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Analysis of selecting the most sustainable alternative to air-condition system for multi-story building by using AHP program

تحليل اختيار البديل الامثل استدامة لنظام تكييف بناية متعددة الطوابق باستخدام برنامج AHP

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البحث مستل

Abstract

Most buildings in Iraq have been designed and implemented using traditional methods, which in turn lead to large consumption of amounts of energy and resources, and negative environmental, social and economic impacts. Where possible, these problems should be dealt with, or their impacts minimized, through the application of the principles of sustainability. This research aims to highlight and demonstrate the role of sustainability and its criteria in the construction sector, as well as the use of sustainable engineering technique to reach the best performance. And have been using the Analytical Hierarchal Process software program (AHP) to reach for the best alternative from Proposed Alternatives to the Air-conditioning system for The building of the College of Administration and Economics at the University of Karbala was chosen as a case study for the application of the proposed management system in redesign or rehabilitation of the building and its conversion from conventional to sustainable building. In the light of what has been identified by the criteria specified weights, the best sustainable value of the proposed alternatives has been reached in determining the optimal alternative (package units system).

الملخص

ان معظم الأبنية في العراق تصمم وتنفذ بطرق تقليدية والتي بدورها تؤدي إلى استهلاك كبير في الطاقة والموارد وكذلك تأثيراتها السلبية على البيئة والمجتمع والاقتصاد ، وممكن معالجة هذه المشاكل أو التقليل من تأثيراتها وذلك من خلال تطبيق مبادئ الاستدامة. يهدف هذا البحث إلى إبراز دور مبادئ الاستدامة ومعاييرها في الحقل الإنشائي وكذلك استخدام تقنية هندسة الاستدامة للوصول إلى أفضل أداء ،وقد تم استخدام برنامج AHP للوصول إلى أفضل بديل من مجموعة بدائل مقترحة لنظام التكييف والتبريد لبناية متعددة الطوابق حالة دراسة (بناية كلية الإدارة والاقتصاد في جامعة كر بلاء) لتطبيق النظام الإداري المقترح في إعادة تصميم او إعادة تأهيل البناية وتحويلها من تقليدية إلى مستدامة . وعلى ضوء ما تم التوصل إليه من أوزان للمعايير المحددة فقد تم الوصول إلى أفضل قيمة مستدامة للبدائل المقترحة لنظام التكييف والتبريد في تحديد البديل الأمثل (نظام الوحدات المجمعة) .

1.0 Introduction

The construction industry is one of the main contributors to depletion of natural resources in the world . Currently this industry consumes around 43% of the energy, 72% of the electricity, 17% of the water, and 32% of the materials and resources; in addition to that, it produces 40% of global green house emissions, 40% of solid waste generation, soil loss, reduction in air quality, and has a higher negative impact on biodiversity. In addition, in many countries, people spend almost 90% of their life inside buildings. In response to this high impact, emerges the concept of sustainable construction. [1]

2.0 Sustainable Building Concept

Sustainable buildings use key resources like energy, water, materials, and land more efficiently than buildings that are just built to code. With more natural light and better air quality, green buildings typically contribute to improved employee and student health, comfort, and productivity.[2]

Waziry regarded sustainable building as the process of building design style that respects the environment, takes into consideration the reduced consumption of energy and materials and resources while reducing the effects of construction and use on the environment while maximizing harmony with nature. [3]

In general the term sustainable building is used to describe design and construction of buildings with some or all of the following characteristics: [4]

1- Buildings that have minimal adverse impacts on local, regional, and even global ecosystems;
2- Buildings that reduce reliance on automobiles;
3- Buildings that are energy-efficient in their operation;
4- Buildings and grounds that conserve water;
5- Buildings that are built in an environmentally responsible manner from low-environmental-impact materials;
6- Buildings that are durable and can be maintained with minimal environmental impact;
7- Buildings that help their occupants practice environmentalism, e.g. by recycling waste;
8- Buildings that are comfortable, safe, and healthy for their occupants.
9-

3.0 The Super Decisions Software(AHP)(Analytical Hierarchy Process)

The super decision software (version 2.2) based on the analytic hierarchy process was developed by Thomas L. Saaty and designed by William J. Adams. This software builds the simplest decision model that has a goal, criteria, sub-criteria and alternatives, which makes judgments (paired comparisons), and computes the results to find the best alternative.

The researcher used this software for determining the weights of the main criteria and sub-criteria, as well as determining the optimal alternative.

A hierarchical decision model has a goal, criteria that are evaluated for their importance to the goal, and sub-criteria that are evaluated for their importance to the main criteria, and alternatives are evaluated for how preferred they are with respect to each criterion.[5]

An abstract view of such a hierarchy is shown in Figure (1).

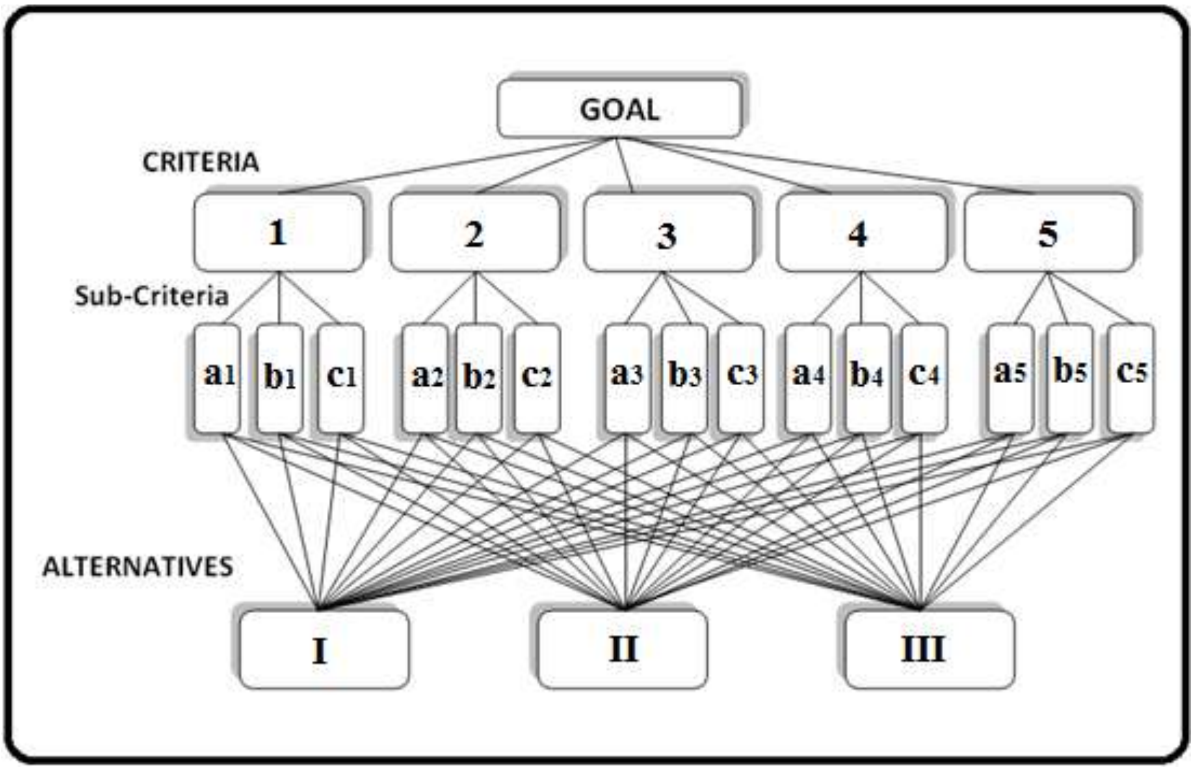


Fig. (1) Analytic Hierarchy Process (AHP) model [5]

A Super Decisions model which consists of clusters of elements (or nodes), rather than elements (or nodes) is arranged in levels. The simplest hierarchical model has a goal cluster containing the goal element, a criteria cluster containing the criteria elements, a sub-criteria cluster containing the sub-criteria elements, and an alternatives cluster containing the alternative elements - as shown in Figure (1). When clusters are connected by a line it means nodes in them are connected. The cluster containing the alternatives of the decision must be named Alternatives.

In general, AHP captures priorities from paired comparison judgments of the elements of the decision with respect to each of their parent criteria; paired comparison judgments can be arranged in a matrix, and priorities are derived from the matrix as its principal eigenvector, which defines an absolute scale. Thus, the eigenvector is an intrinsic concept of a correct prioritization process. It also allows for the measurement of inconsistency in judgment.

4.0 Select of Case Study (multi-story building)

The researcher has chosen a building of the College of Administration and Economics at the University of Karbala as a case study. This is because of the ease of access to data, and the fact that the building selected consumes a large amount of energy.

4.1 General Information about the Building

The building of the College of Administration and Economics (structural building) was completed in 2009, and it is composed of four similar departments and the office of the Dean of the college, over two floors (stories); the total area of the building almost 14200m^2; the building location in the University city in Friha region in Karbala. The implemented parts of the building were office of the dean and only two departments. Each department contains several spaces including the following:

1- Lecture hall 2- Staff room 3- Service room 4- Meeting hall 5- Rest room
6- Head of Department’s room 7- Secretary’s room

The researcher selected one department of the college to consider as the case study for this research. Figures (2) and (3), shows the ground floor and first floor of the building.

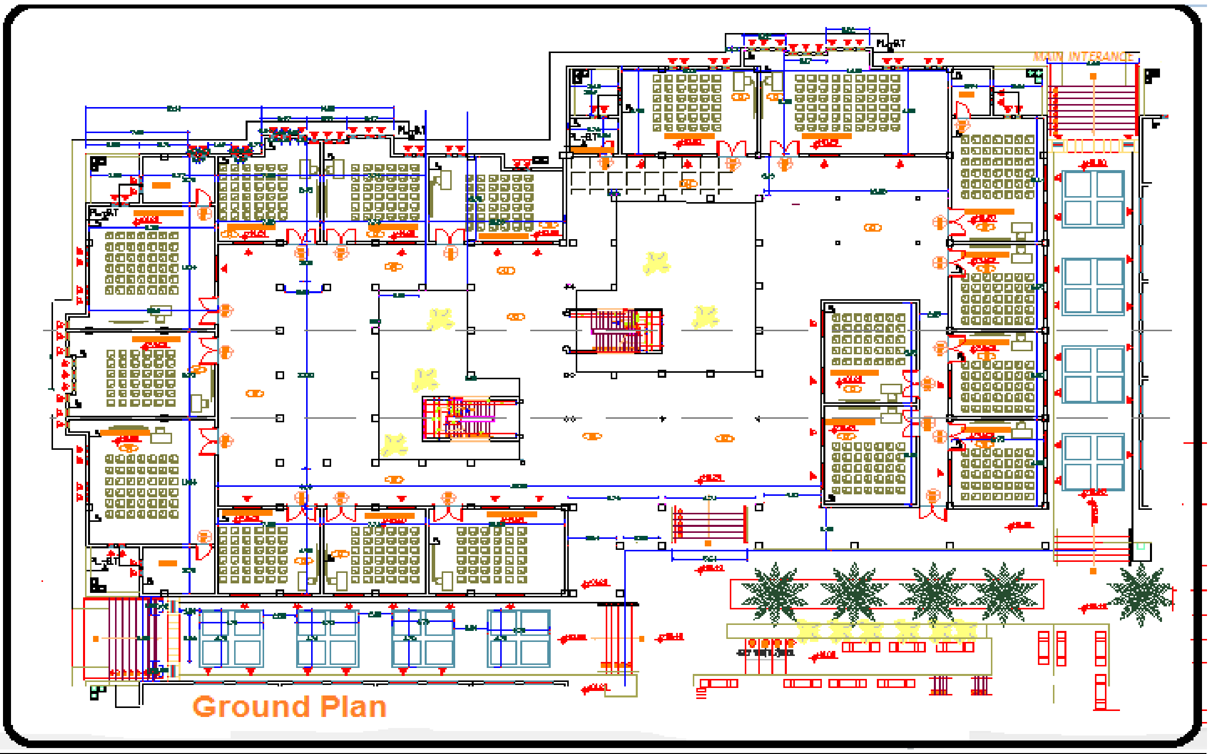


Figure (2) Ground floor plan for one department in the building

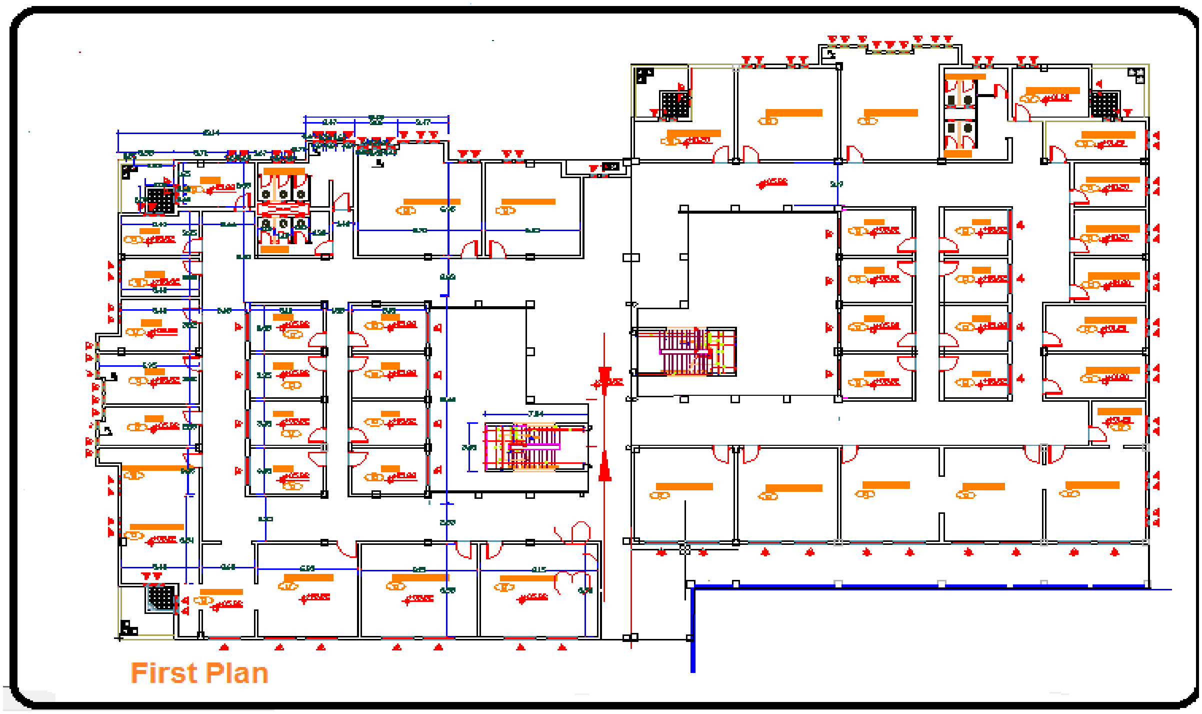


Fig. (3) First floor plan for one department in the building

5.0 Proposed Alternatives to the Air-conditioning System

The selection of a system for cooling and heating of the building (Heating Ventilation and Air-Condition (HVAC)) is a major component of the building needed alternatives to be suggested because it greatly affects the main criteria of sustainability (environment, economy and sociality).

All required data and information have in this proposal were derived or taken from the Department of Engineering Affairs at the University of Karbala (records, calculations, documentation, and opinions of specialist engineers).

The current system used to provide air-conditioning for the building is a split units system.

5.1 Calculating the Load Requirement of the Building for HVAC

The following outlines the procedure for calculating the overall load requirement for a building (one department) in tons:

Total area (requiring air-conditioning) for ground floor = 1400 m2

Total area (requiring air-conditioning) for first floor = 1600 m2

Total area (requiring air-conditioning) for all building = 1400+1600=3000 m2

Total volume or space (required air-conditioning) for all building =

3000*3.4 (height) = **10200 m3**

In accordance with the conditions and the components of the walls and ceiling of the building (case study), and number of the occupants, it is considered that almost every 30 m3 of space needs to have one ton of air-conditioning.

Total volume for required air-conditioning for the whole building = 10200/30=**340 tons**.

5.2 listing of proposals alternatives

Several ideas were recorded for various aspects of the air-conditioning system for the building. Table (1) shows a list of some of the alternatives for the air-conditioning system of the building.

Table (1) List of air-conditioning system proposals

Study Title: Air-condition system	Basic Function: Thermal Comfort	Team: sustainable team
1	Split Units System (current system) (S.U.)	
2	Chilled Water System (C.W.)	
3	Package Units System (P.U.)	
4	Direct Expansion System (D.E.)	
5	Smart Variable Refrigerant Flow System (S.V.R.F.)	

5.3 Analytical of the proposed alternatives

The beginning portion of this phase was used to refine the list of ideas. The feasible ideas were identified and retained, while the other ideas were discarded. Ideas with potential were examined more closely, so that they could be listed with their advantages and disadvantages, as shown in Table (2).

Table (2) Advantages and disadvantages of proposed systems for air-conditioning (Researcher)

Study Title: Air-condition system	Basic Function: Thermal Comfort	Team: sustainable team
Identify their advantages and disadvantages to determine where additional work should be done.		

Idea	Advantages	Disadvantages
S.U.	- faster completion - low initial cost	- increases effort - increases maintenance cost - needs drainage system - shorter life cycle - increases electricity consumed
C.W.	- high efficiency - easy and central control - once time for installation - saving energy - gas use is environmentally friendly - noise control - outdoor air quality control	- must have staff to maintain it and follow up - difficulty for installation - required for routine maintenance - increases initial cost - increases maintenance cost
P.U.	- central system - ease of installation -provide health and comfort for occupants - noise control - gas use is environmentally friendly -provide large capacity for air-conditioning - saving energy - low maintenance cost	- negatively affected by airy dust
D.E.	- central system - ease of installation - benefits for building where there are no ports for the passage of air ducts - provide health and comfort for occupants - noise control - gas use is environmentally friendly - saving energy	- negatively affected by airy dust - requires pipes for routine maintenance - increases initial cost
S.V.R.F.	- central and separate system - does not require a ducting system - benefits for closed building - gas use is environmentally friendly - smart control system - ease of maintenance - saving energy	- increases initial cost - complexity of control system - requires staff training on system - requires large network for pipes

5.4 Development of the proposed alternatives

In this phase the life cycle cost analysis was done for the proposals, as shown in Table (3). This gave a more accurate depiction of the total cost associated with each proposal.

5.4.1 Calculation of Relative Cost for Proposals (life cycle cost analysis)

The method used to determine the relative cost for alternatives was Net Present Value (NPV) (selected by the researcher).

To calculate the net present value of alternatives, follow the following steps: [6]

PW(NPV) = Pi + (P/A , i% ,n) + (P/F , i% , n) – (P/F, i% ,n) ....(1)

Total present worth= Initial cost + Present value for annual cost + Present value for replacement cost – Present value for salvage value ....(2)

In engineering economics, the payments for life cycle cost are applied through the following equations: (Ref.125)

$$P = F\,\frac{1}{(1+i)^n} \quad \text{.........................(3)}$$

$$P = A\,\frac{(1+i)^n - 1}{i(1+i)^n} \quad \text{.........................(4)}$$

where:

P: Present value

F: Future value

A: Annual value

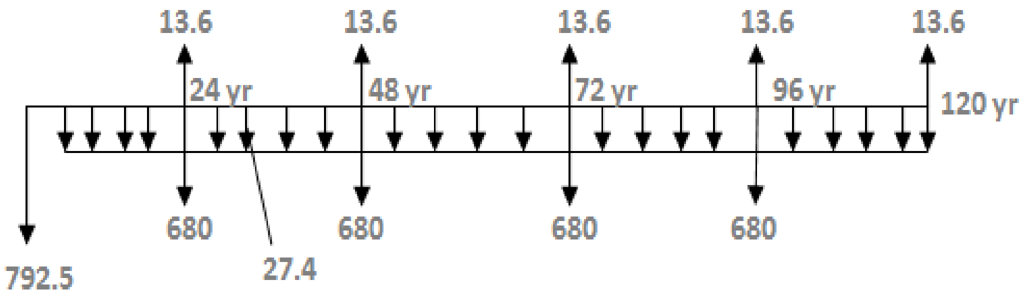
i : Interest (discount) rate

n: Number of period

For comparison between the alternatives by the present value method, the life of all the alternatives must first be unified, and that takes a least common multiple for the ages of the alternatives that is equal to 120.

Following is a sample of the relative cost calculation for alternative No.2:

For alternative No. 2 (C.W.) in Table (3); the following cash flow diagram for payments:



Assume i = 8% (Interest rate dominant in Iraqi banks)

n = 120 period

PW(NPV) = 792.5 + 27.4 (P/A ,8% ,120) + (680-13.6) (P/F ,8% ,24) +(680- 13.6) (P/F ,8% ,48)+ (680-13.6) (P/F ,8% ,72)+ (680-13.6) (P/F ,8% ,96) – 13.6(P/F, 8% ,120) ....(5)

PW = 1260×10^6 ID

Relative Cost for Alt. = $(PW_{Alt.} / PW_{total}) \times 100$ ....(6)

$PW_{total} = PW_{Alt.1} + PW_{Alt.2} + PW_{Alt.3} + PW_{Alt.4} + PW_{Alt.5}$ ....(7)

Relative Cost for $Alt._{C.W.}$ = (1260/4790) *100 = 26.3 %

Table (3) Life cycle cost analysis for proposed systems of air-conditioning

Item: Building air-conditioning systems for 340 tons required		Alter. No.1 (S.U.)	Alter. No.2 (C.W.)	Alter. No.3 (P.U.)	Alter. No.4 (D.E.)	Alter. No.5 (S.V.R.F.)
Initial cost (ID)	Purchase and supply cost	153	775	360	530	516
	Installation cost	18.7	17.5	5.0	6.7	9.3
	Total initial	171.7	792.5	365.0	536.7	525.3
Annual cost (ID)	Operation cost	---	8.5	1.7	5.1	3.4
	Maintenance cost	10.2	10.2	2.4	5.5	6.8
	Energy (electricity) cost	12.7	8.7	10.2	10.9	8.0
	Total annual	22.9	27.4	14.3	21.5	18.2
Replacement cost (ID)		136	680	323	510	425
Salvage value (ID)		0.0	13.6	6.8	10.2	3.4
Life cycle (year)		5	24	20	15	10
Total present worth (PW)(ID)		**748**	**1260**	**630**	**1036**	**1116**
Normal weight (Relative Cost)		**0.156**	**0.263**	**0.132**	**0.216**	**0.233**

Note:
1-All costs in this table have been estimated on the basis of previous BoQ for the same items in the documentations of the Department of Engineering Affairs.
2- All costs in this table are multiplied by 10^6

5.5 Weighted Evaluation (Analysis matrix)

After calculating the cost index of each alternative, the function index is determined by comparing the alternatives with the main criteria and sub-criteria of sustainability using the AHP software program. The main criteria and sub-criteria for sustainability are listed as follows:[7]

1- Sustainable Site (SS)
a- Brownfield and Urban redevelopment
b- Construction-related pollution prevention
c- Development density and community connectivity
d- Heat island effect
e- Impact on ecosystems and waterways
f- Improve site aesthetics
g- Light pollution
h- Promote reduction of erosion
i- Site development impacts
j- Stormwater management
k- Transportation alternatives
2- Water Efficiency (WE)
a- Indoor water use reduction
b- Landscaping water use reduction
c- Wastewater strategies
3- Resourceful Energy (RE)
a- Fundamental building systems commissioning
b- Measurement and verification
c- Refrigerant management
d- Renewable energy use
e- Systems and lighting
f- Whole building energy performance optimization

4- Materials and Resources (M&R)
a- Building reuse
b- Construction waste management
c- Materials reuse
d- Materials with recycled content
e- Rapidly renewable materials
f- Recycling collection locations
g- Salvaged materials
h- Storage and collection of recyclables
i- Sustainably forested wood products
j- The purchase of regionally manufactured materials
k- The selection of sustainably grown, harvested, produced and transported products and materials
5- Indoor Environmental Quality (IEQ)
a- Construction Indoor Air Quality (IAQ) management plan
b- Controllability of thermal and lighting systems
c- Environmental tobacco smoke control
d- Improve acoustics
e- Increase ventilation
f- Indoor chemical and pollutant source control
g- Outdoor air delivery monitoring
h- Provide access to natural daylight and views
i- Use low emitting materials
j- Quality of life and local communities
6- Innovation and Design Process (I&D)
a- Innovative strategies for sustainable design
b- Sustainability professional person on the team
c- The school or university as a teaching tool
7- Risk and Security (R&S)
a- Design risks
b- Implementation risks
c- Financial risks
d- Political risks
e- Durability
f- Structure security
g- Fire protection ability
h- Burglary protection ability
i- Water protection ability
j- Workers' safety and health

8- Economic Factors (EF)
a- Create new markets
b- Operation and maintenance cost
c- Productivity benefits
d- Provide opportunities for local businesses
e- Reduce life cycle cost
f- Social cost
g- Use of new technologies
h- Social equity (poverty)
9- Construction Duration (CD)

Appendix (1) shows the models of pairwise comparisons for alternatives with respect to the criteria.Completing the required data in the software program has been guided by mechanical engineers who were specialists in air conditioning for buildings.

The researcher depends on the results and specified of main criteria and weighted adopted for the previous research (Reference No. 7).

Some criteria have no comparison between alternatives, because they do not influence the alternative on the criterion, so it will be press no comparison for these alternatives in the software program. After the comparison was completed, the whole inconsistency index is less than 0.10, so the results are fine. Figure (4) shows the hierarchy model for criteria and alternatives.

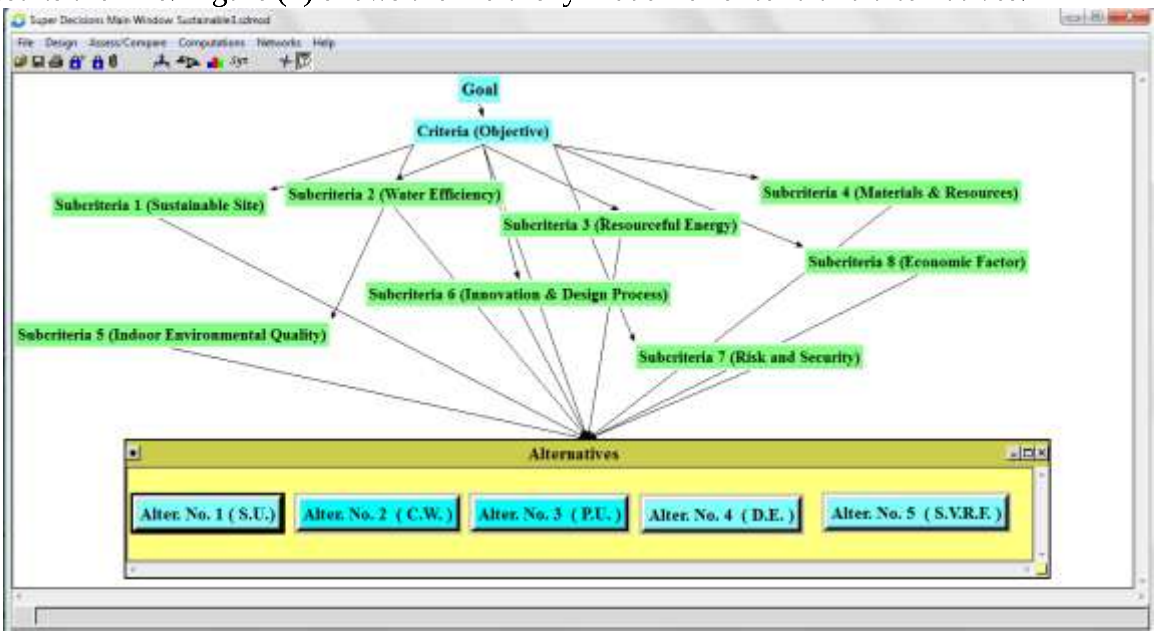


Figure (4) Hierarchy model of criteria and alternatives for HVAC proposals for air-conditioning

The program shows the overall synthesized priorities for the alternatives, as shown in Figure (5). The Raw values come from the Limit Super matrix; the Normalized values are obtained from them by normalizing, and the Ideals are obtained by dividing all Raw values by the largest of them.

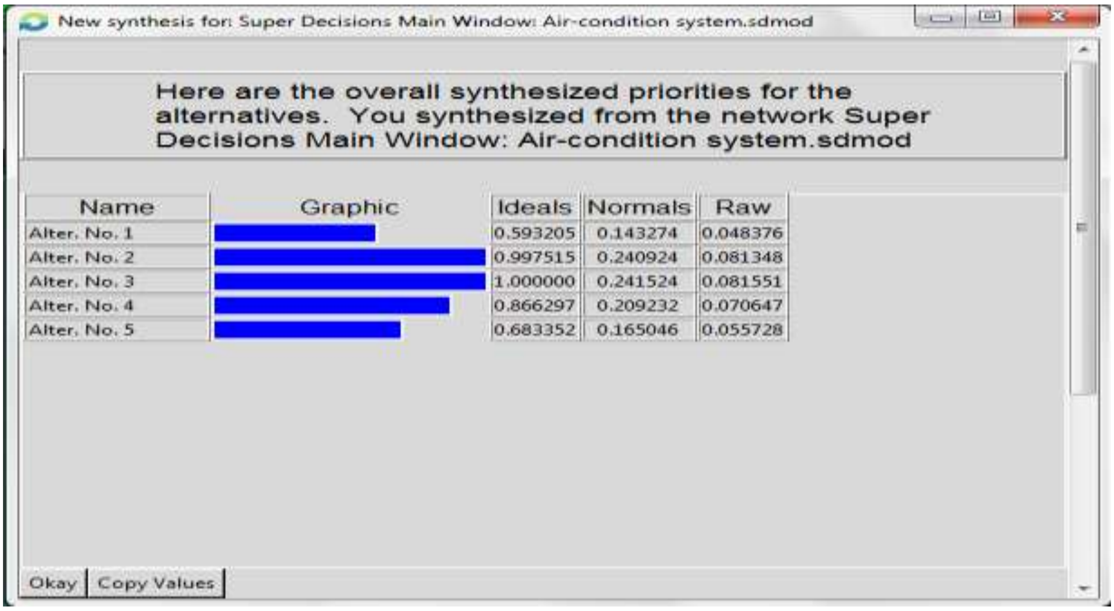


Figure (5) Synthesized priorities for the alternative air-conditioning systems

For determining the sustainable function index for alternatives, the values that are specified in the Normal form will be specified, as shown in Table (4).

Table (4) The sustainable function index for the alternative air-conditioning systems

Alternatives	No.1	No.2	No.3	No.4	No.5
Sustainable Function Index (Normal)	0.1433	0.2409	0.2415	0.2092	0.1650

5.6 Sensitivity Analysis

The AHP computer program was used to conduct a sensitivity analysis of the alternatives according to the criteria. This is done using the following steps:

1- Select computations - sensitivity command.
2- Edit independent variable in order to change it to the goal (optimum sustainable building performance).
3- In the selected node box highlight the current node and click edit.
4- In the input parameter box select parameter type: supermatrix, goal as with respect to node, and one of the criteria as the first other node, for example, the researcher selected the resourceful energy criterion.
5- Click done and update to see the sensitivity graph for that criterion.

That is illustrated in Figure (6).

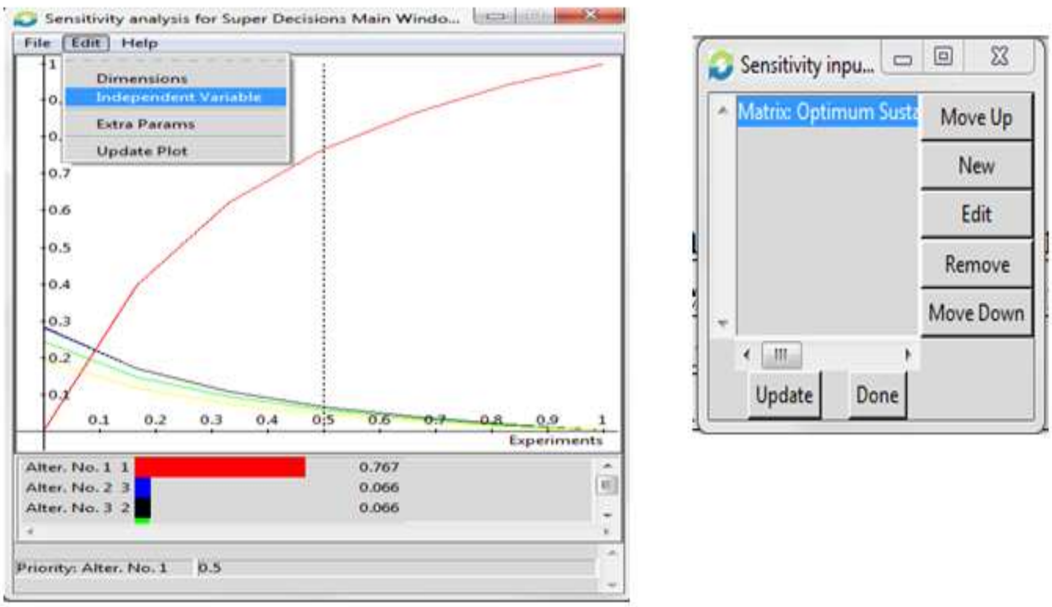


Figure (6) Sensitivity analysis for the alternative air-conditioning systems

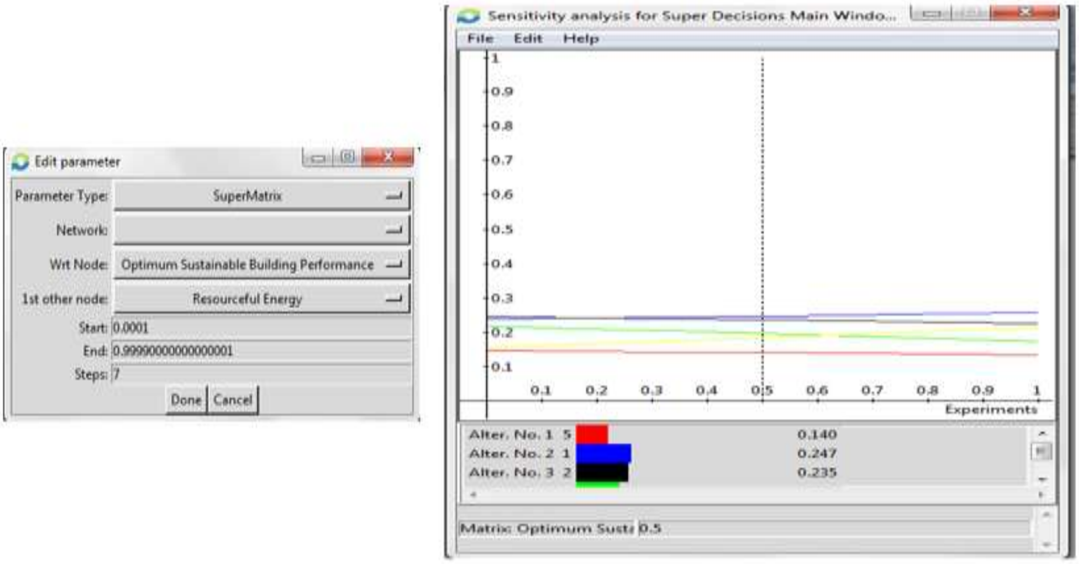


Figure (6) continued

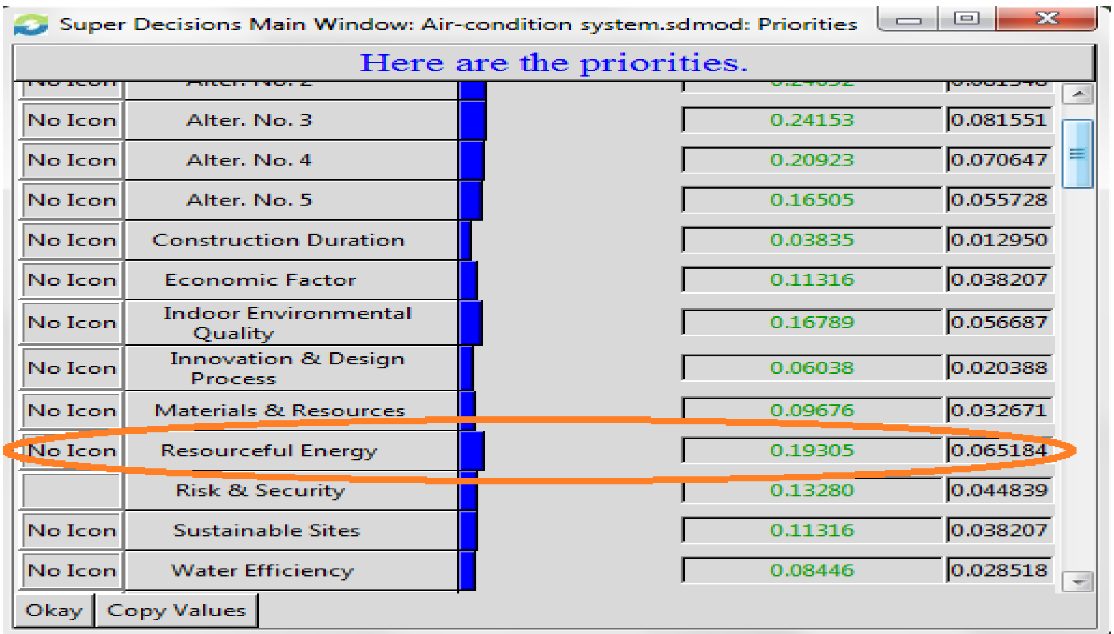
To find out the priority identified by the program for the criterion resourceful energy follow the steps in the program, and then notice the impact of the sensitivity of an alternative priority to change the priority of the specified criterion:

1- Select computations - priorities command to see priorities of all nodes in the model.

2- “Limiting priority” column shows value of resourceful energy from Limit supermatrix (0.06518) (shown in Figure 7).

3- “Normalized by Cluster” column shows overall priority of resourceful energy (0.19305) in the model (shown in Figure 7).

4- Drag the vertical line from 0.5 to 0.19305 on the x-axis in Sensitivity to show the priorities of the alternatives at that priority for resourceful energy (shown in Figure 8).


Super Decisions Main Window: Air-condition system.sdmod: Priorities

Here are the priorities.

No Icon	Alter. No. 3	0.24153	0.081551
No Icon	Alter. No. 4	0.20923	0.070647
No Icon	Alter. No. 5	0.16505	0.055728
No Icon	Construction Duration	0.03835	0.012950
No Icon	Economic Factor	0.11316	0.038207
No Icon	Indoor Environmental Quality	0.16789	0.056687
No Icon	Innovation & Design Process	0.06038	0.020388
No Icon	Materials & Resources	0.09676	0.032671
No Icon	Resourceful Energy	0.19305	0.065184
	Risk & Security	0.13280	0.044839
No Icon	Sustainable Sites	0.11316	0.038207
No Icon	Water Efficiency	0.08446	0.028518

Okay Copy Values

Figure (7) Indicates the priorities of the resourceful energy criterion

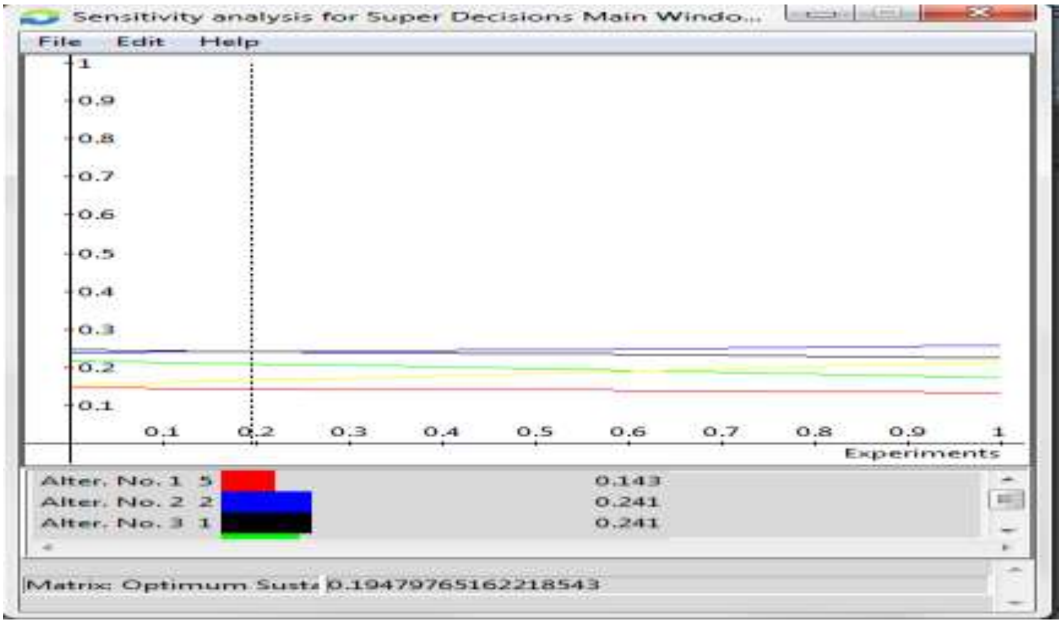
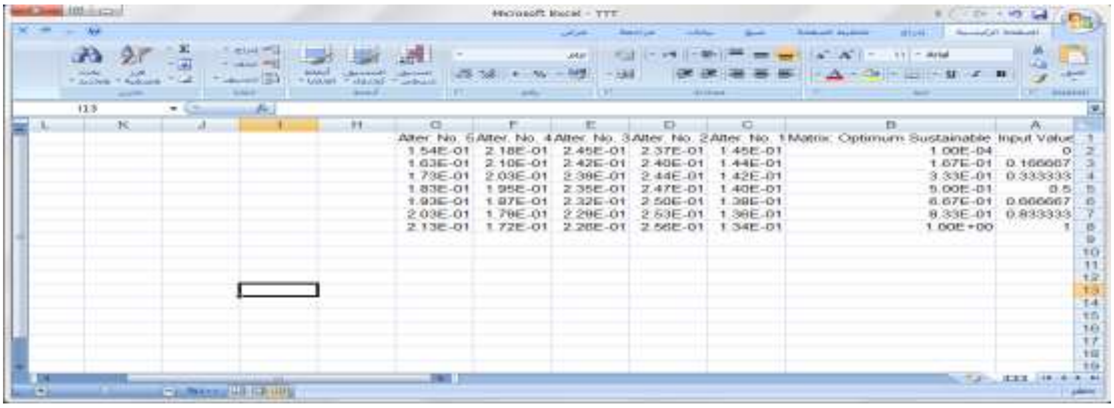


Figure (8) The priorities of the alternatives at the priority of resourceful energy=20%

The results of the alternatives' sensitivity analysis for the criterion resourceful energy can be converted to a table in the Excel program, as shown in Figure(9); the following have been noted:When the priority of the resourceful energy criterion obtains 100%, alternative No. 2 is ranked first in terms of priority and alternative No. 3 comes second and then the alternatives' hierarchy is No. 5, 4, 1, respectively. This shows that alternative No. 2 is the best alternative in terms that satisfy the requirements and considerations of resourceful energy criterion, and the worst alternative for this criterion is alternative No.1.



Alter No 5	Alter No 4	Alter No 3	Alter No 2	Alter No 1	Matrix: Optimum Sustainable	Input Value
1.54E-01	2.18E-01	2.45E-01	2.37E-01	1.45E-01	1.00E-04	0
1.63E-01	2.10E-01	2.42E-01	2.40E-01	1.44E-01	1.67E-01	0.166667
1.73E-01	2.03E-01	2.38E-01	2.44E-01	1.42E-01	3.33E-01	0.333333
1.83E-01	1.95E-01	2.35E-01	2.47E-01	1.40E-01	5.00E-01	0.5
1.93E-01	1.87E-01	2.32E-01	2.50E-01	1.38E-01	6.67E-01	0.666667
2.03E-01	1.79E-01	2.29E-01	2.53E-01	1.36E-01	8.33E-01	0.833333
2.13E-01	1.72E-01	2.26E-01	2.56E-01	1.34E-01	1.00E+00	1

Figure (9) The alternatives' sensitivity analysis for Resourceful energy criterion

5.7 Calculating the Sustainable Value Index (SVI)

The following equation shows how to determine the value index: [8]

Value Index = (Function + Quality)/ Cost

Sustainable Value Index = Sustainable Function / Relative Cost ....(8)

Table (5) shows the sustainable value index of alternatives and is arranged according to priority; it was found that alternative No. 3 is the best alternative in terms of value (the best function and importance and minimum cost) , while alternative No. 5 has the lowest value.

Table (5) The sustainable value index and ranking for alternative air-conditioning systems

Alternative	No.1	No.2	No.3	No.4	No.5
Sustainable Function	0.1433	0.2409	0.2415	0.2092	0.1650
Relative Cost	0.156	0.263	0.132	0.216	0.233
Sustainable Value Index	0.919	0.916	1.830	0.969	0.708
Ranking	**3**	**4**	**1**	**2**	**5**

5.8 Proposal and Report presentation

Table (6) shows the written final proposal for the alternative air-conditioning system. The report phase will continue as data are collected for the actual savings from the alternative.

Table (6) Final proposal for the alternative air-conditioning systems (Researcher)

Sustainable Engineering Proposal: Executive Brief	
Study Title: Building at the University Of Karbala	Proposal: 1(package units system)
Item: Air condition System in Building	Date:
Project: Building of the College of Administration and Economics. It is composed of four departments and the office of the dean of the college over two floors (stories); each Department contains several spaces.	
Original Design: The current system used to provide air-conditioning for the building is a split units system	
Proposed change: Package Units System - it contains apparatus for air-conditioning packages, transit air ducts and air diffusers.	
Advantages: The package units system will have a longer life cycle than the split units system. This system has central control, is easy to install, provides health and comfort for occupants, has noise control, gas use is environmentally friendly, it provides a large capacity for air-conditioning, and has low maintenance cost and saving energy and life cycle cost.	
Disadvantages: Negatively affected by airy dust . Another issue is the increase in initial cost compared with split units.	

Cost summary	Initial cost	Ownership cost (NPV)	Total cost (NPV)	S. Value Index
Original Design	$171.7*10^6$ ID	$576.3*10^6$ ID	$748*10^6$ ID	0.919
Proposed Change	$365*10^6$ ID	$265*10^6$ ID	$630*10^6$ ID	1.830
Savings	($193.3*10^6$ ID)	$311.3*10^6$ ID	$118*10^6$ ID	

5-9 Results and Conclusions

1- The second and third alternatives (chilled water and package units system) are almost equal in terms of function index (worth), where each obtained 24% of priorities; that means that these alternatives provide the best functions in terms of sustainability criteria compared with other alternatives.

2-Alternative No. 4 (direct expansion system)comes in second place in terms of the importance of sustainability criteria, and alternative No. 5 (smart variable refrigerant flow system)came third, while alternative No. 1 (split units), which is currently being used in the building, ranked last (received the proportion of 14.3%); therefore, this alternative does not achieve sustainability criteria as a required level when compared with other alternatives.

3- From the sensitivity analysis it is noted that, for resourceful energy criterion = 50% priorities, alternative No.2 (chilled water system) is the best.

4- From the sensitivity analysis the following points are noted :

a- At resourceful energy = 19.4% (actual value), alternatives No.2 and No.3 are the best.

b- If the priority is present between about 19% - 22% for resourceful energy, alternatives No.2 and No.3 are the best. For any priority greater than that, alternative No.2 is the best, and for any priority less than that, alternative No.3 is the best.

c- If the priority is presents for about 62% of resourceful energy, alternatives No.4 and No.5 have the same priority.

d- In all values of priorities for resourceful energy, alternative No.5 has less priority.

5-From the sustainable value index of alternatives and is arranged according to priority; it was found that alternative No. 3(package units system) is the best alternative in terms of value (the best function and importance and minimum cost) , while alternative No. 5 (smart variable refrigerant flow system) has the lowest value.

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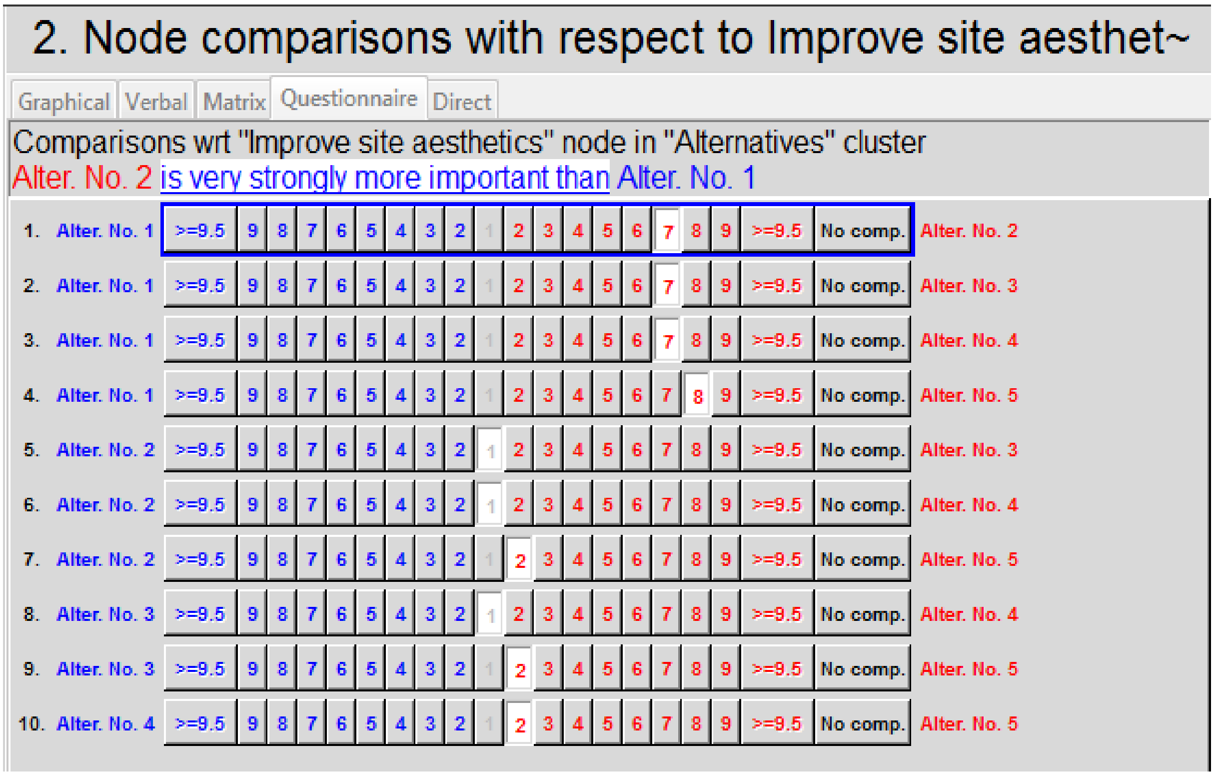
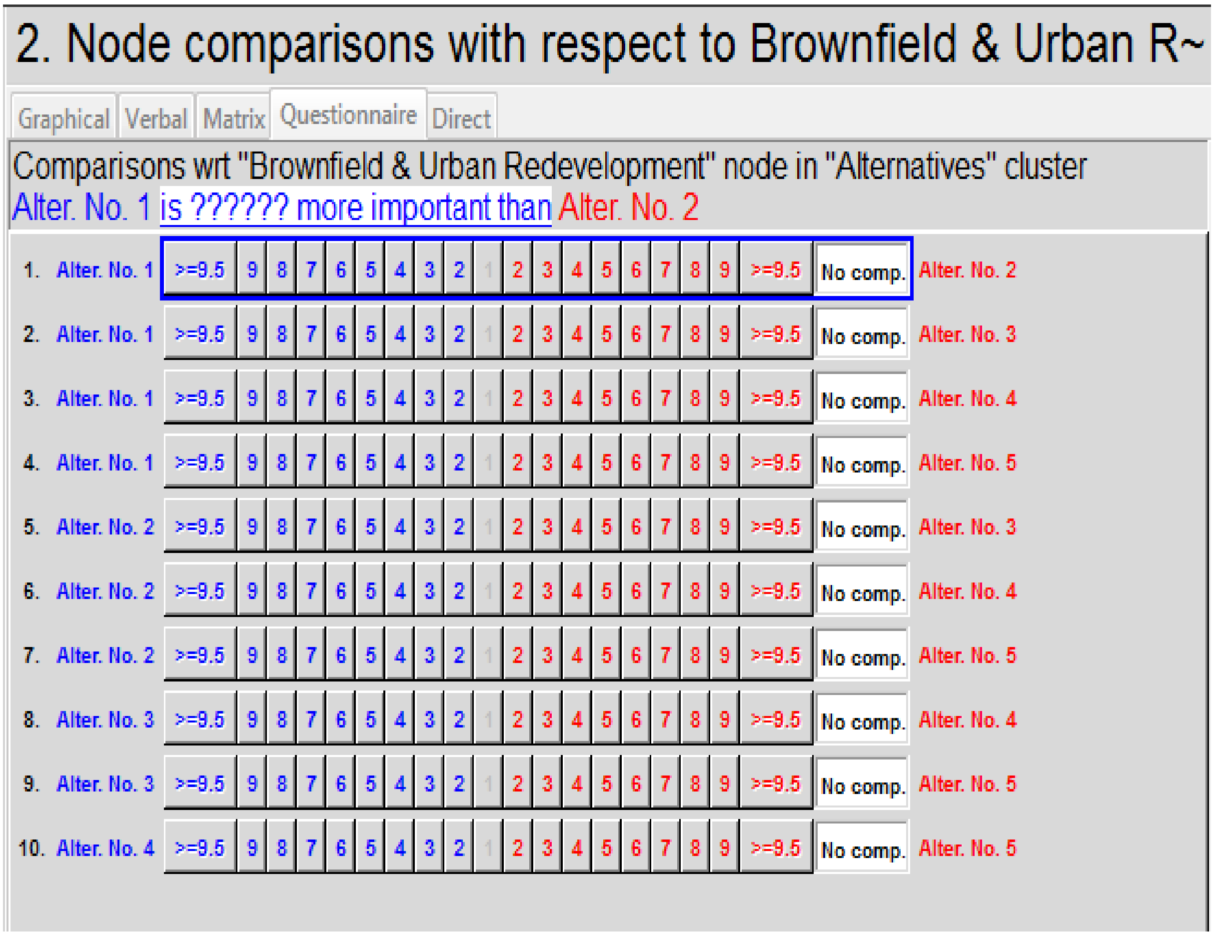
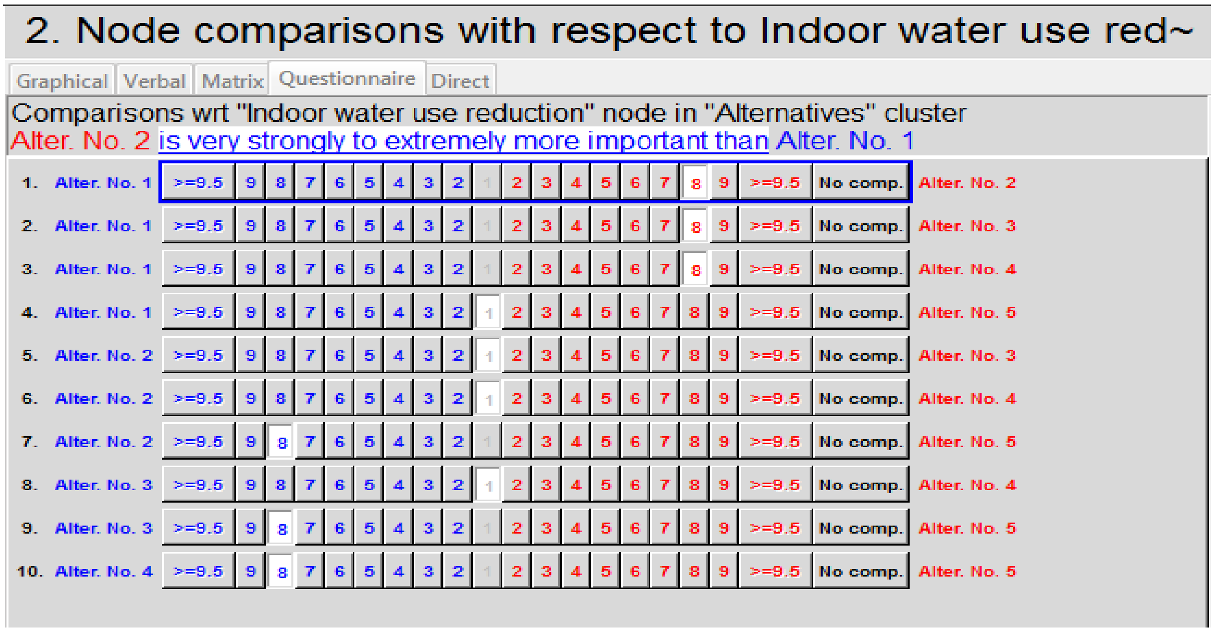
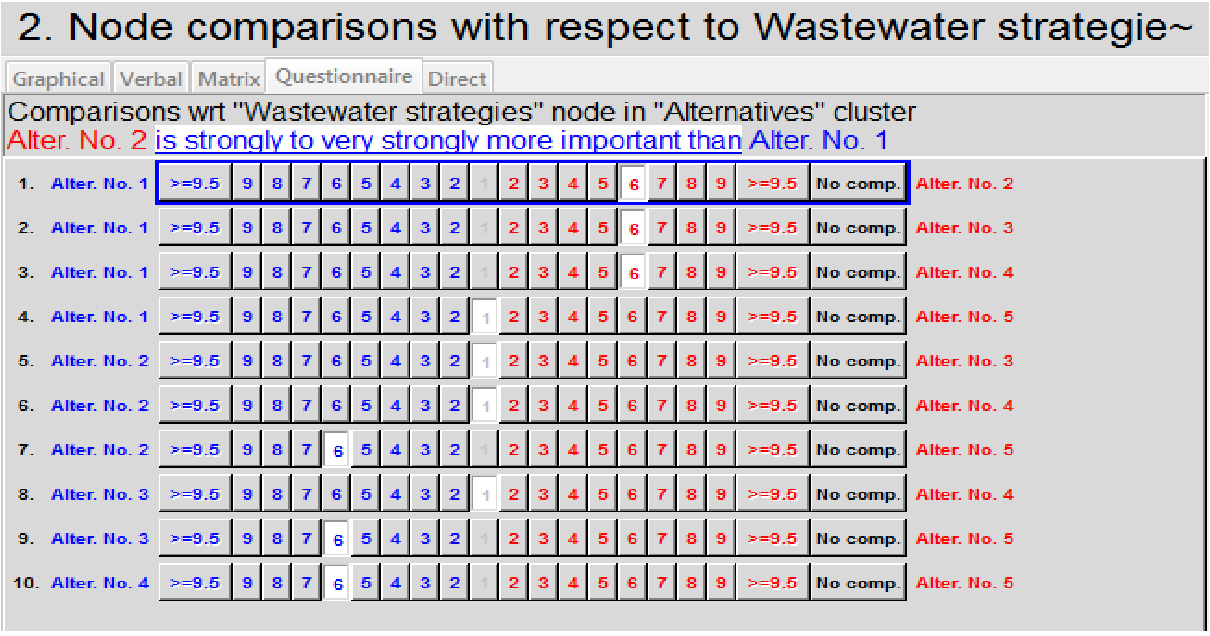
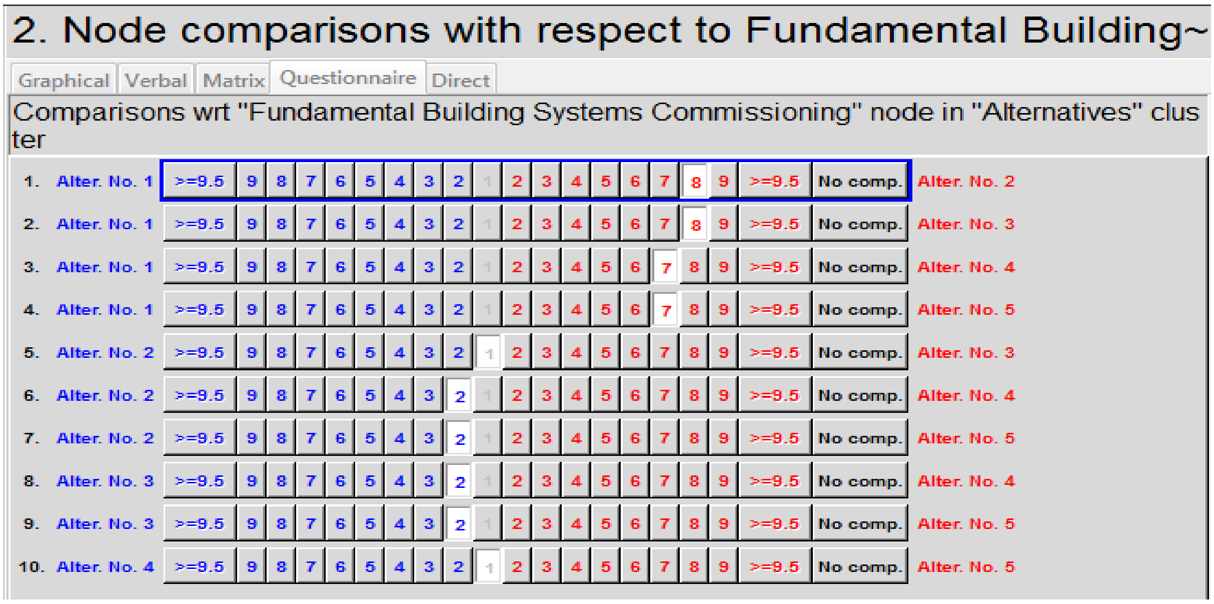
Appendix No. (1) : Pairwise Comparisons for Alternatives to Air-Condition Systems With Respect to the Criteria(AHP Program)

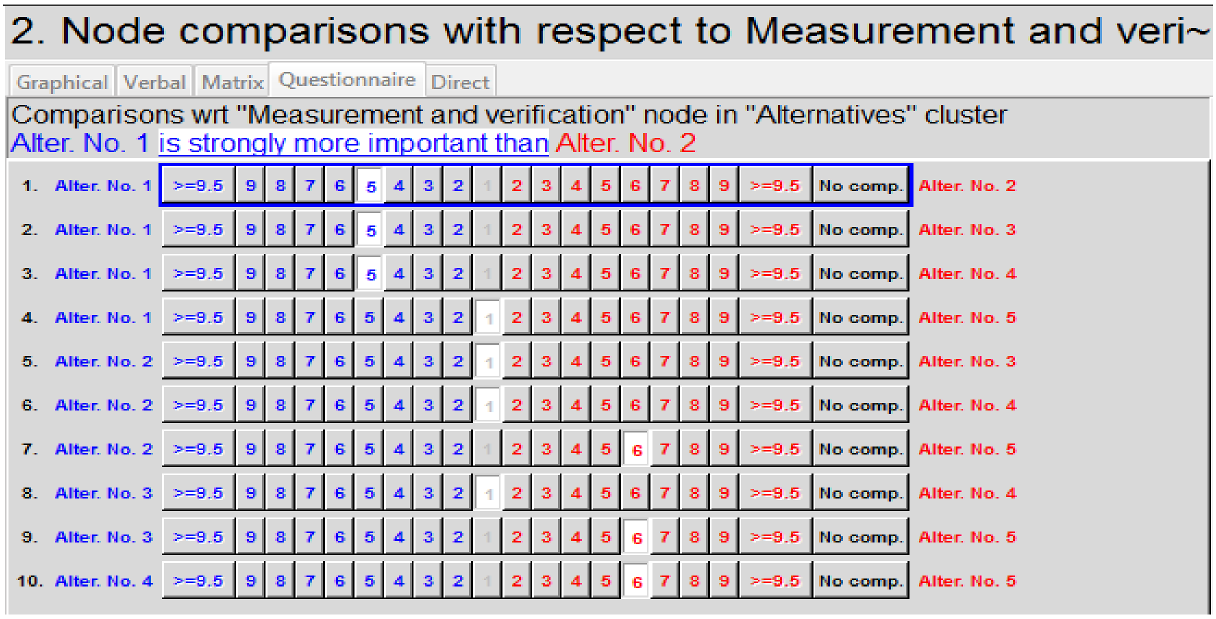


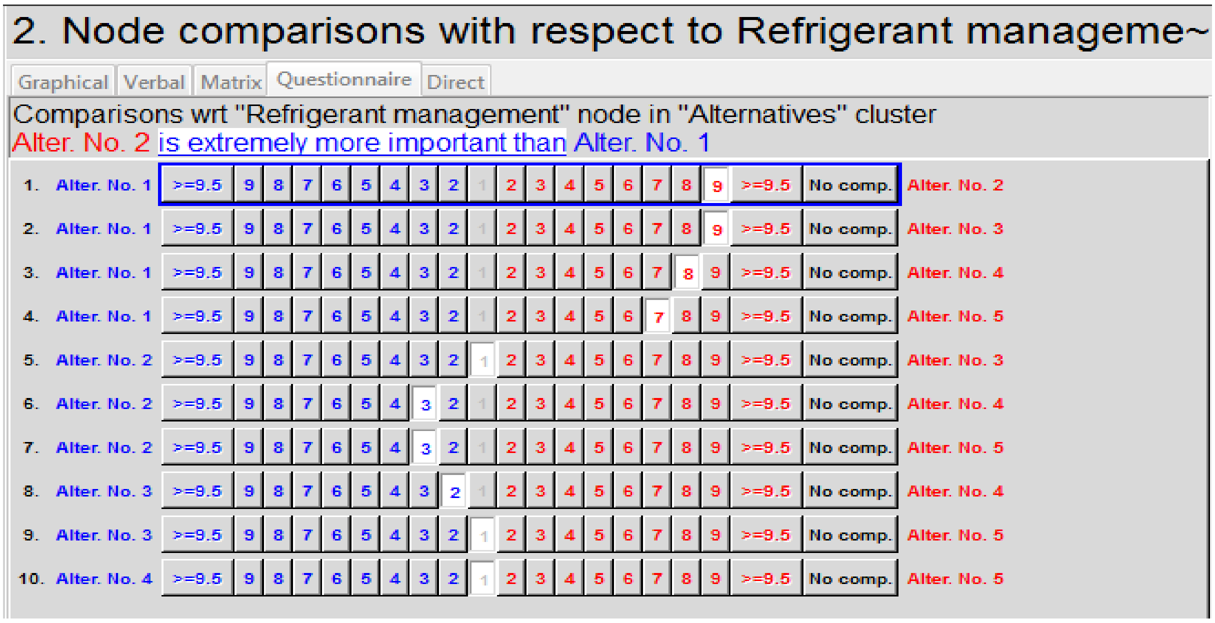


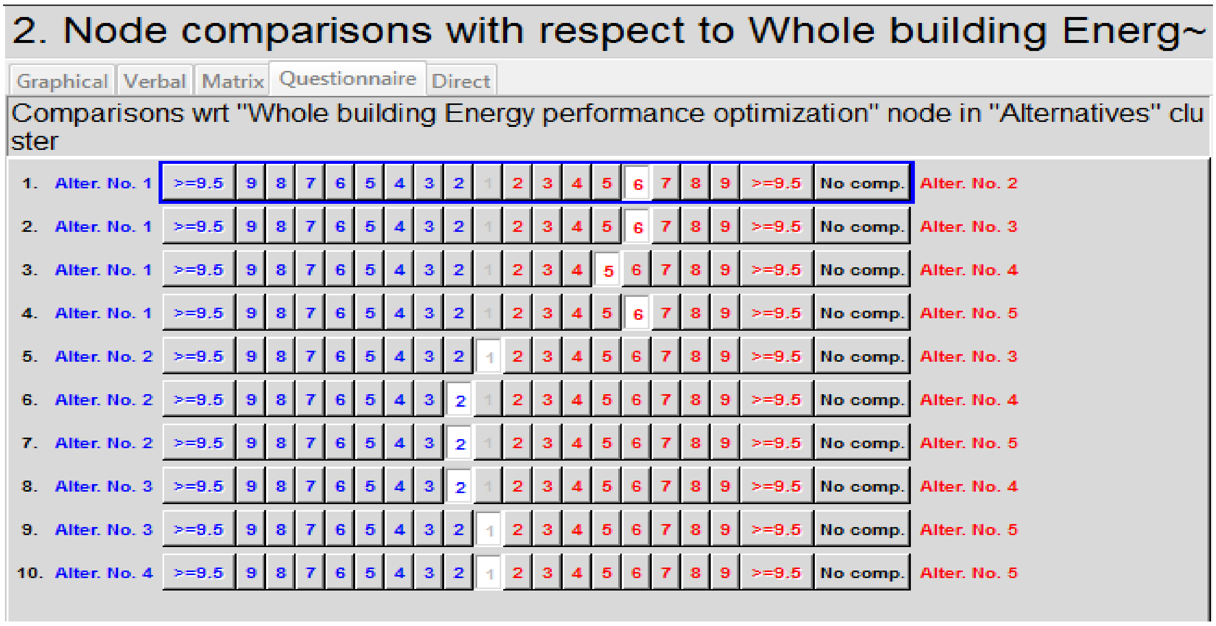

2. Node comparisons with respect to Indoor water use red~
Graphical
Verbal
Matrix
Questionnaire
Direct
Comparisons wrt "Indoor water use reduction" node in "Alternatives" cluster
Alter. No. 2 is very strongly to extremely more important than Alter. No. 1
1. Alter. No. 1 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 2
2. Alter. No. 1 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 3
3. Alter. No. 1 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 4
4. Alter. No. 1 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 5
5. Alter. No. 2 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 3
6. Alter. No. 2 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 4
7. Alter. No. 2 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 5
8. Alter. No. 3 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 4
9. Alter. No. 3 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 5
10. Alter. No. 4 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 5


2. Node comparisons with respect to Wastewater strategie~
Graphical
Verbal
Matrix
Questionnaire
Direct
Comparisons wrt "Wastewater strategies" node in "Alternatives" cluster
Alter. No. 2 is strongly to very strongly more important than Alter. No. 1
1. Alter. No. 1 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 2
2. Alter. No. 1 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 3
3. Alter. No. 1 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 4
4. Alter. No. 1 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 5
5. Alter. No. 2 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 3
6. Alter. No. 2 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 4
7. Alter. No. 2 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 5
8. Alter. No. 3 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 4
9. Alter. No. 3 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 5
10. Alter. No. 4 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 5


2. Node comparisons with respect to Fundamental Building~
Graphical
Verbal
Matrix
Questionnaire
Direct
Comparisons wrt "Fundamental Building Systems Commissioning" node in "Alternatives" clus ter
1. Alter. No. 1 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 2
2. Alter. No. 1 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 3
3. Alter. No. 1 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 4
4. Alter. No. 1 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 5
5. Alter. No. 2 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 3
6. Alter. No. 2 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 4
7. Alter. No. 2 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 5
8. Alter. No. 3 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 4
9. Alter. No. 3 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 5
10. Alter. No. 4 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Alter. No. 5


2. Node comparisons with respect to Measurement and veri~
Graphical Verbal Matrix Questionnaire Direct
Comparisons wrt "Measurement and verification" node in "Alternatives" cluster
Alter. No. 1 is strongly more important than Alter. No. 2


2. Node comparisons with respect to Refrigerant manageme~
Graphical Verbal Matrix Questionnaire Direct
Comparisons wrt "Refrigerant management" node in "Alternatives" cluster
Alter. No. 2 is extremely more important than Alter. No. 1


2. Node comparisons with respect to Whole building Energ~
Graphical Verbal Matrix Questionnaire Direct
Comparisons wrt "Whole building Energy performance optimization" node in "Alternatives" clu ster