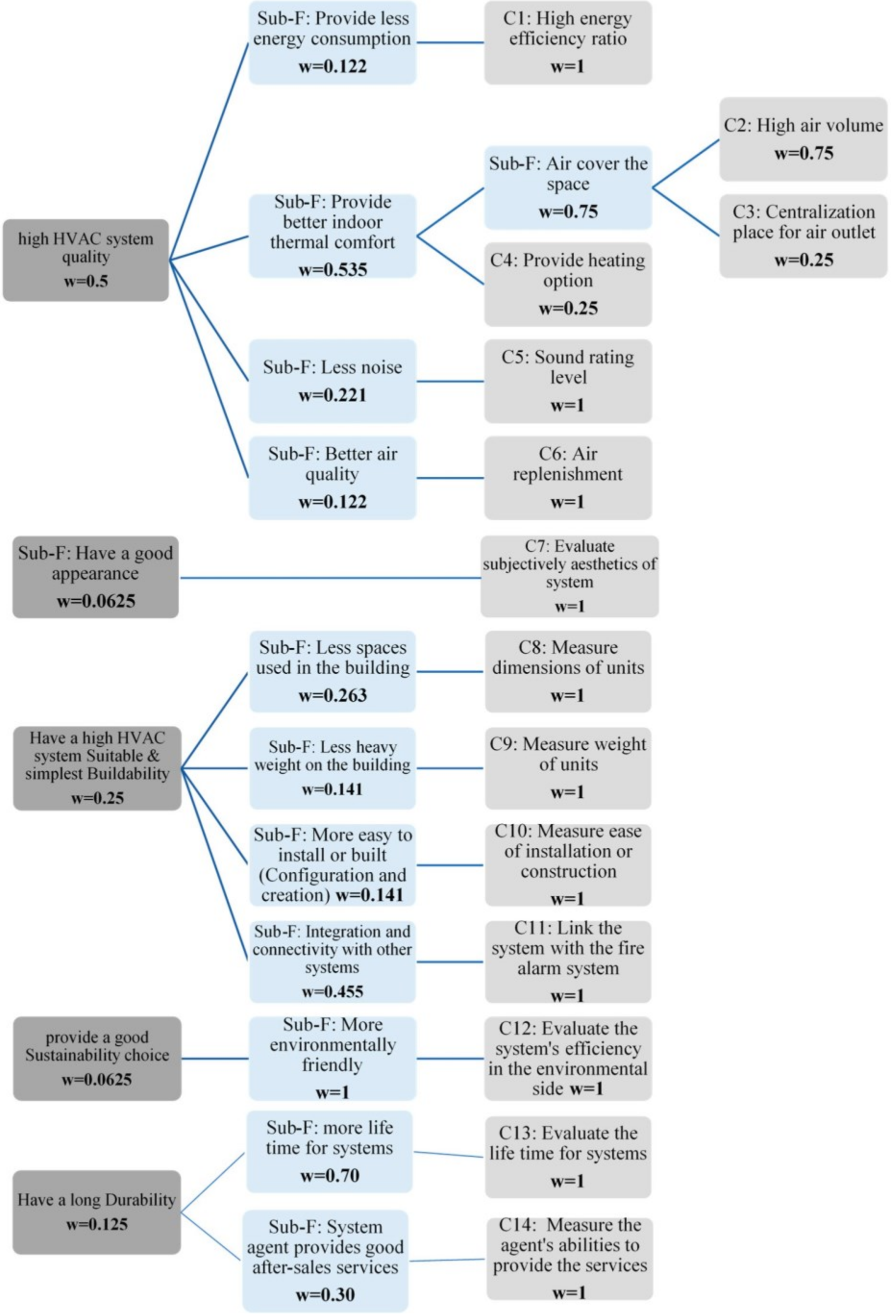

Figure 1. Criteria integration with FAST diagram of a building.

Table 2. Pairwise comparison matrix (function comparison).

High HVAC System Quality	Less Energy Consumption	Better Indoor Thermal Comfort	Less Noise	Better Air Quality	W Vector
Less energy consumption	1 (0.125)	0.25 (0.136)	0.5 (0.1)	1 (0.125)	0.122
Better indoor thermal comfort	4 (0.5)	1 (0.54)	3 (0.6)	4 (0.5)	0.535
Less noise	2 (0.25)	0.333 (0.182)	1 (0.2)	2 (0.25)	0.221
Better air quality	1 (0.125)	0.25 (0.136)	0.5 (0.1)	1 (0.125)	0.122
	1	1	1	1	1

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Table 3. Pairwise comparison matrix (quality comparison).

High HVAC System Suitability and Simplest Buildability	Less Space Used in Building	Less Weight on Building	Easier to Install or Build (Configuration and Creation)	Integration and Connectivity with Other Systems	W Vector
Less space used in building	1 (0.25)	2 (0.286)	2 (0.286)	0.5 (0.231)	0.263
Less weight on building	0.5 (0.125)	1 (0.143)	1 (0.143)	0.333 (0.154)	0.141
Easier to install or build (configuration and creation)	0.5 (0.125)	1 (0.143)	1 (0.143)	0.333 (0.154)	0.141
Integration and connectivity with other systems	2 (0.5)	3 (0.428)	3 (0.428)	1 (0.461)	0.455
	1	1	1	1	1

Table 1. Pairwise comparison matrix (buildability comparison).

High HVAC Buildability HVAC System Meets Occupants' Requirements	High System Quality	Good Appearance	System Suitability and Simplest	Good Sustainability	Long	W Vector
High system quality	1 (0.5)	8 (0.5)	2 (0.5)	8 (0.5)	4 (0.5)	0.5
Good appearance	0.125 (0.0625)	1 (0.0625)	0.25 (0.0625)	1 (0.0625)	0.5 (0.0625)	0.0625
High HVAC system suitability and simplest buildability	0.5 (0.25)	4 (0.25)	1 (0.25)	4 (0.25)	2 (0.25)	0.25
Good sustainability choice	0.125 (0.0625)	1 (0.0625)	0.25 (0.0625)	1 (0.0625)	0.5 (0.0625)	0.0625
Long durability	0.25 (0.125)	2 (0.125)	0.5 (0.125)	2 (0.125)	1 (0.125)	0.125
	1	1	1	1	1	1

Durability

Step 3: Calculate QW for Each HVAC System Alternative

Quantifying the QW value for each HVAC alternative can be carried out after speci- fying the criteria items and CW from step 2. This computation can be achieved in three subsequence tasks. Task 1 establishes the CQW for each criterion, which were normalized in Task 2. Task 3 computes the QW for each system alternative by summing all the normalized CQW values for each HVAC alternative.

Task 1: For each criterion that corresponds to an HVAC system alternative, define the CQW.

Each criterion has to be measured according to international tests or other sources such as manufacturer's information, HVAC system technical specification catalogs, information available from contractors or professional consultants, and other publications, as specified in the first step [70].

The next objective is to apply these accepted tests to various systems to define the HVAC system quality categories. If a criterion is not measured, the CQW is subjectively weighed by design experts based on their experience. The value is from 1 to 5, with 1 = excellent and 5 = poor.

Task 2: Normalize the CQW value for each HVAC alternative.

The tests must first be normalized to a range of 0 to 1. For each HVAC option, the sum of all CQW values should be weighted to one (equivalent to 100%). It is easier to interpret and measure CQW after it has been normalized. Linear scale transformation, max method is one way to normalize values [73]. Equations (6) and (7) are used to adjust quality and LCC in this study according to whether the quality scale is ascending (high quality means high value) or descending (high quality means low value):

$R_{ij} = X_{ij}/(X_{imax})$ (6)

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$R_{ij} = (X_{imin})/X_{ij}$ (7)

Equation (6) is used for benefit values, and Equation (7) is used for non-beneficial values, where R_{ij} is the normalized value of system i for criterion j, X_{ij} is the criterion value of the evaluated system, X_{imax} is the maximum criterion value, and X_{imin} is the minimum criterion value.

Table 2. Calculation of criteria weight (CW).

Function	Subfunction	Criterion	W1	W2	W3	DCW = W1 × W2 × W3	CW = DCW
High HVAC	Less energy	Energy efficiency	0.5	0.122	1	0.061	0.061
High HVAC	Better indoor	High air volume	0.5	0.535 × 0.75	0.75	0.1505	0.1505
High HVAC	Better indoor thermal comfort the space)	Centralized place	0.5	0.535 × 0.75	0.25	0.05	0.05
High HVAC	Better indoor	Provide heating	0.5	0.535	0.25	0.067	0.067
High HVAC	Less noise	Sound rating level	0.5	0.221	1	0.1105	0.1105
High HVAC	Better air quality	Air replenishment	0.5	0.122	1	0.061	0.061
HVAC suitability buildability	Good appearance	Aesthetics of	0.0625	1	1	0.0625	0.0625
HVAC suitability buildability	Less space used	Dimensions of	0.25	0.263	1	0.0657	0.0657
HVAC suitability buildability	Less weight	Weights of units	0.25	0.141	1	0.035	0.035
HVAC suitability and simplest	Easier to install or build and creation)	Ease of installation	0.25	0.141	1	0.035	0.035
HVAC suitability buildability	Integration and other systems	System links with	0.25	0.455	1	0.114	0.114
Good sustainability choice	More environmentally	Environmental efficiency	0.0625	1	1	0.0625	0.0625
Long durability	Longer system	Life time of system	0.125	0.7	1	0.0875	0.0875
Long durability	Agent provides	Agent's ability to	0.125	0.3	1	0.0375	0.0375

quality quality

The case study was an office building, used to validate the evaluation procedures. The building investigated and assessed five types of HVAC systems identified as the most commonly used in the Saudi market. The outcomes can assist decision-makers with determining which system provides the best value.

General Information

Building name: King Saud University Endowment (KSUE) Building 13 Building type: Office building

Building area: 20,985.20 m^2 (225,883 ft^2)

Location: King Abdullah Road, Riyadh, Saudi Arabia Project life span: 30 years

Description

Building 13 is an endowment building at King Saud University. It has an area of 208 m^2 and volume of 52,184.21 m^3. Based on its function type and components, it is occupied by 735 people. The calculated results from Autodesk Revit for this case study show the building requires 768.75 tonnage of cooling. Figure 4 shows a picture of the building and its elevation in 3D.

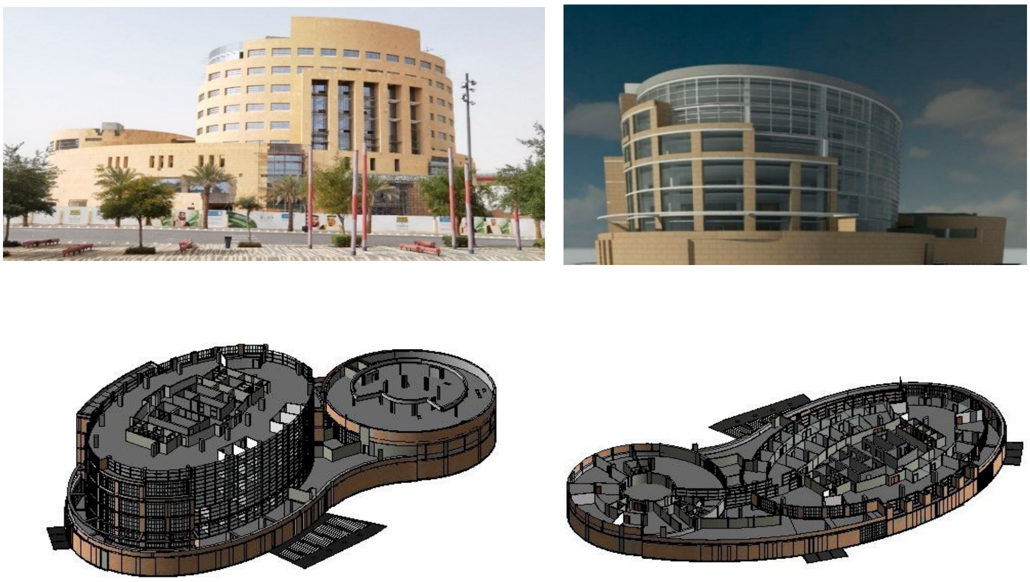

Figure 4. Case study 3D building model. (Building 13, donated by Abdulrahman A. Al Helayel.).

Case Study Procedures

For the case study, steps 2 to 4 of the HVAC selection model were applied to select the highest rated HVAC system among the five types: water and air chiller, VRF, rooftop packaged rooftop, and split wall-mounted.

Step 2: Determine the CW of the office building.

The CW for the office building was established in the model as described before. It was determined according to expert meetings and verified by a questionnaire, as shown in Table 17. These CW values were applied to the case study because its building type is an office building.

Step 3: Determine the QW of five case study HVAC systems.

Table 13 lists the CQW scales for the fourteen criteria. Each of the five identified HVAC systems has its own criteria value that needs to be evaluated and normalized within the CQW in Table 13. Table 22 presents the CQW in terms of unit value and normalized value between 0 and 1 using Equations (6) and (7). The normalized value for criteria 3, 4, and 6 is either 0 or 1 because these criteria do not have a scale. After calculating all normalized values of CQW for all fourteen criteria of the five HVAC systems used in this case study, QW for each system can be determined according to Equation (8) by multiplying each CQW HVAC system type with the corresponding CW in Table 17 and summing all values for each system. For example, the QW of water chiller and fan coil unit 450T is 0.59896268, shown in the last row of HVAC system type (fifth column) according to this calculation:

$$0.59896268 = 0.46222222 \times 0.061 + 0.74103704 \times 0.1505 + \ldots + 0.25 \times 0.0375$$

Step 4: Develop a predictive LCC model for the case study. This step includes three tasks:

Task 1: Identify the initial costs.

The predictive model calculates the initial cost among the market prices to purchase and procure the system and the contractor’s work price to construct the entire system. For some systems, such as VRF and chillers, the price is in Saudi Arabian Riyal (SAR) per ton to construct the system. This price includes procuring and constructing the system to

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commission the user.

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Tasks 2 and 3: Determine the O&M cost.
The model divides the system O&M cost into two categories:
Chillers: Cost calculations obtained for air and water systems will depend on King Saud University Endowment operation and maintenance project data. The data contain the SAR price per ton for the entire system. The price is based on the current utility cost (electricity, water), O&M contractor crew, spare parts, chemicals, and inflation of 3% each year.
Split, packaged, and VRF: The calculations for this category are divided into the maintenance strategy cost (predictive, corrective), operation cost, and inflation of 3% each year.

Table 22. Numerical values of selected criteria + normalized classification matrix.

Criteria	**Optimal**	**Unit**	**Water Chiller Unit 450T**	**Air Chiller and Fan Coil Unit 113T**	**Rooftop Packaged 25T**	**Split Wall-Mounted 1.5T**	**VRF and Fan Coil Unit**	**CW (from Table 12)**
EER	36	(btu/W.h)	16.64	9.7	10.55	12.4	14.15	0.061
		Normalize on	0.46222222	0.2694444	0.2930556	0.3444444	0.3930556	
Air volume	189,000	CFM	140,056	35,588	9200	512	5740	0.1505
		Normalize on	0.74103704	0.1882963	0.0486772	0.002709	0.0303704	
Centralized air diffuser	1		Central place (more covered area)	Central place (more covered area)	Central place (more covered area)	Wall-mounted units (less covered area)	Center place covered area)	0.05
		Normalize on	1	1	1	0	1	
Air replenishment	1		Fresh air	Fresh air	Fresh air	Retained air	Fresh air	0.067
		Normalize on	1	1	1	0	1	
Sound rating level (dBA)	66	dBA	135	130	77	99	114.4	0.1105
		Normalize on scale	0.425	0.4666667	0.9083333	0.725	0.5966667	
Heating option (for cooling season)	1		Not available	Not available	Not available	Available	Available	0.061
		Normalize on	0	0	0	1	1	
Aesthetics of system (subjective evaluation)	1	subjective	2	3	2	4	1	0.0625
		Normalize on	0.75	0.5	0.75	0.25	1	
Dimensions of system (m^3)	0.2008	m3	46.033	23.829	9.804	0.36193	5.998	0.0657
		Normalize on	0.32697888	0.6530326	0.8589822	0.9976339	0.9148712	
Weight of system (kg)	58	kg	9875	5253	959	69.6	1912	0.035
		Normalize on	0.34814077	0.6550465	0.9401726	0.9992297	0.8768924	
Ease of installation	1	subjective	4	3	3	1	2	0.035
		Normalize on	0.25	0.5	0.5	1	0.75	
System linked with fire alarm system	1	subjective	2	2	1	3	3	0.114
		Normalize on	0.75	0.75	1	0.5	0.5	
System's environmental efficiency	1	subjective	1	2	3	3	3	0.0625
		Normalize on	1	0.75	0.5	0.5	0.5	
System lifetime	28	years	20	20	15	15	15	0.0875
		Normalize on	0.55555556	0.5555556	0.2777778	0.2777778	0.2777778	
Agent's ability to provide services	1	subjective	4	4	2	1	2	0.0375
		Normalize on	0.25	0.25	0.75	1	0.75	

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For the O&M costs, the case study relies on the current prices for some brands in the Saudi market, which is not entirely accurate because we need to determine the limits (minimum and maximum values) for each cost category as well. Therefore, the price possibilities can be covered to have more accurate results. In this case, using Monte Carlo simulation can be helpful. As shown in Figure 5, the determinants of O&M costs for each HVAC system were determined. For this, 1000 iterations on an Excel sheet were executed to obtain accurate values.

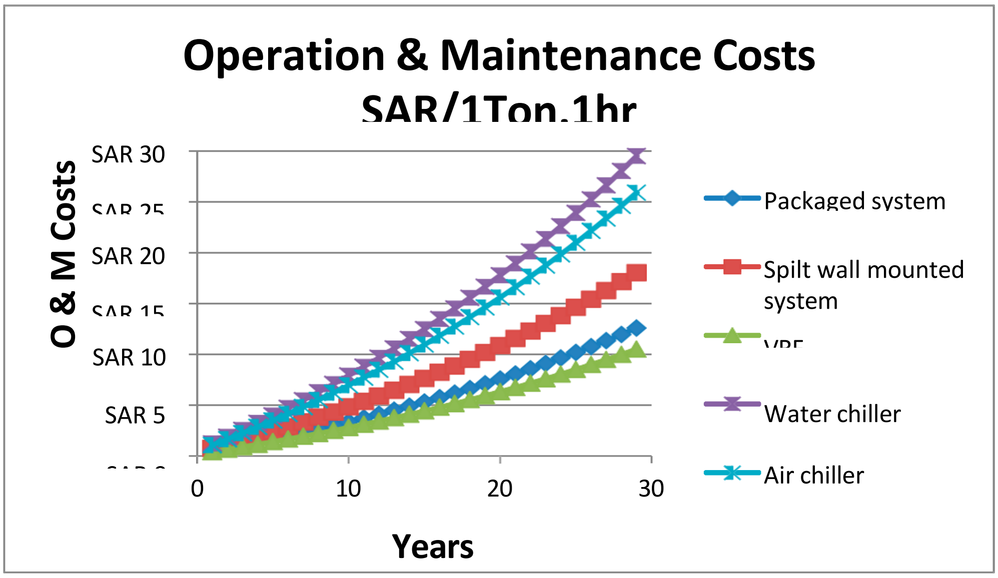

Figure 5. O&M costs for HVAC systems using the Monte Carlo technique.

Each system lifetime listed in the ASHREA standard is considered as part of the initial cost. Lifetime is determined as 20 years for chillers (water, air) and 15 years for packaged, split, and VRF. Table 23 shows the IC calculation for each system based on Monte Carlo analysis.

Step 5: Calculate value scores.

Because the model was programmed with a BIM model (using Revit software) for selection of HVAC systems, this step can be calculated directly. All weights and values for the criteria were entered with the model, and were quickly imported into Dynamo from an Excel spreadsheet. In addition, the cost of the system's LCC was entered for the case study information. The model directly determines the quality scores and values and compares the highest and lowest value alternatives using Equation (1), as shown in Table 24.

Case Study Analysis and Discussion

As seen in Table 24, the case study results show that water chiller, VRF, and packaged systems have essentially identical quality results. However, air chiller and split wall- mounted systems have lower scores. While the cost criteria for the air chiller, packaged, split wall-mounted, and VRF systems are superior to the those for the water chiller, the lower cost gives the system more value in the total score. The value score of the water chiller has the highest equivalent between quality and cost. A large difference in LCC impacts the value index of the selected option (water chiller). The case study result was compatible with the selected case study option. It is noted that the quality levels of the five HVAC alternatives were close to each other. The difference in LCC strongly impacts the value index of the selected option. The LCC forecast model was verified by comparing

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it with the actual O&M contract data of the case study, a KSUE office building in Riyadh, Saudi Arabia. Riyadh has dry weather; thus, humidity did not affect the cooling loads considered in the BIM system.

Ge et al. [74] studied the impact of different climate zones on the energy performance of business buildings in China. Mendes et al. [75] investigated the effects of humidity by comparing three cities (Singapore, Seattle, and Phoenix). However, the proposed HVAC model is not affected by this aspect, as the cooling load is an input to the model, which should consider any humidity effects.

Table 23. Initial cost for HVAC systems using the Monte Carlo technique.

Years	Package	Split	VRF	Water Chiller	Air Chiller
1	89,951.713	3515.312	65,593.985	2,252,460.707	310,525.19
15	136,060.0368	5317.2248	99,216.788	-	-
20	-	-	-	3,949,703.484	544,507.8
30	211,977.1041	8284.063	15,4576.52	-	-
Total IC for 30 years	437,988.8539	17,116.6	319,387.3	6,202,164.191	855,033

Table 24. Results of evaluation from BIM model.

System Type	Water Chiller and Fan Coil Unit 450T	Air Chiller and Fan Coil Unit 113T	Rooftop Packaged 25T	Split Wall-Mounted 1.5T	VRF and Fan Coil Unit 17.5T
Q + F Scores	0.59896268	0.5182834	0.5939699	0.4637295	0.5927076
Norm LCC	0.12744815	0.530197473	0.922395132	0.805415474	1
V score	4.699657704	0.977528989	0.643943012	0.575764329	0.5927076
	Selected system				

Phase 5: Model Validation and Questionnaires

This study's first data-gathering instrument was a self-administered questionnaire. The questionnaire was used for various reasons, including to allow the data to be standard- ized and analyzed more straightforwardly, and to allow information to be acquired quickly from a significant number of people.

Questionnaire Design

In this research, two questionnaires were designed. The first was the main question- naire, which was distributed to 21 experts. Through interviews, three experts reviewed the LCC results based on the external data (project contract) to perform the second validation. Table 25 provides a summary of the questionnaires.

Likert Scale

A Likert scale was used to create the main questions (Table 26). The questions were graded on a scale of 1 to 5, with 1 being the lowest and 5 the highest. The score can be determined by using the weighted points on the Likert scale according to Emerson [76], with Equation (10):

$$\text{Score} = \frac{1}{N}\sum_{i=1}^{5} i * ni \qquad (10)$$

where i is the Likert scale (i = 1, 2, . . . , 5), ni is the number of respondents who chose scale i, and N is the total number of respondents. Scores of 4 or greater than or equal were chosen using this procedure.

Conclusions

The design value is directly affected by the HVAC system choice. Value engineering (VE) is a method for cutting costs while increasing usefulness and quality. A methodical strategy for choosing the most cost-effective HVAC system is presented in this study. Studies that were pertinent to the topic were reviewed in the literature. A satisfactory degree of satisfaction was achieved in identifying fourteen parameters that impact the selection of HVAC systems. An HVAC specialist examined

https://doi.org/10.5281/zenodo.14202373

the criteria, and 21 responders confirmed them to their satisfaction. Both the ranking (CW) and the quality (QW) of the criteria were used to determine their weight. One building type—an office structure—was used to define the CW for the fourteen HVAC criteria that were found. The CW assessment made use of the combined AHP, FAST, and pairwise methodologies. Standard tests and subjective assessment methods were utilized to measure all fourteen criteria for the QW; these QW values may be used to evaluate most kinds of HVAC systems. A questionnaire was used to confirm the existing QW measuring methodologies, which were based on feedback from HVAC professionals. HVAC value index calculations rely on LCC because of its effect on O&M expenses. So, to build a model for HVAC LCC forecasting, the suggested model used expert knowledge in conjunction with the Monte Carlo method. A case study of an office building in Riyadh, Saudi Arabia, owned by the King Saud University Endowment was used to compare the model's projected findings with real contract data, therefore validating the model.

Furthermore, the suggested model was integrated into the BIM model using an API and the Dynamo application in Revit software. The research concluded by applying the presented automated model to the office building that served as the case study. The 450T unit with a water chiller and fan coil was the most beneficial of five HVAC models analyzed and compared in the case study. All of the case study options were consistent with the case study outcome. The five HVAC options were quite comparable in terms of quality, and variations in LCC had a significant influence. which option's value index is being used. The requirements and efficiency of office buildings informed the design of the suggested concept. Additional HVAC functions might be included in the selection procedure if future research generates more building types. Moreover, the HVAC selection model just took into account designs that were approved by the designers and that fulfilled the minimal owner/country requirements inside BIM. In the future, researchers may look at ways to exclude BIM components that don't meet certain standards set by designers.

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