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Indoor physical work environment: An ergonomics perspective

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Abstract— **Work in the contemporary era is predominantly performed indoors. Indoor physical environmental factors (temperature, lighting, noise etc.) affect the performance of humans. Generally due consideration is not given to physical environmental aspects while designing individual workstation/workplace/facilities in an organization/industry. Keeping this scenario in mind it was felt that ample information in a consolidated form pertaining to basic indoor environmental parameters will definitely help managers, supervisors, engineers, designers, entrepreneurs to become conscious and take an effort towards implementation of recommendations adopted and proposed by scientific community/organizations for facilities layout planning. Indian standards are moderately addressed to help readers visualize the role of country specific organizations in promoting development of standardization in agreement with international bodies. National institutions help in evolving strategies for formulation and accordingly recognition of standards in their respective countries. Present paper strives to collect, segregate and arrange needed information to represent an appropriate knowledge body for all concerned. Good indoor environment is beneficial in terms of increasing productivity, satisfaction and overall well-being of people. Variations in specifications proposed by different organizations/bodies and other studies were observed. Standards proposed should be used as a basis, while due attention should be given to ethnic and geographic diversity, individual differences and adaptability while designing/ /planning any indoor workplace/workstation/facility. The need of the hour is location/country specific contextual investigations/research into indoor physical environmental factors. Such initiatives will ultimately result in formulation of standards/recommendations which are specific to industry/ location/ intended people.**

Index Terms— **ergonomics, indoor environment, standards, work-place.**

I. Introduction

In present era most of the work is performed indoors. It is reported that, on an average people spend about 90% of their time indoors in industrialized countries [1]-[2]. This trend is increasingly seen in developing countries also. Organizations like ISO (International Standards Organization), CEN (European Committee for Standardization), ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers), IES (Illuminating Engineering Services), OSHA (Occupational Safety and Health Administration) etc. put forth standards and accepted methods for evaluation of physical environments while periodically revising existing standards and publishing new ones. Developing countries have their own national bodies to formulate or adopt standards for regulating indoor environment. Objective of Bureau of Indian Standards (founder member of ISO) is to provide harmonious development of standardization, marking, quality certification, and evolving a national strategy for according recognition to standards and formulation of Indian Standards [3].

Ergonomics (or Human Factors) is defined as 'the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimize human well-being and overall system performance' [4]. Practitioners of ergonomics, ergonomists, contribute to the planning, design and evaluation of tasks, jobs, products, organizations, environments and systems in order to make them compatible with the needs, abilities and limitations of people [4]. With reference to the context of man machine interaction, Ergonomics/Human Factors can be visualized as study of man-machine interfaces aimed at optimizing human wellbeing and to improve all-round system performance [5].

Ergonomic design of work place/environmental ergonomics/ergonomics of physical environment refer to the creation of ambient conditions that are appropriate, acceptable and does not compromise on work performance or worker's health [6]. Acceptability and performance of the occupants are affected by various factors such as light, noise, air quality and thermal environment [7]. In most of the studies much attention has been paid to indoor environment in offices with the aim of increasing productivity and evaluation of indoor environmental quality by grades (e.g. quite satisfied, just satisfied, just dissatisfied, and quite dissatisfied) instead of numerical value [8]. Questionnaires can be easily administered and also cost-effective to distribute and has the advantage of being easy to handle large samples, thus facilitating general findings [8]. Interestingly when either temperature or noise is outside acceptable range, the entire indoor environment will be considered unacceptable by the subjects as observed during survey in offices [9]. Indoor environmental conditions are measured throughout the year [10] to arrive at satisfactory conclusions.

Parsons, [11] has pointed out that standards will not

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ascertain workplace design but has the ability to give a useful starting point for successful design. With the above thought in mind an attempt has made to compile all need based information regarding basic indoor environmental variables like temperature, relative humidity, lighting and noise.

II. METHODOLOGY FOLLOWED FOR PRESENT REVIEW

Systematic approach has been adopted to search published literatures/articles written in English language from electronic databases: Science Direct, Springer LINK, Google scholar etc. Available hard copy journals, articles and books were also studied. All publications identified were studied thoroughly at least by their abstracts

III. INDOOR PHYSICAL ENVIRONMENT

The main indoor physical environmental parameters relate to temperature, relative humidity, lighting and noise. The following paragraphs elucidate the importance of these factors, recommendations proposed and standards adopted/recommended for evaluation of these factors.

A. Indoor thermal environment

Among different indoor environmental conditions/factors thermal comfort is preferred/ given greater importance [12] compared to visual, acoustic and air quality. Humans have the capability for adapting hot environments due to the presence sweat glands in their skin. Various thermo regulatory mechanisms are at work in human body for maintaining heat balance. Individual characteristics of the worker, thermal environment and the requirements of task are some of the factors which influence the ability to work in heat. Productivity and contentment of the occupants can be increased as a result of improved thermal comfort [12] and their control over the environment [13].

Thermal comfort is the state of mind that expresses satisfaction with thermal environment and is assessed by subjective assessment [14]. The ASHRAE thermal sensation seven point scale ascertains the sensation of warmth/cool that a person experiences whereas Bedford seven point thermal comfort scale estimates the state of thermal comfort experienced by the subject in a given environment [15]. Surveys using the ASHRAE and BEDFORD scales can be administered in real buildings or laboratories (climate chambers) and subsequently 'comfort vote' of subjects is considered to determine a particular temperature (the comfort temperature) or combinations of conditions they find most comfortable [16]. Based on experience it is found that although two scales are semantically different, subjects use these two scales in a similar way [16]. Studies reveal that desired sensation on ASHRAE scale depends not only on outdoor temperature but also on indoor temperature prevailing at the moment [17]. The occupants of an indoor space will feel neither warm nor cold when asked about thermal state and preference if they are thermally comfortable [18].

From observations in British factories, the following recommendations were suggested [19]. Optimum air temperature recommended for persons doing light work is 18.3˚C and comfort zone is between 15.6˚C to 20˚C. Respective values for individuals engaged in sedentary office work and active factory jobs are 19.4˚C to 22.8 ˚C and 12.8˚C to 15.6 ˚C respectively. The optimum mean radiant temperature (globe temperature readings) recommended for light work is 18.3˚C and the comfort range is between 16.7˚C to 20˚C. Maximum relative humidity recommended is 70% and the ideal level of air movement is around 150 mm/sec. In a study conducted in South Africa, subjects, both male and female from all major ethnic groups were tested in a mobile climate laboratory. Environmental conditions likely to be encountered in South African factories were simulated. Best performance for many tasks was observed when air temperature was 32 ˚C (the temperature being in the range of 20 ˚C to 38 ˚C) and relative humidity 25 % although subjects preferred temperatures were between 20 ˚C to 23 ˚C [20].

A detailed list of ISO standards related to thermal environments along with their descriptions was given by Havenith [21]. ISO 9241 has mentioned 20˚C - 24 ˚C for winter and 23˚C - 26˚C for summer as acceptable indoor temperature range for workers [22]. Further, satisfactory ranges for humidity are 60 - 80% for 20 ˚C, 50 - 70% for 22˚C, 45 - 65 % for 24˚C and 40 - 60 % at 26 ˚C while in general, temperatures ranging between 19 ˚C and 23˚C with 40% - 70% relative humidity were found to be acceptable by majority of workers [22]. The acceptable range of temperature was between 20.9 ˚C and 30.4 ˚C, as found in a controlled field study in offices by Huang et al., [9] when the mean daily outdoor temperatures ranged from 25.1 ˚C to 28.8 ˚C, relative humidity ranged from 40% to 65%, (with an average of 51%) and air velocity, between 0.02 m/s to 0.42 m/s. ISO thermal comfort standards are believed to be valid, reliable and usable for practical application, but it is specified that variations could occur due to ethnic, geographic diversity, individual differences, varied prior thermal experiences and adaptability [23]. Field studies by many researchers using subjects in tropical settings indicated that people find certain physical environments comfortable which differ from the recommendations made in ISO7730 especially for buildings which are free running. As a result it is understood that ISO7730 underestimates range of temperatures which people find comfortable [24]-[25]. The PMV-PPD (Predicted Mean Vote- Predicted Percentage of Dissatisfied) model for thermal comfort included in ISO 7730, is based on steady state energy balance of human body and interviews conducted in controlled climatic conditions, which envisages thermal sensation and comfort satisfaction of human body as a function of six parameters related to the indoor environment (internal temperature, air velocity, humidity, mean radiant temperature) and to the occupants (activity and clothing), without any relationship with the external environmental conditions [26]. Moreover the PMV-PPD model does not consider the transient conditions prevalent in naturally ventilated buildings and the variation in occupant's activity and behavior [26]. It was also observed that ergonomic standards concerning physical environment has been proposed taking technical or engineering approach with little importance given for human responses and ergonomic methods [11].

One of the most controversial issues in the applied research area of thermal comfort is the contention between 'static' model which is based on steady state laboratory experiments (ASHRAE's Standard 55 Thermal Environmental Conditions for Human Occupancy and the ISO Standard 7730) and field study based on 'adaptive' model [27]. In the last decade thrust is given towards extensive studies in adaptive thermal comfort. Peeters [25] and de Dear [27] along with their colleagues infer from various literature resources that adaptation (behavioral, physiological, and psychological) of people are based on their experiences, season, climate, semantics, habituations (building design, building function), genetic factors, acclimatization, and adjustment (personal, technological, environmental), demographics (gender, age, economic status), social conditioning and cognition (attitude, preference, and expectations). There is a big argument whether standards based on laboratory experiments are applicable to buildings which are free running (not air conditioned at all) and also its universal applicability (all types of buildings, climates, populations) ignoring the importance of contextual influences that can undermine peoples responses to a given set of thermal conditions [28].

Following are some of the insights reported in literature survey conducted by Frontczak and Wargocki, [18].

- Women and men differed in their ratings on thermal conditions
- Variations regarding nature of the indoor environment (workplace/home/public/private), its characteristics, duration of occupancy, and level of education, the relationship with superiors and colleagues, and time pressure were reflected in rating by respondents
- Ranking was found to vary in different countries
- Color of light influenced the thermal comfort rating very lightly and room decoration had no impact on the rating
- Neutral and comfort indoor temperatures increased with increasing outdoor temperatures in naturally ventilated buildings

Djongyang et al., [29] have stated that thermal comfort is a state of mind and judgment of comfort is a cognitive process influenced by physical, physiological, psychological, and other factors like mood, culture, individual, organizational and social factors. From reviewing literatures they have mentioned that International comfort standards given by ASHRAE and the International Standards Organization (ISO) are based on theoretical analyses of human heat exchange performed in mid-latitude climatic regions in North America, Northern Europe and that these standards are suitable for static, uniformly thermal conditions based on hypothesis that regardless of race, age and sex, human beings feel comfortable in a narrow, well-defined range of thermal conditions. Comfort surveys indicated that factory workers acclimatized to warm humid tropical climatic conditions can tolerate up to 30˚C which can go up to 34˚C if the air velocity is 0.6 m/s while performing light manufacturing activities without much ventilation [30]. Nicol [24] stated that, generally, subjects can be comfortable at temperatures up to or even exceeding 30 ˚C especially if they are using a fan based on results from many field studies in hot climates. It was observed in a survey that neutral temperature was 31.93 ˚C showing occupant's high tolerance and adaptability and it was also found that their perception of thermal comfort varied on account of spatial conditions/visualizations [15]. The range of comfort temperature varied in different climatic zones and also during different months of the year as found during a study in North East India with respect to vernacular buildings [31]. The responses indicated by people to thermal environments in naturally ventilated buildings in hot humid zones of china reveal a close relationship between indoor physical variables and occupants' clothing insulation with outdoor climate [32]. From a literature review based on field evidence of thermal adaptation for built in environment, Brager and de Dear [28] reports the existence of distinction between thermal comfort responses in air-conditioned vs. naturally ventilated buildings, due to combination of past thermal history in buildings and differences in levels of perceived control. In case of free running buildings outdoor environment has a bearing on indoor environmental conditions [16]-[24]-[33]-[25]-[26]. Many researchers have found that the temperature at which the occupants find comfortable (Bedford scale) or neutral (ASHRAE scale) is linearly related to the monthly mean of outdoor temperature [16].

Air temperature, radiant temperature, air humidity and rate of air movement are considered to be the factors deciding whether a person will feel hot, cold or comfortable [19]. Atmaca et al., [34] described air temperature, humidity, air velocity, mean radiant temperature, clothing level and metabolic rate as primary factors affecting thermal comfort. Dry-bulb temperature (DBT), wet-bulb temperature (WBT), relative humidity, globe temperature (GT), and air movement are the parameters involved in measurement of thermal environment [22]. Operative temperature (average of air temperature and radiation temperature) can also be investigated by means of measurement [8]. WBT is measured with the help of a wet-bulb thermometer while GT is measured traditionally with the help of mercury in glass thermometer positioned in a metal sphere painted matt black [22]. Modern heat stress monitors use thermistors (electrical transducers) which can measure DBT, WBT, GT and air movement [22]. PMV and PPD indices meter is also available which can measure air temperature, Mean Radiant Temperature (MRT), airflow velocity, and relative humidity [9]. Generally pictorial representation of the layout is depicted and air temperature, air relative humidity, and air speed measurement at a particular location described as occupied zone is specified along with duration of measurement and time of measurement [9]. Measurements scheduled to cover the entire range of outdoor mean daily temperatures during the year and all the measurements taken at a distance of 1.45 m from the floor level was the methodology adopted in a field study at a large underground car park [35]. When the subjects were filling the survey sheet, Deb and Ramachandraiah, [15] spontaneously measured indoor environmental parameters (including air temperature) at a height of 1 m from ground level in a study involving assessment of thermal comfort of people who were in a seated posture. Three heights of measurements (0.1 m, 0.6 m, 1.2 m) above floor level are specified in ISO and ASHRAE standards [28].

Following information should be taken into consideration while designing facilities for indoor thermal comfort [22].

- ventilation is necessary to make available fresh air and remove accumulated noxious gases and contaminants
- Ventilation removes heat generated in working area by convection and helps in cooling the human body
- At low temperatures, air speeds less than 0.1 m/s tend to cause a sensation of staleness and stuffiness
- Air speeds greater than 0.2 m/s may be perceived as draughty
- Air speeds of 0.2 m/s to 0.5 m/s will help in body cooling in hotter conditions especially when relative humidity is high
- Working areas can be cooled by ventilating buildings at night utilizing the cool outside air

Average temperature (during summer in an automotive part manufacturing factory) decreased by about 3.6 ° C with improvement in thermal comfort as a result of installing axial fan ventilating system [36]. It is significant to note in this context that natural ventilating system capable of controlling summer temperatures can provide adequate ventilation to control level of odour and carbon dioxide production in a building [37]. However it is also highlighted that ventilation rates required to control summer temperatures are very much higher than the ventilation rates required to control pollution or odour [37]. Janssen [38] has given ample information regarding the history of ventilation and temperature control.

B. Relative humidity

The most prevalent measure for humidity of indoor ambient air is the relative humidity [24]. Recommended range of relative humidity is between 30% and 70% for indoors. Lower values tend to have negative effects on mucous membranes of upper respiratory tract leading to dryness which in turn cause them to lose their protective function against infections whereas higher relative humidity levels cause condensation, moistening at cool external walls and formation of mould [12]. The ASHRAE Standard 62-2001 recommends the relative humidity of 30–60% in an office environment and general humidity sensation varies with exposure time [39]. Humidity has been investigated in a number of field surveys in hot climates, and was found to have a significant effect on comfort temperature [24]. But, further research is still needed as the size of its effect is generally small, relative humidity being a relative value is mainly dependent on air temperatures and the fact that water vapor pressure being a more robust measure is not always recorded [24].

C. Indoor lighting environment

Lighting at work place also plays a very important role in improving the efficiency, safety and health of workers. It is said that workplace illumination is among the important parameters influencing worker's productivity in terms of speed, quality of work, downtime, absenteeism, and accident rates [40]. There exists a strong relationship between illuminance and task completion times as shown by Bennet et al., [41]. Recommendations regarding lighting of building interiors with respect to illumination levels required to perform visual tasks at acceptable standards are published by Illuminating Engineering Society (IES). Photometry is known as the science dealing with the measurement of light. The amount of light falling on a surface is termed as illuminance and the unit for measurement is known as lux. Light meter/luxmeter is used for measuring illuminance. The history of lighting recommendations suggested by experts is in fact very interesting. During the early period of last century, illuminance recommended was about 30 lux to 100 lux while by middle of the century (in 1940s) it was increased between 300 and 500 lux, and by 1972, illuminance recommended for office work in U.S. was fixed between 500 lux and 2000 lux [42]. In later quarter of the century recommended illuminance was similar to those recommended during 1940s but it is should be understood that expert opinions reflect the context in which they are suggested [42].

Light intensities in the range of 300 lux - 1000 lux are necessary for manual work and it was observed that lighting by ceiling mounted neon lights often caused headache, eye strain and fatigue [12]. Acceptable level of illumination was above 300 lux as found out in a field study in offices when the illumination intensity in the survey ranged from 93 lux to 1424 lux [9]. A study spanning 16 months reported significant increase in productivity levels of workers who were provided with controllable task lighting arrangement [43]. It is intriguing to know that installing new lighting system may improve the performance of people on account of its impact on visual performance, visual comfort, visual ambience, interpersonal relationships etc [44]. Visual tasks in assembly and inspection tasks like rough work, medium work, fine work, very fine work require 200, 400, 900 and 2000 lux respectively [45]. The recommendations given by Bureau of Indian Standards (BIS) for lighting are found in the following standards. Code of practice for day lighting of factory for different types of industrial buildings and process is given in IS: 6060:1971, Reaffirmed 2004 [46]. Code of practice considering interior illumination for various type of working interiors/activity can be found in IS: 3646 (Part I): 1992, Reaffirmed 2003 [47]. IES recommended higher illumination levels than the European guidelines which indicate the difference of opinions among experts. This is evident from the fact that German DIN prescribes 1000 lux for precise assembly works while IES recommends 3000 lux for the same [48].

D. Noise

Noise has a negative impact on the working efficiency, harms the hearing faculty and annoys the people who are exposed to it [49]. The units used to measure the frequency and intensity of sound is known as hertz (Hz) and decibel (dB) respectively. Measurements can be made using sound level meters (as prescribed by International Electrotechnical Corporation) [50], noise spectrum meter [9], noise dosimeter (instrument worn by the worker) and octave noise analyzer (capability to read output noise levels in dBA and availability of different weighting built in filters). Sound level meters have three types of weighting the sound which are known as A, B and C scales of which dBA scale (or weighting function) is widely used in industries [48]. Occupational Safety and Health Administration (OSHA) regulations in USA have put forward a formula to measure the noise exposure of different intensity [48].

In United States of America it has been regulated to limit noise exposure to 90 dBA for an 8 hour period while in Greece it is suggested that 80 dBA exposure dose is harmless while 85/90 dBA is termed as guide number but, reliability of these exposure limits is debated among the scientific fraternity [51]. ISO specifies the maximum acceptable noise dosage of 85-90 dBA with a maximum exposure time of 8 hours/day and 5days/week (40 hours/week) [52]-[53]. As most of the industrial plants in developing countries work 8 hours/day and 6 days/week which amount to 48 hours/week, it was suggested that a limit be kept at 88 dBA (claimed to be consistent with ISO specifications) for steady noise [53]. The accepted level of noise was found to below 49.6 dB in a controlled field study (to assess the relationship between satisfaction level of acoustic environment and A-weighted sound pressure level) in offices when noise level in the investigations ranged from 44.3 dB to 65.4 dB [9].

In India, IS 15575 (Part 1): 2005 (superseding IS 9779:1981) which is identical with International Electro technical Commission (IEC 61672-1 (2002)) gives specifications for electro acoustical performance specifications for three different kinds of sound level meters [50]. The three sound level meters are conventional sound level meter that measures exponential time-weighted sound level, integrating-averaging sound level meter that measures time-average sound level and integrating sound level meter that measures sound exposure level. The methods of measurement of noise emitted by machines are addressed by IS: 4758-1968 (Reaffirmed 2002) which follows the recommendations made by ISO (495) dealing with the general requirements for preparation of test codes for measuring noise emitted by machines [54]. Taking assistance from ISO 2204-1973 (Guide to the measurement of airborne acoustical noise and evaluation of its effects on man), IS: 9876 – 1981 (Reaffirmed 2001) provides guide lines for measurement of airborne acoustical noise and evaluation of its effects on man [55].

IV. DISCUSSION AND CONCLUSION

A lot of effort has been made to formulate environmental standards for increasing productivity, performance, satisfaction and overall well-being of people working indoors. Standards pertaining to measuring instruments and measurement techniques backed by scientific validation have helped in according universal conformity in instrumentation and measuring practice. But there exists a remarkable variation in the recommendations made by organizations, individual studies and during different time periods. It is apparent that these variations are due to contextual influences, individual preferences, gender difference and adaptability of human beings, influence of subjective assessments, geographic and other factors associated with the subjects/human volunteers involved in investigations. Therefore, apprehensions are expressed regarding the universal adoptability of recommended standards.

Worker/employee is exposed to physical demands and work environment associated with job(s). This presents a strong case for taking the worker into confidence for ergonomic evaluations especially in industrial sector. This approach is labeled participatory ergonomics and its benefits have been well established [56]. Provision to personally control indoor environment improves thermal and visual comfort as well as satisfaction [18]. The need of the hour is location/country specific contextual investigations/research into indoor physical environmental factors. This will ultimately result in formulation of standards/recommendations which are industry/ location/ user (targeted) specific in nature. Governments across the nations should encourage research in this direction. Results obtained should be used for giving birth to national as well as local data bases. Such data bases will be of immense help to engineers/ designers/ ergonomists/ supervisors/ managers/ occupational health care professionals for designing or modifying facilities/layouts at any location. Any new industry/facility in any particular locality should be encouraged to adopt such recommendations and subsequently monitored through necessary enforcement initiatives. Thus, overall system design optimization for human well-being to make them compatible considering their needs, abilities and limitations, being the goal of Ergonomics/Human Factors can be realized on a global scale due to development of contextual location specific recommendations/standards and its subsequent application with respect to indoor environmental factors. Working population is sure to be benefitted by such initiatives.

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