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An Analytic Hierarchy Process for urban heat stress mitigation

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Abstract— In this study, an Analytic Hierarchy Process based approach is proposed for the selection of heat stress prevention measures. This approach provides decision makers with an easy way to evaluate the criteria that help the decision-making process in choosing appropriate measures for hotspots. The study focuses on the key pre-criteria before implementing an intervention. The proposed scheme is based on a comparison between the interventions to show the importance of the alternatives. The evaluation of the measures is obtained from a questionnaire where human judgment is used for a comparison, based on their perception and priorities. The final results showed that green roof is most beneficial option for heat stress mitigation with respect to criteria taken into account.

Keywords—: *Decision making approach, Analytic Hierarchy Process, urban planning, thermal comfort; global warming*

I. INTRODUCTION

Due to global warming phenomena, it is notable that the atmosphere temperature is increasing over the years, and several problems are encountered related to this increase that must be addressed. A prolonged duration of extreme hot weather is called heat wave. Heat waves are one of the most dangerous problems related to global warming [1]. The frequency of heat waves is increasing over recent years, and it is spatially distributed around the world.

At this point the human body cannot be able to adapt itself to excessive exposure to temperature boundaries during heat waves and loses capacity to cool down. It leads to dehydration, hyperthermia, heatstroke and heat mortalities that might cause high quantities of heat-related sicknesses and deaths. In 1980, 10,000 individuals died in the United States because of a heat wave [2]. In July of 1995, it has executed more than 700 individuals in Chicago [3], and in August of 2003, more than 70,000 deaths were recorded in Europe [4]. Extreme heat has been observed to be the deadliest climate-related risk in certain areas [5]. It widespread impacts on human health especially for vulnerable people for example citizens with respiratory, cardio, diabetes, mental disorder or other previous health problems. People, who are illiterate, older, with a low income, and socially disconnected, are likewise at more serious hazard.

In 2050 the part of worldwide urban population will grow by more than 68%. This implies that around 7 billion individuals are expected to live in urban zones [6]. Urban communities are the prevalent home spots for people to live and are more vulnerable to extreme weather conditions. The impact of heat stress could be prevented if proper measures are made. A few urban areas that have executed such measures have experienced decreases in the morbidity and mortality of heat-related illnesses [7]. A review of crisis reaction plans

found that half of the examined urban communities had some specific plans for extreme heat events [8]. However, it is hard for decision makers while choosing interventions for thermal comfort. Therefore, it is important to decide which plans and preventive measures to implement in order to reduce the harmful risks caused by heat stress. Modified and advanced urban planning strategies, green roofs and green facade walls, for example, can reduce the heat stress level and increase the outdoor thermal comfort

In previous studies team of researchers were focused on the several heat mitigation strategies. However, it is important to figure out the best measure which can improve thermal comfort especially in outdoor environment. This selection is quite difficult especially for decision makers due to the lack of sufficient data and unidentified principle of judgment. The main objective of this study is to suggest a benchmarking hierarchy which allows decision makers to think about different aspects and can help to identify the required data-gap of interventions and develop the decision support system on the principle of judgment.

This paper is organized as follows: section 2 contains a general review of heat preventive measures. Selection Process and proposed criteria are described in section 3 while section 4 presents the AHP tool and methodology. Results are discussed in the section 5 and finally, section 6 concludes this work and gives some perspectives.

II. MEASURE OF BEST PRACTICE

There are several preventive measures which helps to decrease the heat stress in urban areas. In this study 5 best practice measures are considered for the application of the methodology which are summarized below in Fig.1.

III. SELECTION PROCESS

An intervention selection procedure is an important tool that helps in decision of suitable measure at desire location. It empowers specialists to survey whether the thoughts and discoveries can be significant and reasonable. It allows decision makers to develop their criteria framework for alternatives to be applied on pilot sites. For this work, we found 5 general criteria that evaluates the outcomes as services and improvement in heat stress reduction. The criteria are defined below.

- a. *Cost effectiveness*: In this study, we acknowledged capital and operational cost with future advancements.
- b. *Efficiency*: defines the thermal comfort improvement in environment and intervention effectiveness within the time frame.

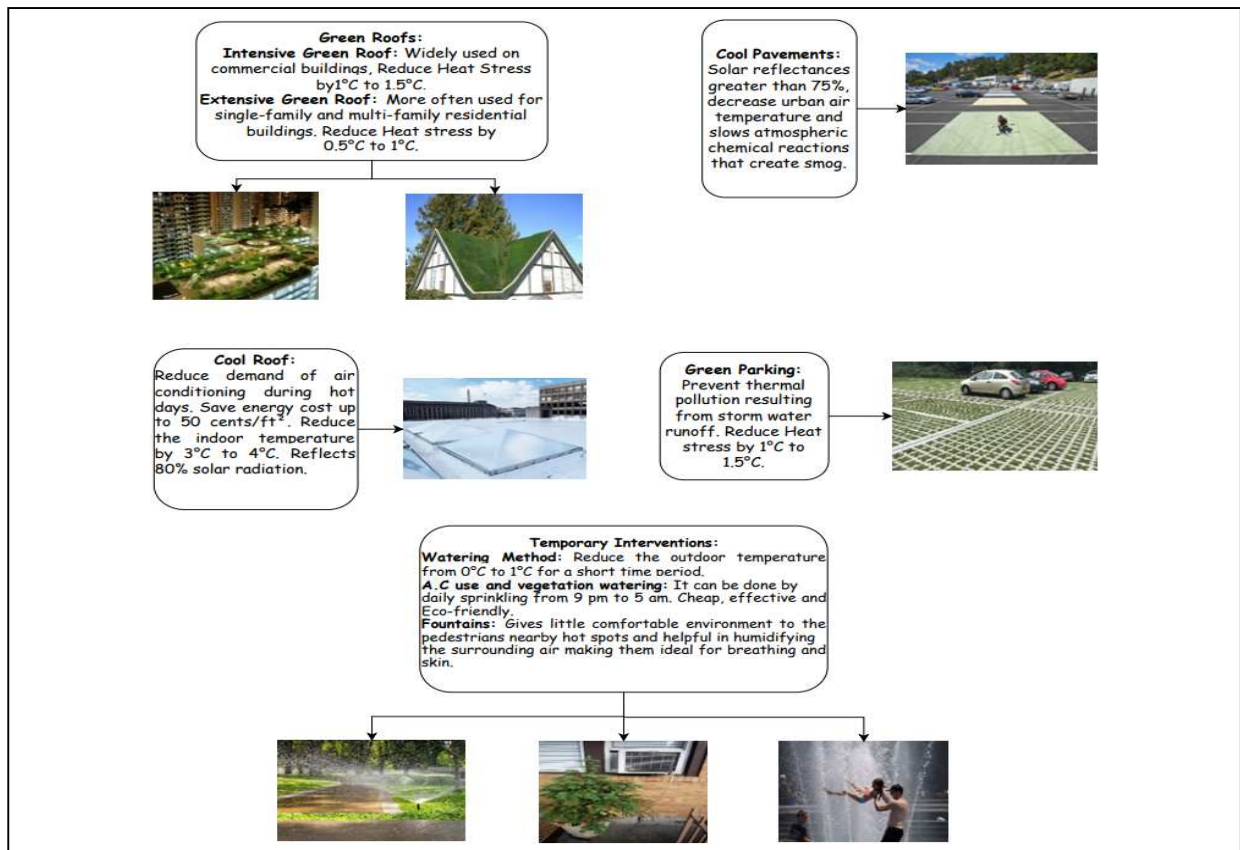


Fig.1 Best Practices measures to improve thermal comfort

- c. **Durability:** Criteria focuses on the toughness of intervention with the capable level of resisting heat and remain useful without demanding extra maintenance while coping with the heat events throughout the service life.
- d. **Environment Impact:** This criterion of investigation is a thorough statistical method for analyzing the impacts of man actuated or natural changes on the environment. By utilizing this intervention investigation, the real difference in the level of pollutants, land or water scarcity can be statistically obtained. For example, it might be essential to decide if a recently introduced intervention significantly reduces the previous mean level of a pollutant.
- e. **Legal:** Approval from authorities is necessary before planning and implementing the mitigation measure in cities

measures[14-15] for example, cost, efficiency, satisfaction feelings and preferences. Several questionnaires were filled by the research team and inputs obtained from these questionnaires are placed in the methodology. AHP permits some little irregularity in judgment that's called inconsistency

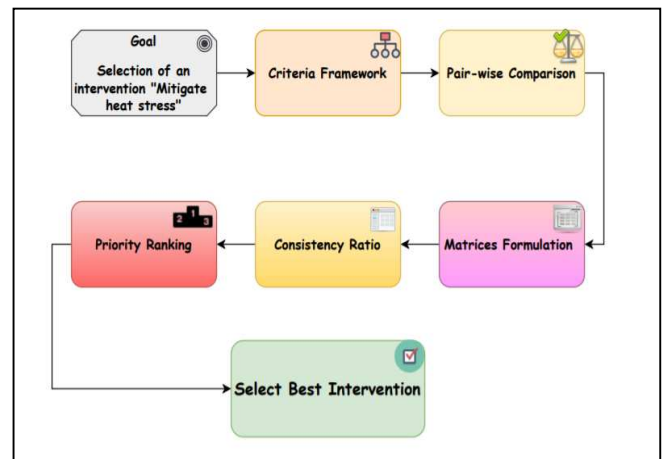


Fig.2 Analytical Hierarchy Process for Selection of an appropriate intervention to mitigate heat stress.

since human isn't always reliable but still, this method helps decision-makers to identify priorities through a pairwise comparison of alternatives.

A. Goal

The goal of this study is to select a preventive measure to reduce the heat stress in urban area. The goal of this study is to select a preventive measure to reduce the heat stress in urban area.

IV. ANALYTICAL RESEARCH PROCESS

Analytical Hierarchy Process (AHP) is one of Multi-Criteria decision-making strategy that was initially created by Prof. Thomas L. Saaty [9]. It is a strategy to get proportion scales from combined examinations. The process is used for several fields of study until now, e.g. The method applied to evaluate the transport policies to reduce climate change impacts[10], An analysis of future water policies in Jordan [11], selection of electric power plants[12], contractor selection [13]. In this study AHP is implemented as a decision-making approach for the choosing intervention to mitigate the heat stress in urban areas under certain criteria. The hierarchy process is shown below in fig.2 and steps are explained in subsections. The information was obtained from specific

B. Criteria framework

This step helps to construct the framework which expresses the aspects of the decision-makers' reflection on the desirable measure. The criteria framework is illustrated in Fig.3.

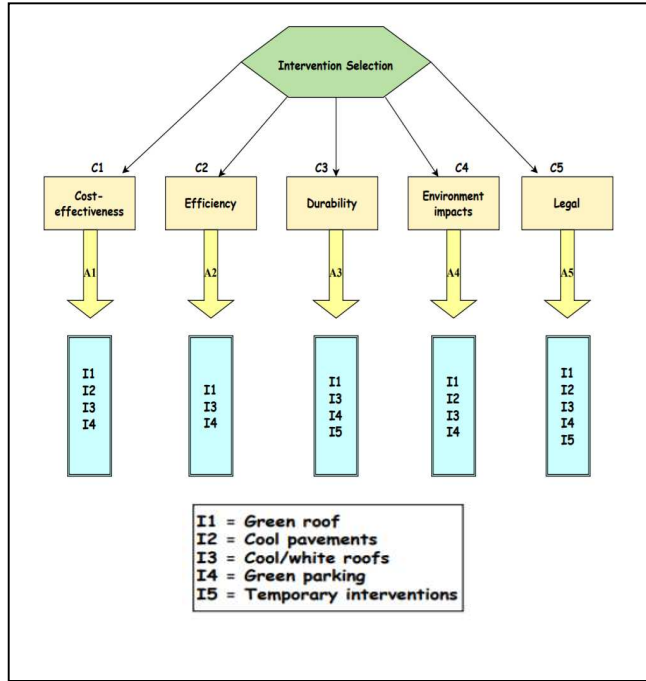


Fig.3 Criteria Framework along with important alternatives.

C. Pair-wise Comparison

This step allows to compare the alternatives with all of them. Formation of pairs depends on the number of alternatives e.g. five criteria are considered for choosing best the intervention which improve the thermal comfort during hot summers. Hence, ten pairs for the criteria are calculated which are: (C1 – C2), (C1 – C3), (C1 – C4), (C1 – C5), (C2 – C3), (C2 – C4), (C2 – C5), (C3 – C4), (C3 – C5), (C4 – C5) with help of the formula shown in Table 1. Example of pairwise comparison between ‘Green Roof’ and Cool Pavements is shown in fig.4. The judgements are made with the help of scales recommended by Thomas Saaty, shown in Table.2

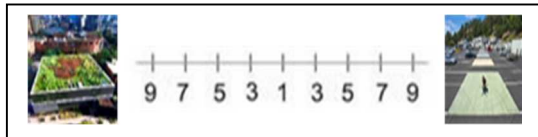


Fig.4 Example of pair-wise comparison between two intervention

Table1 Quantification of pairs

No. of interventions	No. of comparisons
1	0
2	1
3	3
4	6

5	10
6	15
7	21
n	$\frac{n(n-1)}{2}$

Table 2 Linguistic scale by Saaty

Values	Linguistic Scale
1	Equal importance
3	Moderate importance of one element over another
5	Strong importance of one element over another
7	Very strong importance of one element over another
9	Extreme importance of one element over another
2,4,6,8	Intermediate values compromise between two choices

D. Matrices formulation

Outcomes of pair-wise judgment are formulated in matrices; diagonal elements of the matrix are always 1. The two following rules are used to create upper triangular matrix:

- If the judgment value is on the left side of 1, we put the actual judgment value.
- If the judgment value is on the right side of 1, we put the reciprocal value.

In order to set up the priority vector for criteria, AHP suggests an $n \times n$ pairwise comparison of matrix A eq (1).

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} = (a_{ij})_{ij} \quad 1$$

Where a_{ij} is the element of row i column j of the matrix. The reciprocal values of the upper diagonal are used for lower triangular matrix. If the a_{ij} element of row i column j of the matrix, then the lower diagonal is filled using eq (2)

$$a_{ji} = \frac{1}{a_{ij}} \quad 2$$

After building the matrix A, the priority vector of criteria is calculated using the following steps:

- Normalization of pairwise comparison matrix A_{norm} is calculated by using eq (3) where the sum of the entries of each column is equal to 1 i.e $\sum_{i=1}^n \bar{a}_{ij} = 1$

$$A_{\text{norm}} = \begin{pmatrix} \bar{a}_{11} & \cdots & \bar{a}_{1n} \\ \vdots & \ddots & \vdots \\ \bar{a}_{n1} & \cdots & \bar{a}_{nn} \end{pmatrix} = (\bar{a}_{ij})_{ij} \quad 3$$

- The matrix A_{norm} entries $\bar{a}_{ij}$ are calculated using the entries a_{ij} of the matrix A using the eq (4)

$$\bar{a}_{ij} = \frac{a_{ij}}{\sum_{k=1}^n a_{kj}} \quad 4$$

- Priority vector of criteria is an n-dimensional column vector P and it is calculated by eq (5)

$$\Pi = \begin{pmatrix} P_1 \\ \vdots \\ P_n \end{pmatrix} \quad 5$$

Where priority vector is achieved by averaging the entries of each row of the matrix A_{norm} using the eq (5).

$$P_i = \frac{\sum_{k=1}^n a_{ik}}{n} \quad 6$$

E. Consistency Ratio

AHP suggests a consistency ratio (CR) technique based on testing. It is calculated by eq (7) which confirms that results are consistent with the provided judgments. If the consistency ratio value is $\leq 10\%$, the inconsistency is acceptable, but if the consistency ratio is $\geq 10\%$ which means that the subjective preference assessment needs to be revised. The consistency index is called Random Consistency Index (CRI). Professor Saaty [9] provided the random indices shown in Table 3.

$$CR = \frac{CI}{RI} \quad 7$$

Where $CI = \frac{\lambda_{\text{max}} - n}{n - 1}$ and
 $\lambda_{\text{max}} =$
 SOC 1(criteria weight of first row)
 +SOC 2(criteria weight of second row+...

Table 3 Random index

no. of alternatives	Random index
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

V. RESULTS AND DISCUSSION

The participants choose the best-given options for the mitigation of heat stress in summers and their judgements are pair wisely compared and evaluate the importance of criteria over other. Afterward, judgments matrices are formulated to understand the priority vector. The results showed that environment impact is the most important (36.1%) criterion for the selection of an intervention which improves thermal comfort in urban areas, followed by the durability of measure on the desired location (30.8%). Efficiency (heat stress reduction level) is the third dominant criteria while deciding to implement nearby hotspots. Cost-effectiveness and Legal (permission by authority) are also essential criteria; however, it can be mold by investors and favorable arguments. The results of the questionnaire are illustrated in the pie diagram shown in Fig.5

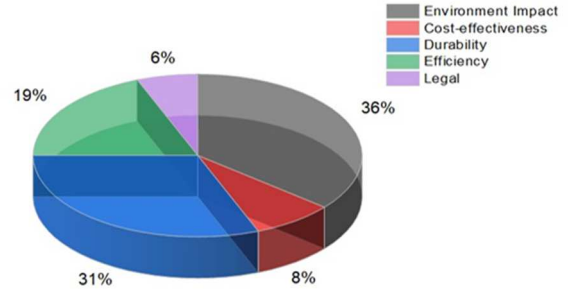


Fig.5 Pie diagram of Criteria Importance

A. Interventions Priority results with respect to Cost-Effectiveness

Cool pavements are 59.2% cost-effective option among all while cool/white roof is 26.5% effective concerning cost. The green roof is 9.9%, and green parking is 4.5% important, presented in Fig.6.

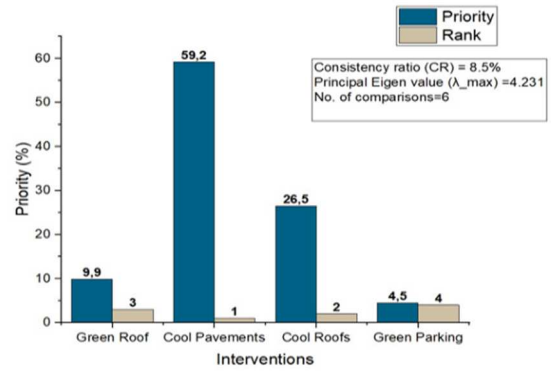


Fig.6 Interventions Correspond to Cost-effectiveness Priority Graph

B. Interventions Priority results with respect to Efficiency

The efficiency of alternatives is prioritized among the three major effective interventions are shown in Fig.7. A green roof is 64.9% efficient to reduce heat stress in the environment followed by green parking with, 27.9%, while cool roof is 7.2% important in terms of efficiency.

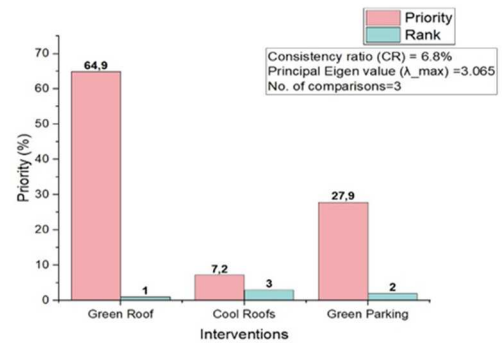


Fig.7 Interventions Correspond to Efficiency Priority Graph

C. Interventions Priority results with respect to Durability

According to the survey green roof is the most durable intervention by 54.9% for outdoor thermal comfort among the other alternatives shown in Fig.8. Green parking is second

ranked by 28.8% while cool roof is 11.5% and temporary interventions (watering method, fountain, other materials, etc...) are 4.8%.

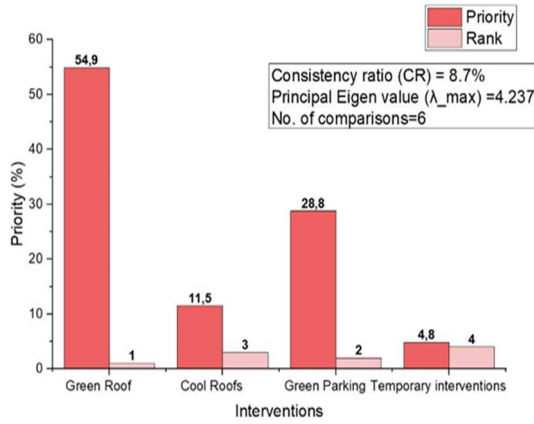


Fig.8 Interventions Correspond to Durability (a) Priority results (b) Priority Graph

D. Interventions Priority results with respect to environmental Impact

Environmental impact is high ranked criterion over all other standards as shown in Fig.5. Results are shown in Fig.9. Green roof is 56.2%, green-parking is 29.3%, 10.1% for cool/white roofs and cool pavement are 4.4% important over each other based on the aforementioned criterion.

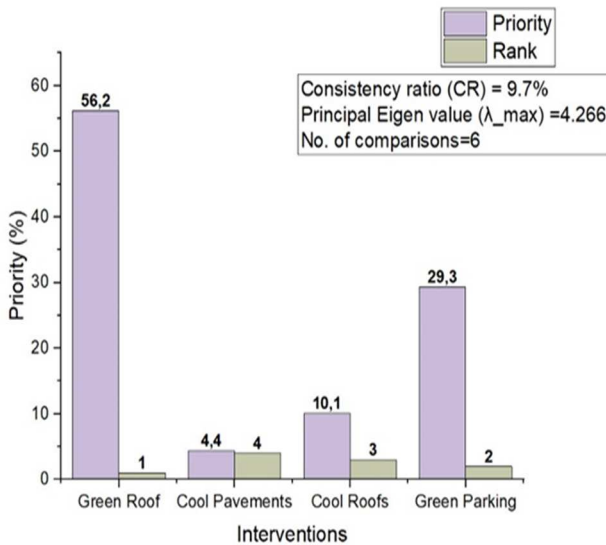


Fig.9 Interventions Correspond to Environment Impact Priority Graph

E. Interventions Priority results with respect to Legal aspects

Before implementing anything, it is necessary to have permission to respect the law. It is a valuable criterion for selection of intervention in the urban area, especially the city center and historical locations. However, it represents only 6% among other approaches that have been chosen. Considering this criterion before taking any action, it is needed to have legal permission for green-parking and green roof since both interventions are 38.7% and 37% important to legal criteria shown in fig.10. On the contrary, cool roofs (13.9%), cool pavements (5.6%) and temporary interventions (4.9%) are less valuable in terms of getting permission to be adapted.

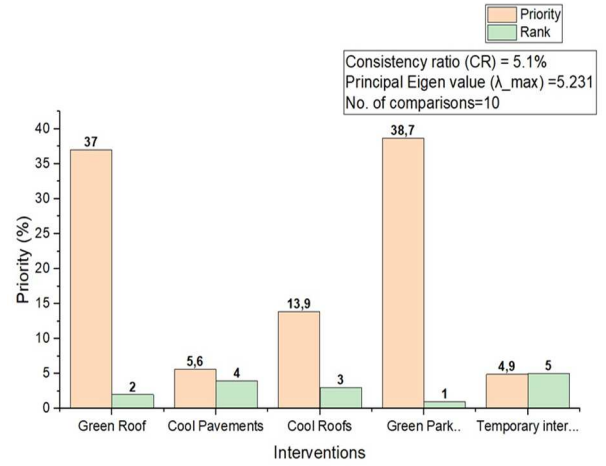


Fig.10 Priority Graph for Interventions Correspond to Legal criterion

F. Final Priority results with respect to all criteria

Interventions are ranked using eq (8). The final rankings are shown in Table.4. According to the survey entries, the green roof is expensive and the installation must meet the legal deadlines, but it gives a good cooling effect, has a significant impact on the environment, and the service life of the intervention is good and does not require additional maintenance but care. While interventions such as water fountains, misting, humidification of streets, use of air condition water for planting are temporary solutions that could be adapted to improve comfort but not solutions that can mitigate heat stress at the city level.

$$\sum_{n=R} = w(C_n I_n) \quad 8$$

Table 4. Final priority ranks

C/I	C1 0.08	C2 0.19	C3 0.31	C4 0.36	C5 0.06	Rank
I1	0.099	0.649	0.549	0.562	0.37	1
I2	0.592	0	0	0.044	0.056	4
I3	0.265	0.072	0.115	0.1	0.139	3
I4	0.045	0.279	0.288	0.293	0.387	2
I5	0	0	0.048	0	0.049	5

VI. CONCLUSION

In this study, an AHP process is applied for the selection of an appropriate intervention to improve thermal comfort in small and medium cities. The pairwise comparison between the criteria and the judgments of the proposed intervention is assessed through a questionnaire based on the perception of the decision makers. The obtained results based on the survey entries showed that green roof is expensive and the installation must follow the legal formalities, but it gives a good cooling effect, has a significant impact on the environment, and the

service life of the intervention is good and does not require extra maintenance comparatively others but care. However, water fountains, misting shouldn't take in to account for implementation since it gives a cooling effect for time being. The ranking results presented in this article are given to illustrate the use of the proposed technique and must not be taken as universal. However, the same procedure could be followed and used in any location. It concludes that application of AHP in urban planning provides a useful decision support tool to local users and stakeholders.

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