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SPECIAL SECTION

Evaluation of the factors determining thermal comfort and occupational health conditions of employees in multi-storey business buildings in the light of expert experiences

Murat CAL[1]* and **Fatih YILMAZ**[2]

[1] American College of the Middle East, Department of Engineering and Technology, Kuwait
[2] Bandirma Onyedi Eylul University, Department of Labor Economics and Industrial Relations, Turkey

Abstract. Previous studies generally focused on the indoor temperature of buildings and air supplies to their environment. The effect of outdoor pollutants on thermal conditions has also attracted some interest in recent years. However, the number of studies on other factors that may potentially affect thermal comfort and health in high-rise buildings is limited. A structured analytical hierarchy process and an improved data envelopment analysis method are used in this study to determine the indoor and outdoor spatial features and climatic effects that influence thermal comfort in multi-storey business buildings. The impact levels of these factors on thermal conditions are determined with heuristic algorithms. Further, two climate zones in two countries are compared in terms of the factors that affect thermal comfort and their individual impact levels. The most critical criterion for Kuwait is external insulation features, whereas for Turkey it is indoor air conditioning. The most critical sub-criterion is temperature for Kuwait, whereas for Turkey it is insufficient heat and light insulation of windows. Data envelopment analysis yields that respiratory health diseases are the most critical effect in Kuwait, and work accidents are the most important effect in Turkey. Temperature and humidity play a significant role in thermal comfort in Kuwait. Insulation and air conditioning are crucial factors in thermal comfort conditions in Turkey.

Keywords: thermal comfort; occupational health; multi-storey buildings; AHP; data envelopment analysis.

1. INTRODUCTION

Multi-storey buildings are structures that offer long-lasting and modern living spaces that aim to maximize the efficiency of users thanks to their architectural features and equipment. These buildings play a key role in providing the shelter needed by the ever-increasing urban population quickly and at optimal costs. However, it is also known that these buildings have several negative environmental, economic, sociological, and health effects. Multi-storey tower buildings are commonly built to be used as business centres. Their temperature is preserved only by central ventilation systems and usually lack natural ventilation. The use of inappropriate interior and exterior coating or isolation materials may become an issue in some applications. These buildings therefore are usually not well designed in terms of thermal comfort and harm the health and productivity of the employees within.

The most reported health problem among workers in air-conditioned buildings with central ventilation systems is the sick building syndrome (SBS). Sick leaves due to the illness cause a significant loss of working days annually. Some studies show that high cold air ventilation, poorly maintained ventilation systems, inadequate thermal design, internal barriers that prevent airflow, lighting styles, high relative humidity, and high bacterial counts detected in air quality measurements increase the incidence of SBS. One study reports that the SBS problems were solved in an examined building over time with certain applications in the offices and the installation of new air handling units [1]. Another study determined that meteorological conditions (outdoor temperature, wind speed, relative humidity) may be as effective in SBS syndromes as indoor and outdoor air pollutants [2]. Significantly higher SBS rates were reported in air-conditioned buildings than in naturally ventilated buildings [3].

A building may either have no ventilation system, or the existing system is inefficient, resulting in relatively higher temperatures indoors. Exposure to extreme heat can cause heat stroke, dehydration, heat exhaustion, heat syncope, heat cramps, heat rash, and even death [4, 5]. Heat can also increase workers' risk of injury, as it can cause sweaty palms, fogging of safety glasses, dizziness, and can create additional hazards by reducing brain functions responsible for judgment. Hot and humid environments negatively affect workers' emotional and psychological states, increase their anxiety levels, and may make them prone to work accidents [6–10]. There is also evidence that working in high-temperature conditions reduces the worker's performance and productivity [11–15].

*e-mail: murat.cal@acm.edu.kw

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Many factors pose the risk of high temperature and humidity in the working environment. When internal spatial negativities (presence of equipment and materials that increase the temperature in the environment, problems with insulation or building design, inadequate or neglected natural ventilation or air conditioning systems, etc.) are added to the climatic conditions of the building location (number of annual sunny and windy days, average temperature values and so on), they might pose occupational health and safety risks for employees [10].

Previous studies focus on optimizing thermal comfort conditions, generally based on the indoor temperature and the amount of air supplied to the environment, which are factors affecting thermal comfort conditions in air-conditioned buildings. The effect of outdoor pollutants affecting thermal conditions is also a subject that has attracted more attention in recent years. Thermal comfort is affected by many factors such as the general and internal structure of the building, the coating and insulation materials used, climatic conditions (humidity, number of sunny days, temperature, wind, and so on), natural ventilation opportunities in the building, floor and covering materials, equipment used in the building and defects in electrical installations. In one study, it was determined that increasing the thermal performance of building walls generally requires the correct selection of thermal insulation materials [16]. In two other related studies, suggestions for the design of residential buildings in terms of heat and energy efficiency were offered and an algorithm was developed for monitoring indoor thermal comfort conditions [17, 18]. Also, the investigation included the variables related to the health and comfort of building occupants indispensable in modelling ventilation systems and mentioned that such studies for energy saving and building control are necessary and important [19]. Hu *et al.* [20] determined that there would be an increase in thermal comfort and a decrease in energy consumption with the correct design, insulation, and natural ventilation precautions in residential buildings in hot climates.

Analytical hierarchy process (AHP), one of the multi-criteria decision-making methods (MCDMM), is used extensively in occupational health and safety (OHS) services and OHS-related issues to rank and compare KPI-based (key performance indicator) measurement dimensions [21–25]. Shin *et al.* [26] also examined the relationship between the company's understanding of OSH services and innovation activity using data envelopment analysis (DEA) [26]. Zhang *et al.* [27] analyzed the dynamic game relationship between SMEs, governmental authorities, and external safety service agents with similar methods.

Few of the existing studies are related to the health effects of thermal comfort and these are focused on residential buildings, schools, and public buildings. Studies examining the indoor and outdoor spatial factors and their health effects in multi-storey commercial buildings are limited in the literature.

This study was carried out to achieve three different goals with two different methods. First, it determines all the indoor and outdoor spatial features and climatic effects that affect thermal comfort in multi-storey business buildings and determines the effect level of these factors on thermal conditions with intuitive algorithms.

The second objective is to examine the factors affecting thermal comfort conditions in two climate zones by comparing the factors affecting thermal comfort and their impact levels in two different countries located in two different climate zones. For this purpose, the data obtained from the surveys conducted on experts in the Marmara Region, located in the temperate climate zone of Turkey, and Kuwait, situated in the hot climate zone, will be analyzed using a structured AHP and presented comparatively.

Finally, the study explores the impact levels of thermal conditions on employees' health in multi-storey buildings, with the approaches of experienced occupational safety experts and workplace physicians. An improved DEA analysis method is used for this purpose.

2. MATERIALS AND METHODS

2.1. Survey design

A survey consisting of six main sections was created to examine the effects of thermal comfort conditions in multi-storey buildings and to list the factors that provide thermal comfort. In the first four sections, the factors affecting thermal comfort are examined and the sub-factors within each main factor are compared with each other. While determining these factors, a huge factor pool was first created from the universal factors obtained from the literature review. Afterwards, the survey ends with creating elimination criteria and filtering for Kuwait and Turkey, for building and office environments, and finally for air conditioning.

Following the first four sections, the fifth one presents seven different health problems related to thermal comfort conditions and their degrees of importance relative to each other. These health problems are also included in the study due to respiratory diseases and psychological and physical damage resulting from thermal conditions.

In the last section, participants are asked to measure which of the factors given in the first four sections had the most impact on these health problems by awarding points. The survey is presented in Table 1.

2.2. Data collection

To complete the surveys, two separate efforts were made to obtain the opinions of experts in Turkey and Kuwait in the Excel environment. The survey was prepared in both Turkish and English, and survey participants were asked to answer in the language they were most comfortable with. To avoid any misunderstandings in the surveys conducted in the State of Kuwait, Arabic equivalents of some terms were also provided to the participants when necessary.

Experts selected from both countries must have experience in multi-storey building design or air conditioning studies, preferably have worked in the fields of mechanical engineering or civil engineering, and also have knowledge and experience in the fields of occupational safety and occupational health. Since it is impossible to fulfill all these conditions at the same time, experience in the field of multi-storey building design and air

Table 1
Survey design

Main factor	Sub-factors
1. EXTERNAL INSULATION FEATURES OF THE BUILDING	a) Unsuitable plaster materials used on the exterior of the building
	b) Unsuitable outer covering insulation materials
	c) Insufficient or excessive amount of glass coating used on the exterior
	d) Insufficient heat, light, and insulation in the windows
	e) Errors in the brick or other reinforced concrete applications used (such as wall thickness)
2. INTERNAL INSULATION FEATURES OF THE BUILDING	a) Insufficient natural ventilation (e.g. number and size of openable windows)
	b) Unsuitable interior covering materials used on the floor and walls
	c) The amount and unsuitability of furniture and decoration materials used in workplaces
	d) Insufficient airflow or presence of elements obstructing airflow
	e) Design errors
3. CLIMATIC ENVIRONMENT OUTSIDE THE BUILDING	a) Temperature
	b) Humidity
	c) Annual number of sunny days
	d) Number of windy days
4. FACTORS AFFECTING INDOOR AIR CONDITIONING	a) Number of heat-emitting equipment that increases the temperature in buildings
	b) Number of people working in and visiting the buildings
	c) Inadequacy and lack of maintenance of compulsory ventilation systems
	d) Defects in electrical installations inside the building
	e) High humidity inside the building
	f) Errors in the use of ventilation systems
	g) High light intensity inside the building
	h) Inappropriate personal equipment and clothing of employees
	i) Insufficient engineering services
5. EFFECTS OF INAPPROPRIATE THERMAL COMFORT CONDITIONS ON EMPLOYEE HEALTH	a) Stress
	b) Respiratory system problems
	c) Fatigue and boredom
	d) Skin disorders
	e) Low efficiency
	f) Anxiety and similar psychological problems
	g) Increase in work accidents
6. CAUSE-EFFECT SCORING	FACTORS EFFECT Main Factor 1 Effect 1, Effect 2, . . . , Effect N Main Factor 2 SCORE TABLE . . . . Main Factor 4

conditioning was prioritised, and then a survey was conducted among people who had experience in building construction and insulation, as well as air and heat transfer in buildings. If this condition was not met, a survey was carried out among people with academic backgrounds who have worked in civil and/or mechanical engineering, preferably in thermal insulation. 26 surveys were conducted, and four of them were deleted because they were not suitable for evaluation in the study. 40% of the experts are experienced in multi-storey design and air conditioning, 60% are experienced in civil engineering and 40% are experienced in mechanical engineering. 90% of the participants surveyed are knowledgeable about heat transfer and thermal comfort conditions. The remaining 10% worked as managers or project engineers during the construction process. The procedure is as follows: An expert first compares all factors in the first section, for example, plaster materials with outer covering, then plaster materials with the amount of glass coating, then plaster materials with insufficient heat, and so on until he or she compares all factor combinations within that section. Then the expert proceeds with the next one until all factors are compared with each other. The expert also compares the health problems of employees in the fifth section and finally in the last section, the effects of all technical factors in the first four sections on employee health are evaluated by the expert. Based on a scale of 1–9, a score is assigned by the expert for every factor comparison. The greater the score is, the more important is that factor for the expert.

2.3. Data analysis: An AHP-DEA approach

AHP is a widely used method for selecting and ranking multiple alternatives. In the survey applied in the study, a hybrid method based on AHP and DEA is used for the comparison and ranking of the main criteria given in the first four sections, the ranking of the sub-criteria, the ranking of the health problems given in the fifth section, and the analysis of the scoring in the sixth section.

The surveys were analyzed using the AHP technique on different platforms for the two countries, and all subcriteria for the first four sections were compared with each other. Following this, the ranking of health problems was carried out with a separate AHP application. The scoring system given in the last section, which was applied to examine the effects of the main criteria on health problems, was analyzed by data envelopment analysis to examine whether the comparison made by the participants for their health problems coincided with the scores they gave independently. The DEA analysis completed the AHP in terms of efficiency analysis and provided insights into the ranking of the factors that caused all health problems in the fifth main factor.

3. RESULTS

The rankings for the top five sub-criteria for Turkey and Kuwait are given in Table 2. According to these results, "insufficient heat and light insulation of the windows," "outer covering insulation materials", and "insufficient airflow or presence of elements obstructing airflow" are ranked in the top five in both Turkey and Kuwait. The other two criteria in the top five for Turkey are "insufficient natural ventilation" and "defects in bricks or other reinforced concrete applications." For Kuwait, the remaining two criteria were temperature and humidity.

The rankings for the bottom five sub-criteria for Turkey and Kuwait are given in Table 3.

Table 2
First five sub-criteria rankings

Turkey's first 5 criteria	Score
1d) Insufficient heat and light insulation of the windows	0.080
1b) Outer covering insulation materials are not suitable	0.079
2d) Insufficient airflow or presence of elements obstructing airflow	0.071
2a) Insufficient natural ventilation	0.061
1e) Errors in the brick or other reinforced concrete applications used	0.055
Kuwait's first 5 criteria	**Score**
3a) Temperature	0.393
1b) Outer covering insulation materials are not suitable	0.338
3b) Humidity	0.325
2d) Insufficient airflow or presence of elements obstructing airflow	0.294
1d) Insufficient heat and light insulation of the windows	0.270

Table 3
Last five sub-criteria rankings

Turkey's last 5 criteria	Score
4g) High light intensity inside the building	0.024
3c) Annual number of sunny days	0.023
3d) Number of windy days	0.022
2c) The amount and unsuitability of furniture and decoration materials	0.013
4b) Number of people working in and visiting the buildings	0.013
Kuwait's last 5 criteria	**Score**
4d) Defects in electrical installations inside the building	0.080
2c) The amount and unsuitability of furniture and decoration materials	0.076
1a) Plaster materials used on the exterior of the building are not suitable	0.075
4g) High light intensity inside the building	0.074
4b) Number of people working in and visiting the buildings	0.052

According to these results, "high light intensity inside the building", "the amount and unsuitability of furniture and decoration materials", and "the number of people working in and visiting the buildings" are ranked in the bottom five criteria in both Kuwait and Turkey. For Turkey, the remaining bottom two criteria are "number of sunny days" and "number of windy". In Kuwait, these are replaced by "plaster materials outside the building" and "defects in electrical installations".

The rankings of the main criteria are provided in Table 4. It should be noted that these rankings are derivations from the ranking of the sub-criteria, which reveals that the most important criterion is "external insulation features" (0.361) in Kuwait, while the most important criterion in Turkey is "factors affecting indoor air quality" (0.324).

Table 4
Main criteria rankings

Kuwait: Criteria rankings	Score	Turkey: Criteria rankings	Score
1. External insulation features of the building	0.361	4. Factors affecting indoor air conditioning	0.324
4. Factors affecting indoor air conditioning	0.240	1. External insulation features of the building	0.292
3. Climatic environment outside the building	0.203	2. Internal insulation features of the building	0.252
2. Internal insulation features of the building	0.196	3. Climatic environment outside the building	0.132

The ranking of health problem-related sub-criteria for Turkey and Kuwait is given in Table 5. Accordingly, the most important health problem is "respiratory system problems" in Kuwait followed by "low efficiency" and "fatigue". Whereas Turkey ranks the "increase in work accidents" the first, followed by "fatigue" and "low efficiency". As can be seen, the two countries share the "low efficiency" and "fatigue" concerns.

Finally, it is compared to what extent the scores given by the countries on the main criteria in the fifth main factor (effects of

Table 5
Criterion 5 rankings

Kuwait: Criterion 5 rankings	Score	Turkey: Criterion 5 rankings	Score
5b) Respiratory system problems	0.182	5g) Increase in work accidents	0.240
5e) Low efficiency	0.172	5c) Fatigue and boredom	0.160
5c) Fatigue and boredom	0.169	5e) Low efficiency	0.154
5g) Increase in work accidents	0.160	5f) Anxiety and similar	0.133
5f) Anxiety and similar	0.158	5b) Respiratory system problems	0.126
5a) Stress	0.086	5a) Stress	0.117
5d) Skin disorders	0.072	5d) Skin disorders	0.070

inappropriate thermal comfort conditions on employee health) fit into the main criteria ranking, and with the help of DEA, the rate of this compliance is calculated and presented for both countries.

For the DEA, the inputs are the scores given by each participant, and outputs are the rankings of the main factors. The participants provide the scores as designed in the sixth section of Table 1. Accordingly, for each main criterion and health problem, the participants gave a 0-100 scale score to determine how much the main criterion is associated with the corresponding health problem. For instance, if the cell in the intersection of main factor 1 and stress is 80, external insulation features of the building are 80% associated with stress. After collecting and pooling the data, for each main factor, a linear programme with seven input variables corresponding to the sub-factors in the fifth main criterion and one output variable corresponding to the main criteria ranking was created and solved using Excel Solver. The non-Archimedean epsilon assumes a value of 0.0001. In the end, the efficiency results were obtained in Table 6.

Table 6
DEA results comparison

Main factor	Efficiency for Kuwait	Efficiency for Turkey
1. External insulation features of the building	1	1
2. Internal insulation features of the building	0.549	0.739
3. Climatic environment outside the building	0.507	0.782
4. Factors affecting indoor air conditioning	0.433	0.903

Based on the DEA results, participants show consistency with the first main factor because the first main factor has an efficiency rate of 100% both for Turkey and Kuwait. In other words, the scores they gave in the sixth section of the survey and their ranking of the main criteria are consistent.

For the remaining factors, the rates are lower for Kuwait than for Turkey. The second main factor has an efficiency of 0.549 for Kuwait and 0.739 for Turkey. The participants gave high scores for the second main factor in the sixth section of the survey, stating that it is significantly associated with the problems in the fifth main factor. However, when it comes to ranking the main factors, the second main factor is ranked the last in Kuwait (Table 6). The same for Turkey, where the second main factor is ranked third, thus, leading to a rate of 73.9%. The same situation applies to the third main factor, where the efficiency rates are 50.7% and 78.2% for Kuwait and Turkey, respectively.

Looking at the fourth main factor, it has an efficiency of 43.3% while it is 90.3% for Turkey. The fourth main factor is ranked first in Turkey and second in Kuwait, so the difference is due to the scores provided by the participants. The participants in Kuwait gave higher scores for the fourth main factor but ranked it the second, while the participants in Turkey gave lower scores for it compared to the scores for the first main factor, but they ranked it the first.

4. CONCLUSIONS

In this study, the factors affecting thermal conditions in multi-storey business buildings and the effects of poor thermal conditions on worker health were evaluated from the perspective of experts. According to the results, the first three sub-criteria affecting thermal comfort in Turkey are determined as “insufficient heat and light insulation of the windows”, “outer covering insulation materials are not suitable” and “insufficient airflow or presence of elements obstructing airflow”. For Kuwait, these are “temperature”, “outer covering insulation materials are not suitable” and “humidity”, respectively.

In the main criteria ranking, while the main criterion considered to be the most important by experts in Kuwait is “external insulation features of the building”, in Turkey it is determined as “factors affecting indoor air conditioning”.

These results are significant. Kuwait is extremely hot, especially in June, July, August, and September. August and September are the most humid months and temperatures in these months reach up to 60 degrees. It should be noted here that the main sub-criteria affecting thermal comfort conditions are “temperature” and “outer insulation materials”, in addition to “humidity”. However, since the other sub-criteria in the third main factor have little relevance in Kuwait, this main factor is ranked third in the ranking despite containing the “temperature” criterion. Instead of these climatic factors, outer insulation factors are favoured by the participants and ranked first in Kuwait, because keeping the cool air inside is significantly more important than the temperature outside. Kuwait construction companies plan separately for outer insulation because it is important to stop the heat in the first place and to prevent it from entering households and office environments. After this comes “air conditioning”, as seen in Table 4, and only after that the climatic factors are mentioned.

It appears that for Turkey, factors related to indoor ventilation are more important. In many buildings with natural ventilation facilities in Turkey, appropriate temperatures can be provided in the spring and autumn periods without the need for internal ventilation and air conditioning elements. At the very least, it may not be necessary to over-operate forced ventilation systems to achieve appropriate thermal comfort values. However, in Kuwait, especially in particularly hot months, it is impossible to achieve appropriate thermal comfort values ??without the aid of central systems. In this case, appropriate and sufficient external insulation elements are of vital importance to preserve the temperature inside the building under the existing climate conditions. Otherwise, excessive heat and humidity may occur inside the building, which may be harmful to the health of employees, and to the environment as well, due to excessive energy consumption and emissions.

The experiences of experts in Kuwait and Turkey seem to differ by a small margin regarding the possible effects of inappropriate thermal conditions on employee health. The most important occupational health problem in Kuwait is "respiratory system problems", whereas in Turkey it is an "increase in work-related accidents". Other important problems are "low efficiency" and "fatigue and boredom" in both countries. The reason for this slight difference may be the effects of geographical and climatic conditions. In addition to having an extremely hot and humid climate, Kuwait is a country where the risk of exposure to dust is higher than in Turkey. Dust is one of the most important causes of lung diseases. In addition, the harmful effects of inhaled dust increase when combined with humidity in the air. In Turkey, in the regions where the research was conducted, both the operating times and temperature settings for central air conditioning systems are relatively low. As such, the frequency of lung problems in those working in buildings in Turkey may be lower than for those in Kuwait.

The ascertained effect of a low thermal comfort environment on "decreased productivity" and "fatigue-boredom" in employees of the two countries coincide with the findings of previous studies.

According to the DEA results, which examine the relative effects of the main elements affecting thermal comfort in buildings, experts in both countries agree that the factor with the highest influence on the thermal comfort conditions for multistorey building employees is "the external insulation elements of the building". For Turkey, "factors affecting indoor air conditioning" also have an important level of effectiveness. In contrast, the second most effective factor in Kuwait is the "building internal insulation" properties. In Turkey, the efficiency scores of all factors except "external insulation" are higher than in Kuwait. Internal and external insulation applications seem to be much more important in terms of balancing thermal comfort in multistorey buildings compared to other criteria, in both countries.

Inappropriate thermal conditions also have negative effects on employee health. For this reason, when providing thermal comfort conditions in high-rise business buildings, proper architectural design and engineering practices related to climatic conditions should be adhered to, appropriate materials should be used in the interior and exterior insulation of the building, and the experiences of employees and occupational health and safety experts should be heeded. Thermal comfort is a multifaceted issue that includes many branches of science such as health, management, psychology, and statistics, as well as various engineering fields. When the occupational health aspect of the issue is evaluated together with climatic design principles, multidisciplinary practices become important in creating optimized thermal conditions for employees.

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