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THE IMPACT OF FLOOR-TO-CEILING HEIGHT ON HUMAN COMFORT

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ABSTRACT

Creating a comfortable environment is one of the most important parameters to be considered when designing buildings. Human comfort condition is investigated by many researchers from different points of view. In this paper, the effect of changes in floor-to-ceiling height on comfort condition in a certain indoor thermal condition is investigated. Changes in net height have been discussed in details from thermal, energy, economical, architectural, safety and other related perspectives in previous studies and Results are published in organized forms or as standards. However, what emphasized in this research is people's feeling of comfort. The investigation carried out in a laboratory with adjustable ceiling height designed for the test. People's opinion on comfort satisfactory is collected and results are presented. It is possible to take advantage of the findings to suggest the optimum height for common urban residential units in Iran.

Keywords: Human comfort; floor-to-ceiling height; residential spaces

1. INTRODUCTION

Human comfort is defined as the state of mind that expresses satisfaction with the surrounding environment. Human comfort condition is investigated by researchers in different situations [1-6]. Studies show there are some factors that affect human comfort in a building. Being aware of these factors may help designers to provide comfort condition. Researches on similarities between feeling of people of comfort condition reveals in spite of differences in characteristics and nature, people show the same feelings in similar comfort conditions. This is much obvious taking into account thermal condition.

Experimental studies conducted over many years in different countries have led to the specification of some comfort levels. Although the experiments carried out on different situations according to the people cultural and spiritual characteristics, test locations and test

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method but due to similarities of people in specifying the level of comfort, the findings of any research study that considers the issue with a new vision may lead to offering a new mechanism such that it may be utilized in formulating related dimensional criteria or in revising them. Accordingly, comfort level was decided to be studied in a variable roof height space under a uniform climatic condition. Therefore, a laboratory with adjustable floor– to-ceiling height was constructed. The findings of the project, which is unique of its kind, are contained in the notes of early research results concerning setting the optimum floor– to–ceiling height for common residential units [7,8,9].

2. FLOOR–TO–CEILING HEIGHT VARIABLE VERSUS HUMAN PERCEPTION

Human comfort condition usually has investigated by considering climatic conditions and their impact on thermal comfort of people and also changing the variables of thermal comfort equations and calculation of interactive relations. In the current study A unique innovative method is adopted in order to evaluate people's feeling about suitable floor-to-ceiling height; The research is conducted in an adjustable roof height laboratory in which, constant climatic conditions is provided according to the basis of test necessities only. Subsequently, a desirable thermal comfort condition is considered for the laboratory during the test. Then people's feeling according to the changes in floor–to–ceiling height in the uniform climatic conditions of the laboratory environment is collected.

It is worth noting that the level of comfort and thermal conditions of the laboratory room is measured by the data logger-thermal comfort unit. The device is equipped with sensors that receive climatic conditions of the laboratory environment and it measures the rate of satisfaction and dissatisfaction of the people in the room in which they are located, through calculation of (PMV-PPD)[1], applying the international standards specified for thermal comfort and with respect to the level of physical activity and clothing considered for the device. [10, 11, 12, 13]

3. FACTORS AFFECTING COMFORT

Many factors can affect human comfort. Among these, temperature, human metabolism, body heat transfer mechanisms and related factors, air temperature, air current, person's type of activity, physiological problems, body workability under climatic conditions of the interior space, type of clothing and human comfort equations with respect to the points mentioned and also perception and mentality of the people, spiritual and mental problems and many other factors may be named. Clearly, some of the mentioned parameters are not measurable and some others, in combination with each other produce a different consequence. Therefore, a careful attempt is needed to convert these factors to quantitative ones and make it possible to establish comfort foundations. [14, 15, 16]

[1] PMV (Predicted mean vote); PPD (Predicted Percentage of Dissatisfied)

4. COMFORT AND THERMAL COMFORT CONCEPTS

Human being has always thrived to provide thermally suitable environment. This target always has affected construction traditions worldwide. Nowadays creating thermally comfortable environment is one of the most important parameters envisaged by people.

Satisfaction or comfort feeling virtually means a special feeling in which all body organs of human physiological system carry out their chores and duties easily and naturally, without intervention or help of any other tool.

Generally, the adopted definition of comfort describes thermal comfort as mental conditions in which satisfaction is expressed in terms of contentment of thermal conditions of the environment (ASHRAE, 1992).

According to the standard ISO 773, the precise state of thermal comfort is felt only when human brain is in the right condition to accept the heat level. This definition is most approved by people. It should be noted that such definition is hardly convertible to physical parameters.

5. PMV AND PPD INDICATORS AND THERMAL COMFORT CONDITIONS

PMV or Predicted Mean Vote is used to express the human perception of thermal comfort. The index has been defined by statistical research of a large group of individuals, who are to evaluate their own perception of thermal comfort in a specified indoor climate. The index includes the combination and interdependencies of some factors of thermal comfort, as follows: metabolic activity (met), clothing insulation (clo), air temperature, mean radiant temperature, air movement and humidity. [17]

There are also individual votes that indicate heat or cold sensation along with dissatisfaction, in the same environment (Table 1).

PPD (Predicted Percentage Dissatisfied) describes the percentage of occupants that are dissatisfied with the considered thermal conditions [17]. PMV is controllable by one of the following means:

a) By calculation of its equation, using computer.

b) When the values of PMV tables are given in terms of different combination of activity, clothing, operation temperature and relative intensity.

c) By direct measurement, using complete sensors.

(The PMV index predicts the mean response of a larger group of people according to the ASHRAE thermal sensation scale [10, 18] – Table 1)

Table 1: List of the rate of satisfaction (PMV)

Very warm (hot)	+ 3
Warm	+ 2
Relatively warm	+1

Indifference (Neutral region)	o
Relatively cool	−1
Cool	−2
cold	−3

Comfort dissatisfied is the one whose vote is not -1, +1 or zero. PMV is formulated in Fanger's Comfort Equation as follows [10, 18]:

$$PMV = \left(0.303e^{-0.036M} + 0.028\right)L \qquad (1)$$

Where M is metabolic rate and L is thermal load defined as the difference between the internal heat production and the heat loss to the actual environment for a person hypothetically kept at comfort values of skin temperature and evaporative heat loss by sweating at the actual activity level.

Fanger related the PPD to the PMV as follows [10,18]:

$$PPD = 100 - 95e^{-\left(0.03353PMV^4 + 0.2179PMV^2\right)} \qquad (2)$$

As it was mentioned earlier, data logger – thermal comfort unit was utilized in this research to quantify comfort (Fig. 1). [1]

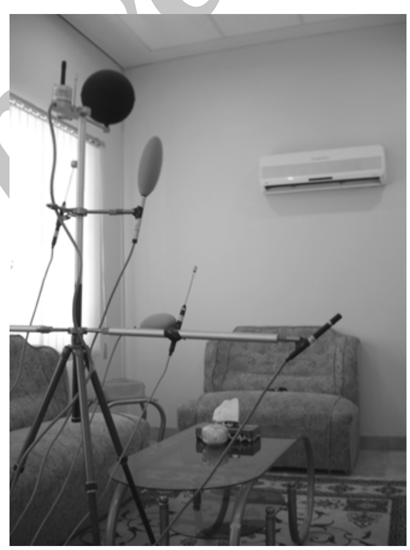


Figure 1. Laboratory room for comfort measurement

Human comfort measurement tools in laboratory environment and its role in assessment.

As it was mentioned earlier, comfort assessment may be done by calculation of comfort equations, using computer. It is noted that calculation of comfort equations is also possible by special equipments that gauge physical parameters. With the aid of comfort assessment devices (Fanger unit, data logger - Thermal comfort unit…) and with the knowledge of conditions under which, environmental comfort is achieved, it would be possible to adjust the conditions of the space under consideration.

6. NECESSARY PRECAUTIONS TO CARRY OUT THE TEST

A controlled laboratory space with adjustable floor-to-ceiling height (with vertically sliding roof) is utilized in this research.

6.1 Configuration of the interior environment of the laboratory and test procedure

Before starting preliminary studies and collection of necessary data, the study team reviewed possible procedures to achieve the desired results. Considering available possibilities, construction of a laboratory with vertically adjustable roof (that is, the floor –to–ceiling variable) was suggested so that test participant people's views may be assessed in the controlled and uniform environmental conditions in which, the only variable is floor–to–ceiling height. Therefore, an adjustable roof is designed and constructed in order to control floor–to–ceiling height. . Numerous ideas were investigated in order to select the final plan and construction was begun right after applying the required modifications. Interior design of adjustable roof laboratory and related sensors for measurement of human comfort are demonstrated in Fig. 2. In theses figure roof height increases from 2100 to 4000 mm heights in cases A to D, respectively [1].

The surface area of the laboratory space was equal to 16 m^2 (mean space area for common urban residential units), and its height was considered as 4500 mm, as reported by test requirements. The interior area and the furniture were decorated according to a residential apartment unit in Iran.

Although the height of the room could be changed from zero up to 4500 mm, but since the project is aimed at urban residential apartment unit, it was decided to adjust the roof height from 2100 to 4000 mm Therefore, specific stops were considered at 2100–2200 mm, 2700–2800 mm, 3000-3100 mm, and 3750–4000 mm distances in order to survey and review test participants points of view.

Once the construction work of designed laboratory was over, by adjusting its roof at prespecified heights it was decided not to mark up any special sign on the walls.

Therefore, signs were arranged such that only researchers of the project are aware of the exact height setting. This was to prevent from prejudgments of the test taking individuals so that their minds are not directed towards prejudgment of numerals before being aware of the test subject.

It is worth noting that after revealing the research subject to the participants some of them requested to redo the test at the roof heights at which they had given their views, in order to ascertain and reconfirm their early views. Test individuals were selected randomly, among which there are various specialists regarding their profession and their activities. Also, it is tried to have the same number of male and female participants. Eventually, after receiving written views in questionnaires, views of the present individuals were transferred to one another by short discussions so that basic arguments and analyses were exchanged in their presence. In such communications, new ideas and issues were also developed, a number of which are grouped and introduced at the end of this section.

Variations of the floor–to–ceiling distance in this laboratory led to the point that individuals present at the lab site considered the issue differently and paid more care and attention to many problems that they had not thought of before and they analyzed and discussed the problems more carefully. This indicates how important living and business spaces are to their users. Therefore, this specifies the significance of the responsibility to select the size and measurements carried out. Ultimate accuracy must be observed in this regard.

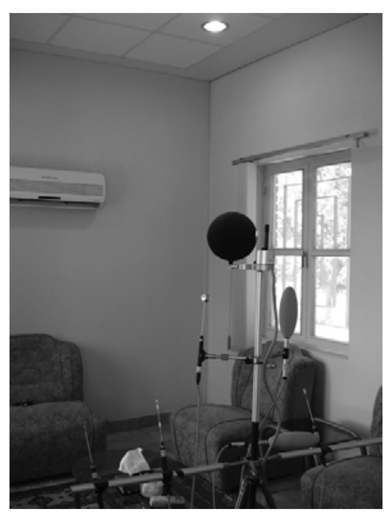
6.2 How to establish the necessary conditions to carry out tests

A brief description of the method adopted to establish required conditions to carry out the tests is now offered. At first a space called "Reference environment" is provided, which is an area with the same conditions as the laboratory and with almost equal surface area; the only difference being its fixed roof. The individuals present at the reference environment shall express their rate of satisfaction strictly with respect to thermal comfort vision regardless of the floor –to– ceiling height.

Climatic conditions of the said environment are measured by the data logger unit and the PMV or the rate of satisfaction is given by it.

The laboratory environment is hence adjusted according to climatic conditions of the reference space so that individuals may feel the same thermal state except that with the possibility so evolved to change the floor–to–ceiling distance, their rate of satisfaction in conditions similar to those of the reference environment and in different ceiling heights is investigated. In this way, it would become clear whether dissatisfaction originates in floor–to-ceiling distance or not. It is worth noting that during the test, changes in height would lead to no tangible difference regarding thermal conditions in the space inside the laboratory (this is controlled by the thermal comfort unit) [1].

Case A: height=2100mm-2200mm



Case B: height=2700mm-2800mm

Case C: height=3000mm-3100mm Case D: height=3750mm-4000mm

Figure 2. Interior design of adjustable roof laboratory and related sensors for measurement of human comfort [1]

Comfort measurement device is utilized not only for controlling environmental conditions, but also to compare individual's response with that of the instrument so as to ensure existence of specified comfort conditions; the unit also serves to observe consistency of internal conditions during height changes. Therefore, if the comfort conditions remain within a defined limit, but individual's responses express their satisfaction or dissatisfaction, this means, changes in height, has influenced the people's responses.

6.3 Mind survey method

In order to collect data it was decided to utilize questionnaires. Hence, a form was designed to enable us to be aware of people's views (questionnaire form 1-2). The test was performed on 39 people (19 women and 20 men), selected on a random basis (Table 2).

7. PERIPHERAL UTILITIES VERSUS ESTABLISHMENT OF HUMAN COMFORT CONDITIONS

Peripheral utilities are other effective parameters concerning human comfort condition. For instance, clothing as a peripheral utility can prevent reduction in body heat and people can mostly improve their own thermal comfort easily by changing their clothing.

The unit generally applied to measure clothing is "CLO". Living appliances such as table, chair and also walls, floors and others have significant role in thermal comfort. For example, since feet are in direct contact with the floor, discomfort of feet is due to change in floor temperature. Performed tests show that warm roof and cold windows are responsible for most human discomforts, but cold roof and warm walls account for least disturbed feelings in human beings.

8. PERCEPTION PROCESS IN THE COURSE OF SPECIFYING FLOOR TO CEILING HEIGHT IN COMMON RESIDENTIAL SPACES

When investigating the factors affecting the process of specifying floor–to–ceiling height in common residential buildings, there are some factors that cannot be ignored. These factors contain methods of providing physical and mental comfort as well as parameters like economical saving mechanisms in construction.

Essentially the relation between physical and mental comfort of the individuals and physical characteristics of an architectural space (especially the size of space or its longitudinal, transversal and vertical dimensions) are in turn strongly affected by performance of the pertaining space and by the objective behavior of the individuals in the same space. Physical comfort of the people as related to the size of the space, with respect to ergonomic domain is subject to review and investigation.

Mental–psychological comfort of the people, in relation with the size of space and especially to the size of its height is studied in different branches of psychological science.

Table 2: Mind survey through questionnaire

BHRC

Project title: Determination of floor–to–ceiling height in common residential buildings based on evaluation of samples in controlled laboratory spaces

Name:

Family name:

The city where you work:

Education:

Age:

Gender:

Nationality:

Time of stay in the city of Tehran:

Date of taking the test:

Table 1- rate of satisfaction PMV

3 Very warm	2 Warm	1 Luke warm	o Comfort	-1 Cool	-2 cold	-3 Very cold

Ceiling height:

1) Rate of satisfaction (PMV) from the space with fixed roof at 2200 mm height is specified in table 1

2) Rate of satisfaction (PMV) from space with following heights:

2100-2200 mm

3 Very warm	2 Warm	1 Luke warm	o Comfort	-1 Cool	-2 cold	-3 Very cold

2700-2800 mm

3 Very warm	2 Warm	1 Luke warm	o Comfort	-1 Cool	-2 cold	-3 Very cold

3100-3300 mm

3 Very warm	2 Warm	1 Luke warm	o Comfort	-1 Cool	-2 cold	-3 Very cold

3750-4000 mm

3 Very warm	2 Warm	1 Luke warm	o Comfort	-1 Cool	-2 cold	-3 Very cold

3) Specify tangible factors in providing dissatisfaction of space

Air current : temperature: humidity:

Other factors:
4) Express your views about rapid change in roof height:
5) Length of time spent in the laboratory space:

Explanations:

The laboratory space for duration of test is the work place in the BHRC
- Space conditions at test time
- Clothing (CLO):
- physical activity:

9. DISCUSSION

At this stage in the process, comfort values given to each of the roof stop points, adjusted according to uniform climatic conditions of the laboratory in different ceiling heights and in compliance with climatic conditions of the reference space were collected. During test period, rate of satisfaction measured by the data logger is almost (-0.5).

It is worth noting that the quantity of CLO defined for the device, according to the season and the people's clothing was set to 0.8, and the level of activity of individuals was set to the stationary state while studying or talking. The same condition is provided in the reference room according to the real physical activity of the people. Then individual's points of view were collected.

It is noticeable to take into consideration that individual's reasons for satisfaction or dissatisfaction in different case are discussed in details in main report. Some of the reasons are briefly described as follows:

- case A: Test results in floor-to–ceiling height of 2100mm–2200 mm condition, shows that 14 of the individuals' rate of satisfaction(PMV) was between -0.2 to -0.5 and others declared climatic conditions of room as -1 or -2. Generally speaking, except for two persons, all the others expressed their dissatisfaction of this height.
- case B: According to the test results in floor-to–ceiling height of 2700mm–2800 mm condition, 37 individuals stated their satisfaction by a PMV of 0.2 and zero. All of them expressed their satisfaction and comfort feeling for this height.
- Case 3: According to the test results in floor-to–ceiling height of 3100mm–3300 mm condition, 17 individuals, stated their satisfaction by a PMV of -0.5 and 22 people declared it as (-1). However, majority of them preferred this height more than case a).
- Case 4: According to the test results in floor-to–ceiling height of 3750mm–4000 mm condition, 9 individuals expressed PMV of climatic condition of the room as -0.1 and -1.5, 26 expressed (-2) and 2 persons declared (-3). Almost everybody announced their dissatisfaction of this height.

Accordingly, the height 2700 – 2800 mm was unanimously selected as the most appropriate height for common residential urban units.

It must be noted that if floor–to–ceiling height is shorter or taller than a certain limit, in addition to human comfort and climate problems, it would affect economic problems, building maintenance, observance of architectural size ratios, structural and earthquake calculations, quantity of materials, building components and appliances standards, cleaning, prefabrication, industrial production, mass production, etc. The height issue has a positive reflection, especially on human comfort, environmental users and on mental and psychological perceptions of the residents. Therefore, the individuals' views and their rate of satisfaction from living spaces can help scientists take proper steps towards accurate specification of that distance. There are many points worth discussion and presentation, which are included and accessible in the comprehensive report. Continuance of this report for future completion and revision is envisaged by researchers of the Building and Housing Research Center and it is hoped that it would be useful in practice.

10. CONCLUSIONS

In this study, effect of floor–to–ceiling height of a residential unit on human comfort condition is investigated. In the conducted tests which were conducted in a laboratory with adjustable roof height, 39 individuals satisfaction rate were collected. Four roof heights between 2100mm and 4000mm is considered for the test. Results show that floor–to–ceiling height between 2700mm and 2800mm is the most desirable height for common residential urban units.

The points brought up in this paper are the results of research project and tests carried out at BHRC, by Nikravan Mofrad. Mojgan. Project title: Investigation on the effect of the height of rooms and spaces on the comfort of human in the residential buildings based on evaluation of the samples in controlled laboratory spaces, Research Report, BHRC Publication No. R – 528, 2011.

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