

Research Paper

Evaluation of environmental comfort parameters of workspace in industrial buildings (Case Study: typical control building of combined cycle power plants)

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Abstract

Due to the superiority of functional requirements of equipment and systems over human requirements in the field of architectural and environmental design of industrial buildings, users have to adapt themselves to the conditions which might be followed by imposed biological and psychological pressures. The present study examines the components and environmental parameters influenced by building features (thermal comfort, lighting quality, office layout, interior decoration, acoustic quality, air quality, cleanliness and maintenance) in typical control building of combined cycle power plants. Using a questionnaire based on Vischer's model of environmental comfort regarding people's environmental perception, the level of users' satisfaction with the environmental factors and their self-estimated performance in relation to these factors at the two levels of physical and functional comforts has been determined. The statistical analysis of the results shows that the lack of consideration of the environmental comfort parameters of workspace in the process of architectural design of industrial buildings influences users' satisfaction with these factors which is directly related to their self-estimated performance in workplace and consequently their job satisfaction by decreasing them. Taking into account the fact that the amount of impact of various environmental factors on the individuals' function was evaluated differently, prioritizing the physical factors in the work place for corrective purposes was finally done using affectability of performance in the degree of satisfaction with any factor.

Keywords: Industrial Building, Control Building, Environmental Comfort, Self-Estimated Performance, Satisfaction.

1. INTRODUCTION

The conditions of indoor environmental parameters have far-reaching implications for people health, general well-being and performance. In the process of environmental design of any construction project, several parameters are taken into consideration. One of the influential parameters in design is the physical and spiritual characteristics which the amount of contribution of that in the physical or architectural environment of buildings varies with their

type of buildings.

Human's living environments can be divided into two categories depending on the activity being carried out there. Kiyoo Izumi¹ believes that some buildings are mostly designed for the proper functioning of machines and equipment rather than for people working with them. In other buildings, human needs are given more importance.

He calls the first type "anthropozemic or non-humanitarian buildings"² and the second type "anthropophilic or humanitarian"³ [1]. Thus, the art of creating human living spaces is granted a deeper meaning in the field of anthropomorphic buildings. The environment must be planned to provide the desired behaviors, otherwise, people would adapt their behavior to the environment. This adaptation might be followed by imposed biological and psychological pressures. According to dissonance theory⁴, these pressures occur when people are in any unwanted situations negative [2].

Accordingly, the created environment and architecture

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This article is derived from PhD thesis of Mrs. Fatemeh Hashemi with title of *Developing and Utilizing Advanced Criteria for Architectural Design of Combined Cycle Power Plant's Control Building to Provide Environmental Comfort at Workplace*, with supervisors prof Seyed Rahman Eghbali and prof Mohsen Hamedi in Imam Khomeini International University

play an adapting rather than imposing role. Due to the fact that many parameters are involved in the design of industrial projects and the main part of its requirements is non-humanitarian, only the fulfillment of basic human needs in Maslow's pyramid (safety, health and security) have been important. This issue reveals the need for identifying employees' demands in this kind of buildings in relation to workspace and their interaction with the physical and architectural factors for the purpose of further reduction of tensions and energy wastage more than ever. Since control room plays an important role in operating normally and facing accidents and their consequences in every power plant, it acts as the brain. Providing environmental comfort to control room staff significantly prevents man-made disasters from happening in power plants.

In this regard, the purpose of present study is the evaluation of environmental comfort parameters of workspace in typical control building of combined cycle power plants. It also pursues the following goals:

A: the evaluation of environmental comfort parameters of workspace based on the level of employees' satisfaction with environmental factors,

B: the evaluation of the impact of different factors on the self-estimated performance of the personnel based on their prioritization,

C: the prioritization of the parameters for taking corrective measures based on the level of employees' satisfaction with the above-mentioned factors and its impact on their performance.

2. LITERATURE REVIEW

At time being, with the more complex structure and operation of organizations, organizing workspace and creating a peaceful and efficient environment so that it leads to the further activation of human resources, enhancement of the quality of work life, the development of services and finally the achievement of the desired result is one of the concerns of executives and supervisors of organizations.

This reveals the necessity of performing applied researches on improving the quality of work life⁵ [3].

Some researchers consider the quality of work life includes the kind of planning, strategies and environment which all affect the employees' satisfaction [4]. In environmental psychology which is a new branch of psychology, a framework of viewpoints, studies and hypotheses is also created that can help us better understand the interactions of humans and the environment. With this knowledge, some assessments, before designing and constructing, can be conducted which is considered the best tool for professional designers [5].

Many studies have been carried out on the environmental perception of indoor environment of buildings and on the features providing comfort from the viewpoint of the occupants [6]. Despite the fact that the building users are exposed to different environmental factors and their environmental perception is a combination of their evaluation of different components, the studies conducted in this field focused more on one of the environmental factors [7] which include the studies in the field of visual environment [8], acoustic quality [9], thermal comfort [10], and air quality [11]. The results of the study on office buildings have shown that the users' satisfaction does not depend only on the above-mentioned components. Rather, it is influenced by workspace features, building characteristics such as view, control over environmental conditions, visual, and auditory privacy, furniture, and interior design [12]. Based on the users' experiences in the workplace, Vischer's⁶ pyramid model has been designed for providing environmental comfort [13]. According to figure 1, this model is composed of three stages: providing physical comfort, functional comfort and psychological comfort. In studies on physical comfort, the fulfilment of basic human needs such as safety and health in workplace are taken into consideration. The lack of fulfilment of these factors in an environment makes it an uninhabitable space [14].

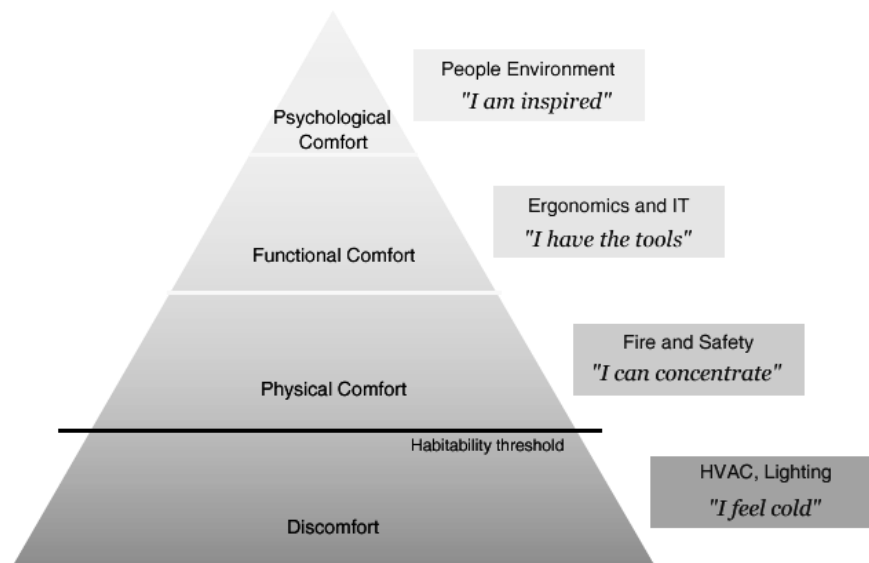


Fig. 1 The 'Habitability' pyramid Source: [15]

The studies on functional comfort deal with the supportive effect of the aforementioned environmental factors on the physical comfort so that the employees carry out their responsibility correctly. The concept of users' satisfaction with workspace is the first step in the evaluation of the environment which is achieved during the process of the individual's perception and judgment of environment [16]. Environmental assessment studies such as studies after the occupation of space seek to determine the exact characteristics that lead to satisfaction or dissatisfaction of users. Most of these evaluations are based on the questionnaire regarding the individuals' perception and judgment about the workspaces depending on their understanding of spatial quality [17]. Assessment by this concept consists of two essential elements [18]:

- ✓ The functional characteristics of the space which is self-estimated and include the factors affecting people's efficiency.
- ✓ The spatial quality of the environment that leads to satisfaction or dissatisfaction of users.

When the physical comfort of users refers to basic and fundamental needs, the concept of functional concept is defined as the environmental support of users' function regarding job duties and business activities. The difference between supportive and non-supportive environments lies in the amount of attention and energy that the employees spend on adaptation to unfavorable environmental conditions rather than on carrying out their duty [19]. The Information obtained from functional comfort analysis sets the standard for designers, planners and managers. Psychological comfort includes a sense of belonging, ownership and control over one's environment which links psychological characteristics of users with environmental design and personnel management in the workspace. One's sense of belonging to the environment is Proportional to his/her loyalty and commitment to the organization and its environment [20].

The International studies in the field of the impact of

various factors on environmental comfort of employees reveal the need for giving importance to national industrial projects for the improvement of the quality of work life more than ever.

3. RESEARCH METHODOLOGY

The present study evaluates the environmental components and parameters of workspace based on Vischer's model (the model that is used by Center for the Built Environment, University of California, Berkeley). This process is carried out based on determining the level of users' satisfaction with environmental factors and assessment of their self-estimated performance in this regard [12]. To collect information about environmental factors, in addition to visiting the building, the standard form of environmental factors questionnaire prepared by Center for the Built Environment, University of California, Berkeley (CBE) has been used. This extensively tested and refined method is a web-based survey which offers opportunities to broadly include occupants around the world in a building performance feedback loop [21]. At this center, the questionnaires have been prepared for office, residential, healthcare, laboratory and school buildings. Asking the personnel questions in the questionnaire with official buildings has been carried out according to the following structure (Table 1):

A: The evaluation of the level of individuals' satisfaction with each of the factors (lighting quality, acoustic quality, air quality, etc.) in the current workspace. The responses are divided into 3 groups at 7 scales: satisfied (1 to 3), neutral (0) and dissatisfied (1 to 3).

B) The level of impact of each of these factors (lighting quality, acoustic quality, air quality, etc.) on one's self-estimated performance in the current workspace. The responses are determined at 4 scales of 0, 1, 2, and 3. The selected numbers indicate the importance of the impact of above-mentioned factors from the viewpoint of respondent on his/her function in the current workspace.

Table 1 List of parameters assessed by the CBE occupant satisfaction survey.

	Questionnaire item (satisfaction)	Questionnaire item (self-estimated performance)
	Amount of space available for individual work and storage	
Office layout	Level of visual privacy	Office Design
	Ease of interaction with co-workers	
	Comfort of office furnishings (chair, desk, computer, equipment, etc.)	Furniture and appearance features (color and texture), Making periodic changes in the appearance of workspace
Office furnishing	Ability to adjust furniture to meet your needs	
	Colors and textures of flooring, furniture and surface finishes	
Thermal comfort	Temperature in your workspace	Thermal comfort
	Air quality in your workspace	
Air quality	(i.e. stuffy/stale air, air cleanliness, odors)	Air quality
	Amount of light in your workspace	
Lighting	Visual comfort of the lighting (e.g., glare, reflections, contrast)	Lighting quality
Acoustic quality	Noise level in your workspace	Acoustic quality

	Sound privacy in your workspace (ability to have conversations without neighbors overhearing and vice versa)	
	General cleanliness of the overall building	
Cleanliness and maintenance	Cleaning service provided to your workspace	Maintenance and cleaning processes
	General maintenance of the building	
General comments	Your personal workspace	
	Building overall	

Finally, the analysis of the results achieved by the personnel's responses to the questionnaire has been performed by analytical software Excel 2014 and the output is drawn as diagrams for evaluation.

4. RESEARCH SCOPE

Due to Combined cycle power plants account for more than 40 percent of domestic fossil fuel power plants and 25 percent of current fossil fuel power plants are gas power plants that Ministry of Energy has set an agenda for converting them into combined cycle power plant as a national strategy, the focus of interest in the present study is to evaluate two primary stages of physical and functional comforts in the typical control building of combined cycle power plants.

In general, the spaces that are specified in a combined cycle power plant fall into three categories:

- **Anthropozemic or non-humanitarian spaces**

The spaces that used for locating the equipment and systems of plants. The role of human in these spaces are occasional and for carrying out maintenance processes, like turbine buildings.

- **Anthropophilic or humanitarian**

Office spaces in the plant that are designed for humans. In designing these spaces, the usual standards and criteria of office buildings are observed.

- **Man-Machine Interface**

Human work permanently in these spaces. In addition to being designed for meeting the requirements of equipment location and systems, they should be designed for providing different levels of human comfort.

Control Building in Combined Cycle Power Plant

which is the case study in the present research has all kind of spaces. Due to the fact that control processes are very sensitive and human errors during the process bring about many consequences, in case of users' dissatisfaction with the environmental conditions, the people in charge undergo a lot of stress for carrying out the tasks correctly.

Driven by demands for safer, more reliable and efficient operations in the design of user-system interfaces and their associated operational environments, ISO⁷ 11064 specifies ergonomic principles, recommendations and requirements to be applied in the design of control centers, as well as in the expansion, refurbishment and technological upgrades of control centers. Based on internal power plants professionals' assertion, this standard does not play significant role in designing Iranian control buildings, thus there is no exception for combined cycle power plant's control buildings⁸.

4.1. The Typical Combined Cycle Power Plant's Control Buildings

The typical Control Building is a two-story building with dimensions of about 30 * 25 meters, the facades are brick-made and do not invoke any identity or specific utility to the audience (Figure 2). Electrical room, battery room and cable gallery are located on the ground floor. These rooms fall into the category of anthropozemic or non-humanitarian spaces in which humans are needed for carrying out maintenance processes that is why they are not examined in the present study. The main control room, engineering room, administrative offices on the first floor of the building have been studied as man-machine interface and Anthropophilic spaces (Figure 3).



Fig. 2 The picture on the right- the typical control building near the of power plant turbine building, source: URL1
The picture on the left- the façade of the typical control building, source: authors

As it is obvious in the Figure 3, the control room is a rectangular space with dimensions of 25*10 m, 3.5 m height which has only two windows in order to meet safety

requirements (the orientation of windows is depend on the orientation of control building- in this case windows are in the northern and southern sides of room).

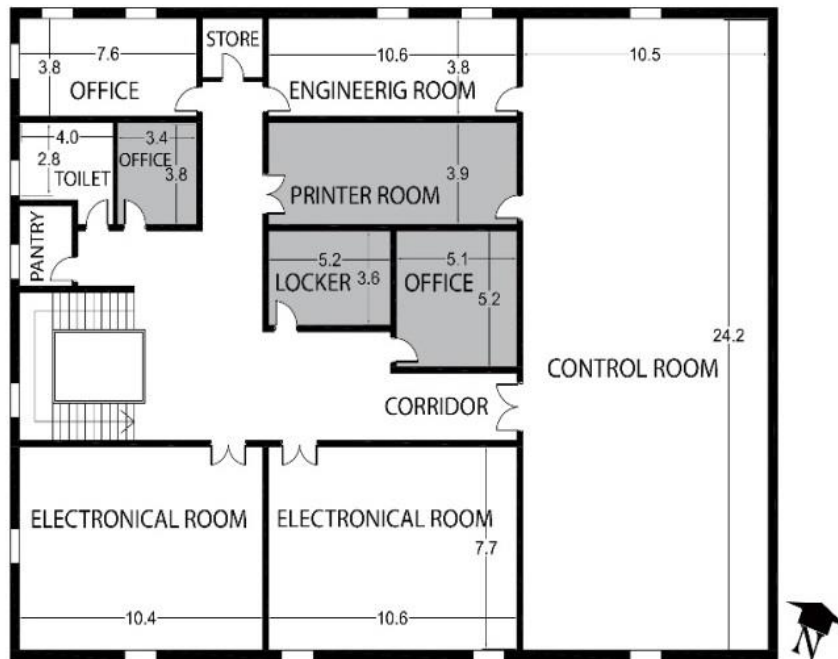


Fig. 3 the plan of the first floor of typical control building, remapping of constructor documents

After using control room for years, because of psychological problems resulting from the lack of windows, last year, proof windows were embedded in the eastern wall to improve the situation. In figure 3, the gray interface spaces lack outdoor windows. This space includes office room, print room and a room furnished with shelves. With a little change in the layout of spaces on this floor, a window could be embedded in the personnel's workspace. In addition to causing positive psychological effects on personnel, considering this issue contributed to reduction in energy consumption of building for lighting and ventilating demands.

5. DISCUSSION

The personnel of the control building who work in three shifts as shift workers participated in the questionnaire (18 people). All the male personnel are 30 to 50 years old. 17 number of personnel have been working in this building for more than 5 years and have been working more than one year in their current workplace. Only one of them has joined this team for less than a year. 15 people described their workspace as an open space without partitions, divided using work tables, one described as a stall with high partitions and 2 people defined it as enclosed and private office. Working hours for 15 people was more than 30 hours a week which indicate the need for paying attention to environmental factors for providing job satisfaction and finally enhancing people's life quality in this building. The number of

satisfied, dissatisfied and neutral people in different factors has been compared in diagram 1.

As it is displayed in the diagram 1 the highest frequency of dissatisfaction is related to some factors including colors and textures of flooring, furniture and surface finishes, visual comfort of the lighting (e.g., glare, reflections, contrast) and sound privacy in workspace (ability to have conversations without neighbors overhearing and vice versa) with 94% frequency of dissatisfaction.

The lack of attention to measurement of appropriate size of the window in terms of providing natural lighting without causing visual problems (e.g., glare, contrast and reflection of light) and Not doing relevant thermal calculations have caused many comfort problems for the users of this space. Figs. 4 and 5 refer to the problems caused by lack of attention to the necessary requirements in designing and locating the windows. In addition to reducing the efficiency of individuals, long time working in the displayed spaces will bring about visual disturbances. In this case, employees have complained of diseases such as headache and dizziness which are caused by visual problems.

Besides causing visual problems resulting from the large number of windows without curtains and sunshade and unadjusted building heating systems, users are experiencing bad thermal conditions. Despite the fact that the place was visited at the end of February and in the cold season, a number of windows were open to adjust thermal condition and interior ventilation. This brings about heat lost and consequently the increase in the energy consumption of buildings.

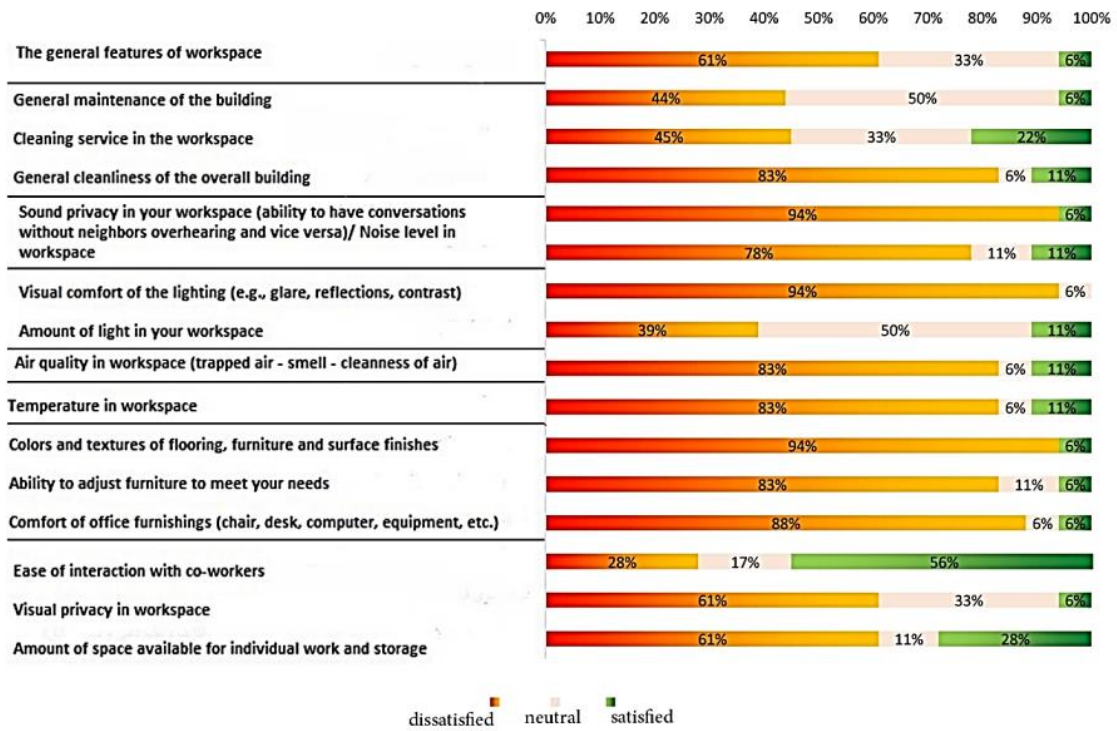


Diagram 1 The number of satisfied, dissatisfied and neutral people in different factors, source: authors



Fig. 4 The photo on the right- control room has a false floor covered with anti-static vinyl tiles. The reflectivity of flooring has tremendously reduced visual quality of space
The photo on the left, monitors became lightproof because of the location and window form in rear wall. Source: authors

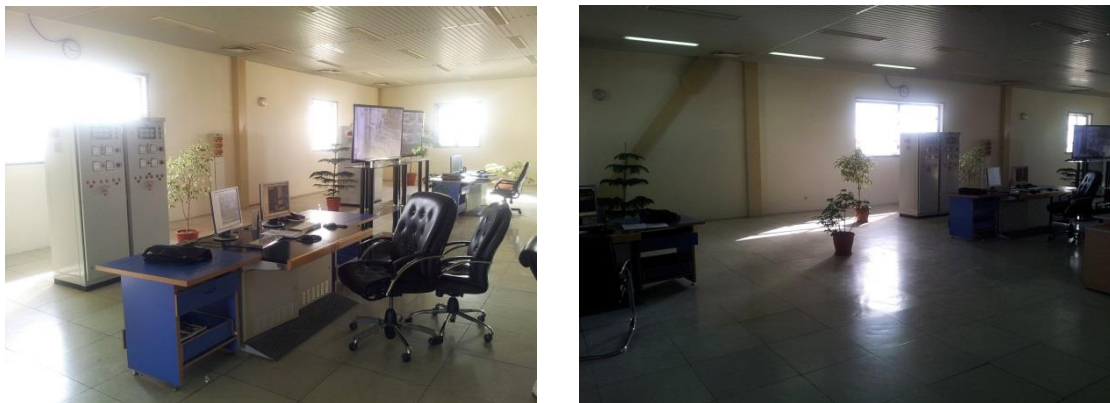


Fig. 5 The picture on the right- the location of windows have not been taken into consideration in the design of electrical lighting. As it is shown, ceiling lights are turned off in the middle of the control room and they are turned on near the windows. Distribution of light in the space is inappropriate and disturbing
The picture on the left- the size and number of windows have been considered without calculating the amount of desired lighting. Incoming light from the window is very much due to the clear sky and the absence of barrier around the building.

The large size of the control room and the emptiness of the room have created poor acoustic conditions in the space. Office furnishing, issues of aesthetics, comfort and a sense of belonging to the workplace have not been taken into consideration. Due to the fact that working in control building requires concentration and it is a profession without job creativity and diversity, the tensions created by the monotony of control process can

be reduced by using furniture and paying attention to interior decoration. As shown in figures 4 and 5, an attempt has been made to adjust the workplace by using some vases, however, this is not sufficient. After visiting the site and having an oral interview with the personnel, it became clear that the space has more potential for design and interior decoration. Figure 6 shows the administrative offices in the building.



Fig. 6 The picture on the right- arrangement of office furniture in engineering room is not in accordance with the windows. The curtain is not properly selected for uniformity and fragmentation of incoming light from the windows
The picture on the left- the administrative office lacks external windows. For improving the enclosed interior conditions false windows have been embedded. Using white electrical lighting has intensified the interior adverse conditions. Source: authors

The highest frequency of satisfaction in diagram 1 was related to the factor “ease of interaction with co-workers”, as a result of the type of office design (56 percent satisfaction).

Figure 2 compares the mean scores given to the different factors by the respondents. In this diagram, the factors are arranged from the lowest score to the highest one.

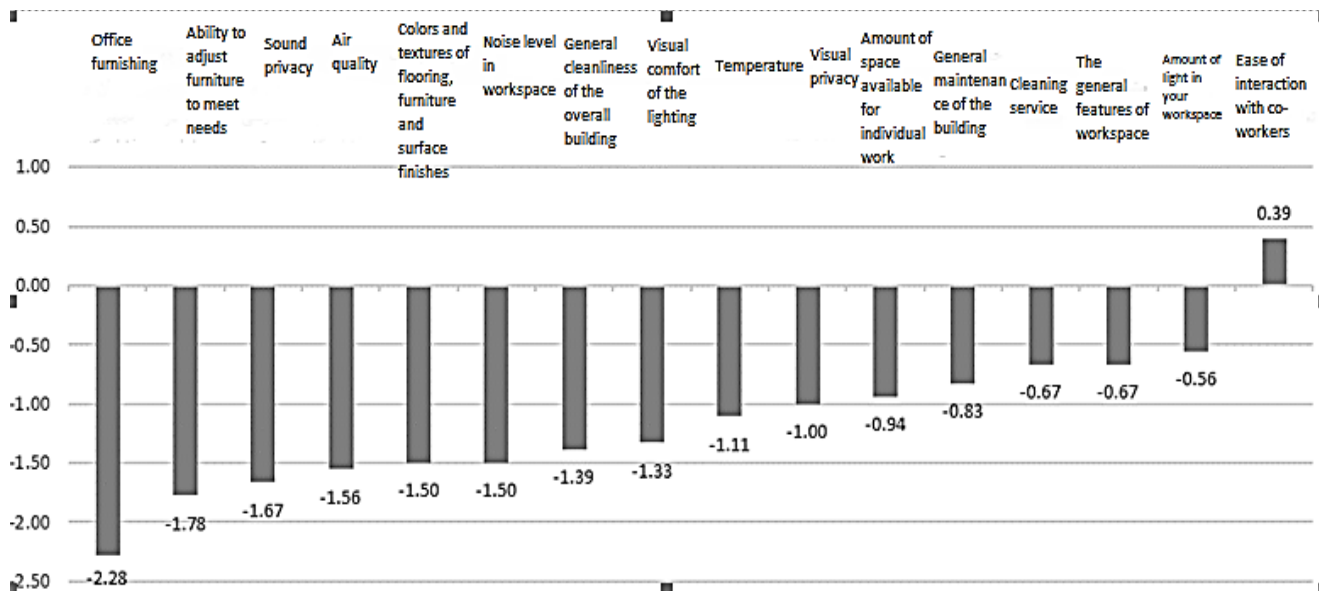


Diagram 2 comparison of the mean scores given to the different parameters by the respondents, source: authors

As diagram 2 indicates, visual comfort of lighting (e.g. glare, reflection and contrast) which had the highest frequency in diagram 1, became the median in scoring chart. This can be ascribed to people’s shift work. That is to say, when working at night, people are not influenced by day lightning and the problems previously mentioned in Figure 4 and 5 and their performance is independent of this factor.

Diagram 3 indicates the mean scores given by the respondents regarding the impact of different workspace factors on their self-estimated performance. The order of effectiveness of the factors is as follows:

Making periodic changes in the workspace, acoustic quality, cleanliness and maintenance, Cleaning service, air quality, amount of light in your workspace, furniture and appearance, thermal comfort and finally office design.

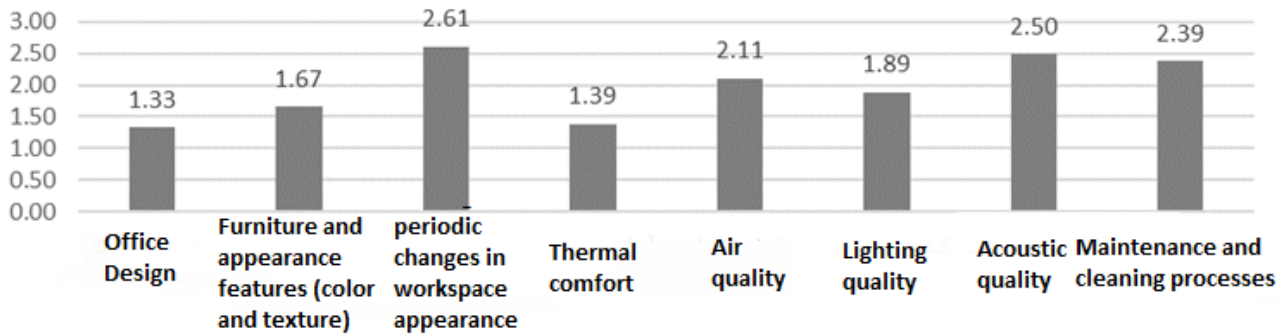


Diagram 3 comparison of the mean scores given by the respondents to the impact of different parameters of workspace on their self-estimated performance

Diagram 1 compares the number of satisfied, dissatisfied and neutral people with different environmental factors. In diagram 2, the mean scores given to the factors were investigated. In diagram 3 the level of effectiveness of different factors on the self-estimated performance of the personnel was examined and now in diagram 4, by combining the previous diagrams, the factors are prioritized in terms of corrective potential for the enhancement of personnel performance. In this

diagram, the corrective potential of each factor is obtained by multiplying the absolute value of personnel satisfaction mean of the above-mentioned factor in the mean of its impact on the performance of the personnel.

According to the diagram, the factor “interior design” (furniture, materials, wall colors, variety in decoration and adjustment with personal needs) and acoustic quality of the environment have highest corrective potential which aim to improve the performance and productivity of the personnel.

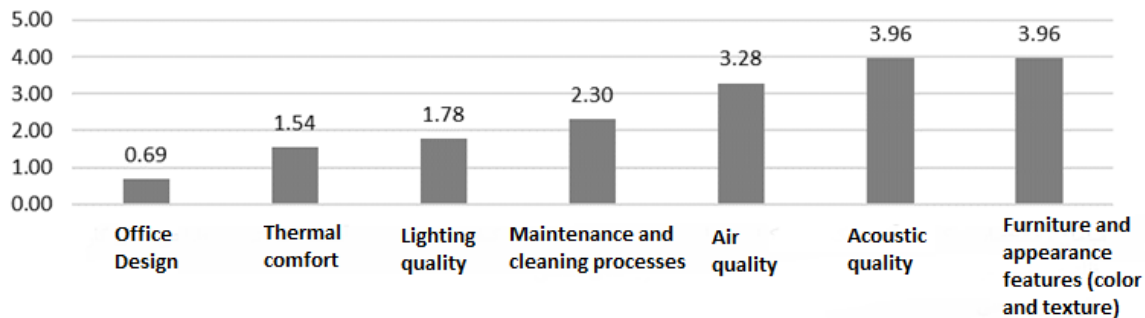


Diagram 4 prioritization of parameters in terms of their corrective potential for the enhancement of personnel performance, source: authors

5. CONCLUSION

From the viewpoint of the occupants, people’s environmental perception of the indoor space of the building and the characteristics which provide comfort determines their level of environmental perception. Environmental satisfaction with workspace is one of the factors of job satisfaction that influences one’s life quality. In addition, there is a direct relationship between people’s job satisfaction and their absence and even exclusion from work which can cause many financial losses for employers. Therefore, providing environmental comfort leads to the greater activation of human resources, their vitality, reduction in likely risks, increase in the quality of working life and depression, the improvement of services and finally the achievement of the desired productivity.

Since industrial buildings fall into the category of anthropozemic or non-humanitarian buildings, the role of architects as the one who adjusts the stressful environmental conditions is of great significance. According to interviews conducted with the decision-makers in the field of design, construction and operation of internal power plant projects during this study, the

presence of the architects in the related teams is possible only with upholding this approach that an architect acts as a coordinator between facilities designs, structures, predetermined stereotyped architecture and the accuracy of their implementation. In the preparation of architectural plans, the requirements related to systems’ operation, tools and machineries are taken into consideration, and human requirements are considered in terms of safety and security at the plant.

The present study shows adverse environmental conditions in combined cycle power plants using the architectural and environmental model of the typical Control Building from the viewpoint of the users of man-machine interface spaces. Of the environmental factors, only the component “ease of interaction with co-workers” as a result of the type of design provided satisfaction. The scores given by the personnel based on the level of dissatisfaction factors from the highest to lowest one are as follows:

Office furnishing (-2.28), ability to adjust furniture to meet the needs (-1.78), sound privacy (-1.67), air quality in the workspace (-1.56), colors and textures of flooring, furniture and surface finishes (-1.50), noise level (-1.50), general cleanliness of the overall building (-1.39), visual

comfort of the lighting (-1.33), temperature in workspace (-1.11), level of visual privacy (-1.00), amount of space available for individual work and storage (-0.94), general maintenance of the building (-0.83), cleaning service provided to workspace (-0.67), general specifications of the building (-0.67), amount of light in workspace (-0.56).

In this case, employees declared that they have to adapt themselves to the uncomfortable work condition to maintain their job position. This conformity mandatory has been led to biological and psychological pressures along with impairment in their function. The order of factors' effectiveness on employees' self-estimated performance is as follows:

Making periodic changes in the workspace (2.61), acoustic quality (2.50), cleanliness and maintenance (2.39, air quality (2.11), amount of light in your workspace (1.89), furniture and appearance (1.67), thermal comfort (1.39) and finally office design (1.33).

By assessing the level of space occupants' satisfaction for the environmental factors and evaluating the impact of these factors on their self-estimated performance, the corrective potential of different factors with the approach of the enhancement of personnel's performance has been determined. According to the result, the factor "interior design" (furniture, materials, wall colors, variety in decoration and adjustment with personal needs) and acoustic quality of the environment have highest corrective potential which aim to improve the performance and productivity of the personnel.

The results of this study primarily represent the building conditions to operations managers and secondly guide them in decision-makings about taking corrective measures using interior design professional experts in different factors.

NOTES

1. Professor Kiyoo Izumi: Professor of Urban and Regional Planning at the University of Waterloo in Ontario has conducted many studies on cognitive issues in human and building.
2. Anthropozemic or non-humanitarian
3. Anthropophilic or humanitarian
4. It is an unpleasant feeling that occurs when a person has simultaneously two inconsistent ideas. Theory of cognitive dissonance proposes that people have a motivation to reduce dissonance. They do this by changing their attitudes, beliefs and actions. Dissonance also reduces by justification, accusation and denial. This theory is one of the most influential and studied theories in social psychology.
5. Quality of work life is determined based on comfort factors in workspace, occupational factors and inter-organizational factors.
6. Dr. Vischer is the Head of Interior Design Department, University of Montreal.
7. The International Organization for Standardization
8. The comparison between international standards and internal standards regarding to control building design will be discussed in another paper.

9. As shown in the table grouping the factors, each main factor has one or several subfactors. At this stage, the overall satisfaction with the main factor is gained through averaging the satisfaction with subfactor. Furthermore, due to the fact that the building control personnel did not have any experience in making periodic changes in the appearance of the workspace, the impact of these factors on the performance of personnel and the component of furniture and workspace appearance features has been averaged and in the potential diagram, the obtained number is multiplied by the level of personnel satisfaction with furniture and appearance features.

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CONFLICT OF INTEREST

The author declares that there are no conflicts of interest regarding the publication of this manuscript.

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