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Colour as an Agent for Low Energy Design: A Field Experiment Implemented in Sri Lanka

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Abstract

The potential of incorporating theoretically-established cool colours within the interiors of a hot humid tropical climate – as an alternative strategy for energy conservation – was tested by this preliminary field investigation with reference to a garment factory in Panadura, Sri Lanka; ventilated using ceiling fans to achieve thermal comfort. It was hypothetically assumed that cool colours can psychologically induce a relatively cool thermal perception than the real thermal condition within inhabitants, leading to a reduction of the operational speed of ceiling fans, and thereby resulting in a reduction of cooling costs. The research examined the impacts of neutral (white), warm (red) and cool (blue) colours on the indoor thermal perception of factory workers by changing the colour of the internal walls of a selected work space by the use of coloured fabric. Fan speed in five progressive levels (L1-L5), corresponding to elevating levels of power consumption, was manipulated within 10 minute intervals until the subjects reached the thermally comfortable level. The study revealed a correlation between the interior colour and the preferred fan speed. 63.63% of workers were found to achieve their perceived thermal comfort with the maximum fan speed L5 in the controled white space while, 31.81 % and 4.5 % preferred L3 and L4 respectively. A majority of the workers (86.36 %) achieved comfort with L5 when exposed to colour red, demanding high energy consumption, while 13.63 % preferred a moderate speed (L3). When exposed to blue, 63.63 % were satisfied with L5, while 9%, 13.63% and 13.63% perceived thermal comfort in L4, L3 and L2 respectively. Blue was revealed to be the most supportive colour in achieving perceived thermal comfort at a comparatively lesser level of energy consumption. Incorporating colour blue in interiors was found to be favorable and red non-favorable for energy conservation in a hot humid tropical climate.

Keywords: Thermal perception, Warm colours, Cool colours, Hot climatic region, Garment factories, Energy conservation.

Introduction

The ever-increasing demand for energy consumption is known to be one of the major challenges faced by the contemporary world. Exploring innovative approaches for energy conservation to optimize energy consumption in the built environment has become one of the most extensively focused areas in the current global research sphere. Sri Lanka being a developing country, consumes fossil fuels, hydro power, wind power and solar power to fulfil its day to day power consumption.

The Sustainable Energy Authority of Sri Lanka, playing a major role in managing and conserving energy within the island, has requested most of the industries to reduce their energy consumption by using renewable energy sources and innovative mechanisms in order to optimize their energy usage in the built environment (Gunasekara, 2009). Being a country having a hot humid tropical climate, a considerable percentage of its energy is utilised for mechanical ventilation to achieve thermal comfort in building interiors. As clarified by Rim, Schiavon and Nazaroff (2015), high ventilation rates require substantial amounts of energy to cool and dehumidify supply air in tropical climates. A range of environmental and personal factors will work together contributing to the perception of thermal comfort. The environmental parameters could be identified as air movement, humidity, radiant temperature and air temperature, while the personal parameters have been identified as clothing and metabolic heat generation (Fanger 1982; Parsons 2003; ASHRAE 55 Standards). Transcending beyond the conventional ways of meeting the comfort threshold using energy-intensive mechanical interventions, diverse design strategies are now being tested with an optimized energy consumption. This is implemented via incorporating natural ventilation to the maximum by appropriate orientation, spatial planning and reducing heat gain by appropriate construction technology, building materials and finishes. The concept of adaptive thermal comfort is an emerging approach in harnessing natural ventilation in buildings (Olesen. 2000), which allows the occupants to have the control over their immediate environment to survive in a wider range of thermal conditions beyond the fixed comfort zone.

Meanwhile, the definition of 'Thermal comfort' is being re-questioned by many scholars beyond its long-established conventional understanding of a physiological response to be a psychophysiological response. There is increasing evidence which support that thermal perceptions are affected by factors that are not recognized by current comfort standards. These factors include thermal history, non-thermal stimuli and psychological expectations [Humphreys (1996); Karyono (cited in Ogoli 2007)].

Accordingly, the potential of psychologically manipulating the perceived thermal condition against the real thermal condition can be recognized as a latest development in this respect. Within this context, the current investigation attempts to test the possibility of integrating psychologically-induced thermal impacts of colour as a novel alternative strategy of energy conservation; within interiors of hot humid tropical climate as Sri Lanka.

Supportive Literature

Colour is electromagnetic energy (300nm -700 nm) perceived via the visual sense. The use of colour in built environment is presently limited to aesthetic and visual purposes only where the potential of colour to manipulate human feelings, emotions and behaviour is barely utilized.

"Colour is an integral element of our world, not just in the natural environment but also in the man-made architectural environment. Colour always played a role in the human evolutionary process. The environment and its colours are perceived, and the brain processes and judges what it perceives on an objective and subjective basis. Psychological influence, communication, information, and effects on the psyche are aspects of our perceptual judgment processes. Hence, the goals of colour design in an architectural space are not related to decoration alone" (Mahnke, 2015).

Accordingly, transcending beyond the typical decorative beautification value, colours can be integrated in built environment to enhance psychological and physical behaviours of human beings, in a positive way to enhance optimum existence. This investigation focuses on a unique aspect of colour psychology; colour associated thermal perception to manipulate perceived thermal environment of hu-man beings.

Over time, colours have been explained in thermal terms (Ballast 2002 cited in Daggett at el., 2008; Mahnke 1996). The 'colour wheel' identified in the theory of colour, distinctively differentiates between warm colours and cool colours. As explained by Stone (2001) and Ballast (2002), red, orange and yellow are perceived as warm colours which are having a stimulating impact on the human body, while blue, green and purple are perceived as cool colours having a pacifying effect. As per Mahnke (1996), people are found to be fairly unanimous in their opinion of colours that visually induce either effect.

As cited in Mahnke (1996), Scheurle (1971) reported that most test subjects perceived a red room to be significantly warmer than a blue counterpart, although temperature settings were the same for both. Hettiarachchi (2014) researched on the logic behind manifestation of colour associated thermal perception with reference to red and blue colours in a controlled laboratory environment (26^{o}C/ 50% rh /350 lux) testing three hypothetical sub questions; the possibility of thermal perception triggered by colour stimuli to be an actual thermal sensation, a biological response (alteration in core body temperature) or a psychological response. The psychological parameters were statistically significant against the parameters of actual thermal sensation and core body temperature and thus, the study statistically established the fact that thermal perception associated with colour is a psychological response. Accordingly, it is assumed that people may tend to be psychologically manipulated by the thermal impacts of colour and demonstrate relevant behaviour. Following up this theory, a preliminary field experiment was executed by Welitharage & Hettiarachchi (2014) to investigate the impact of a warm colour (red-Cranberry Zing) and a cool colour (Duck egg blue) on indoor thermal perception within a tropical upland climate in Thalawakele, Sri Lanka; characterized with a cool thermal condition. Participants consistently perceived red room to be warmer (90% - warm and 10% - slightly warm) and blue room to be even cooler (64.5% - cool/ 29% - slightly cool) than the real thermal condition. Red was found to be highly supportive to psychologically induce a warmer thermal perception than the real condition in this tropical upland climate, potentially reducing cooling costs.

Itten (1970) observed a clear difference of 5-7 degrees in the feeling of heat or cold between a workroom painted blue-green and one painted red-orange. The occupants of the blue-green room felt that 59^{o}F was cold, whereas the temperature had to fall to 52^{o}F in the red-orange room before the subjects felt cold. Mahnke (1996) reporting the findings on Clark's experiment states that the employees complained of the cold, although the thermostat was set at 75^{o}F in an air-conditioned factory cafeteria with light-blue walls. Once the walls were repainted in orange maintaining the same temperature setting (75^{o}F), the interior was perceived by the employees to be too warm and therefore, it was reduced to 72^{o}F - a three degree difference which consumes more energy. People tend to set the thermostat four degrees higher in a blue room than in a red room (Porter and Mikellides as cited in Mahnke 1996), signifying the less heating energy required in a red room to achieve perceived thermal comfort due to psychologically-induced warmth, and vice versa in the blue room. The said ability to induce a psychologically altered thermal perception against the actual thermal sensation explains a synesthetic link according to Mahnke (1996), between two sensory modalities (visual and thermal), which may work together to conserve energy. This is an entirely novel approach in terms of energy conservation in the Sri Lankan context.

Energy Usage in Industrial Buildings with Reference to Sri Lanka

Amidst the diverse building typologies involved in energy usage, the current investigation has significantly focused on 'Industrial buildings' characterized by their high level of energy consumption, which critically demand strategies for energy conservation. An 'Industrial building or structure' is defined as a factory, laboratory or other similar premises for the purposes of a trade, carried on in a mill (Taxes Consolidation Act Number 39 of 1997). According to Dheerasinghe (2003), a large amount of energy is used by industries to power various processes in a vast range of manufacturing and resource extraction. According to Ceylon Electricity Board (CEB) Statistics for years 2013 and 2014, the domestic (33.4%, 32.4% respectively) and industrial (31.5%, 31.6% respectively) sectors are reported to have the highest percentages of electricity sales (by TARIFF). The overall electricity consumption trend of the industrial sector demonstrates a drastic increase from 1970 (500 GWH) - 2004 (2,750.00 GWH) (CEB Statistics). As further clarified by CEB, food and beverage, leather and textile are the industry sectors that consume the highest amount of electricity. The ever-increasing requirement for energy in the industrial sector, demands a unification of all the possible alternative and hybrid options to optimize energy efficiency. The current study probes into the garment industry in this regard.

Garment Industry in Sri Lanka

The garment industry plays a vital role in Sri Lankan economy. As explained by Dheerasinghe (2003), it has become Sri Lanka's largest export industry since 1986. More than 330,000 direct employments have been created by this industry. 5% of country's total employment is represented by the garment factories. According to Dheerasinghe (2003), the garment industries are identified in four main categories based on the number of employees – small (0-100), medium (101 – 500), large (501-1000) as well as extra (above 1000) – and the energy demand may drastically vary based on this classification. The current study is focused on a small scale garment factory.

Fan usage in the Garment industry in Sri Lanka

Achieving a thermally comfortable environments to optimize worker efficiency and productivity in garment industry is critical in Sri Lanka, characterized by its hot humid tropical climatic conditions. Thermal environment of a factory interior may be determined by the heat produced by the equipment, machinery, lighting and also body heat generated by the workers.

Small scale garment factories in Sri Lanka, to a greater extent, have been observed to choose ceiling fans against air conditioners in achieving a thermally comfortable working environment, mainly based on the affordability. Fans are well known to be a cost-effective option for reducing air conditioner electricity demand (U.S. DOE & U.S. EPA 2010 as cited in Sathaye et al., 2012). Thus, the energy efficiency of ceiling fans is an important area to address in reducing the overall energy consumption in the garment industry.

Ceiling fans are electrically powered and designed with variable speed control; 1-5 speed levels in general terms. They introduce slow movement to still and hot air in interiors, for the inhabitants to feel thermally comfortable by means of evaporative cooling. Having controllable speed levels, fans are designed to achieve comfort within a range of thermal conditions. The fans should be able to operate at the minimum speed level and increased up to its maximum level when necessary to achieve comfort in a worst case scenario. However, in realistic situations, fans in most occasions, are being operated at the maximum speed.

Connection between fan speed and energy consumption.

A main theoretical supposition considered in this investigation is that fan speed has a direct correlation to power consumption. Even though the energy consumption may vary per speed level based on the design and the brand, it can be generalized that the fan speed is directly proportionate to the energy consumption. This line of thinking is substantiated by the graph above, which represents power consumption of three types of fans against the speed of which they operate. Accordingly it is necessary to find strategies in order to design

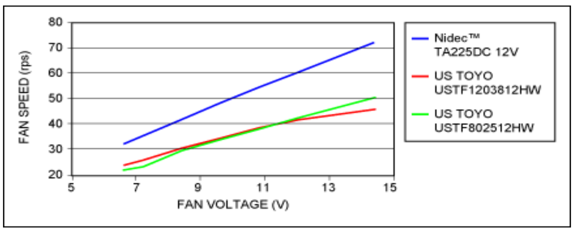

Figure 1: Fan Speed Vs Fan Voltage (12V-rated fans).
Source: http://www.maximintegrated.com/en/app-notes/index.mvp/id/1784

factory interiors in such a way that comfort can be achieved by maintaining the fan speed at lower levels to reduce power consumption.

Research Gap

Based on a research carried out in India, Sathaye et al., (2012) stated that ceiling fans contribute significantly to residential electricity consumption, both in an absolute sense and as a proportion of household consumption in many locations; especially, in developing countries, in warm climates. However, there has been little detailed assessment of the costs and benefits of efficiency improvement options for ceiling fans. The economic and engineering literature as well as data on ceiling fan energy consumption or efficiency improvement options are sparse (Sathaye et al., 2012).This statement could be directly applied to Sri Lankan context and further, to the garment industry. Accordingly, the need for alternative/hybrid strategies to optimize energy usage with reference to ceiling fans in Sri Lanka with special reference to garment industry, is vital. Despite the factor of colour being well established for thermal impacts, less attempts have been made to integrate it as an energy saving tool in the built environment. The minimum number of scholars who have worked on this paradigm have focused on the possibility of thermal impacts of colour to manipulate the perception of a fixed thermal environment regulated by the air conditioners as claimed by Itten (1970), Clark (1975) as well as Porter & Mikellides (as cited in Mahnke, 1996). However, no recorded literature is found on the investigations done to integrate colour to improve cost efficiency of ceiling Fans.

One study by Hettiarachchi (2014) recommended the integration of colour to psychologically manipulate the perceived thermal environment; against actual thermal condition to alter the comfort zone. As a follow-up research, the current investigation attempts to fill the aforementioned research gaps simultaneously by developing the usage of applied colour to psychologically manipulate the perceived thermal condition against the actual thermal condition; as an effective and affordable hybrid method of conserving energy spent on ceiling fans in industrial buildings.

Hypothesis

It is assumed that introducing the thermal impact of colour may be a psychological trigger to physically alter the fan speed by the factory workers. Following the supposition that fan speed is directly proportional to the energy consumption, the current study hypothesizes that cool colours (blue) integrated in factory interiors of a hot humid tropical climate may psychologically induce the workers to perceive the interior as comparatively cooler than the actual thermal condition, and operate the ceiling fan at a comparatively low speed level than the level corresponding to the real situation. Cooler thermal perception psychologically induced by a cool colour in an interior of a hot humid tropical climatic condition can compensate the energy to be spent on cooling the interior to some extent; a hybrid remedy for energy conservation.

Aims and Objectives

The aim of the research is to test the above hypothesis via conducting a preliminary scientific inquiry. The objective of the research was to seek the possibility of integrating the psychological impacts of colours to have a favorable effect on the perceived comfort levels of the workers within an industrial environment.

The findings of this study may establish the importance of colour selection as a decisive factor in the process of formulating energy efficient design strategies, and open up new avenues for architects and designers who are seeking novel/hybrid design strategies to improve thermal comfort in warm climatic environments.

Limitations

Amidst the established diverse environmental and personal parameters contributing towards thermal perception of humans (ASHRAE 1966), the study limits itself to the impact of colour on the perception of thermal environment. Accordingly, a neutral colour (white), a warm colour (red) and a cool colour (blue) was tested. Investigation was limited to a small scale garment factory located in Panadura (Western Province) characterized by a hot humid tropical climate, fulfilling below conditions.

- Usage of ceiling fans as the mode of mechanical ventilation: As workers were physically and psychologically conditioned to the interior thermal environment maintained by the ceiling fans with a fixed level of fan speed over the years, the slightest change introduced in the thermal environment was assumed to have a psychophysiological impact.
- Sufficient enough participants to generate an accurate result: the selected space to conduct the experiment accommodated 22 workers.
- Communication ability of the research participants; this is a major necessity when it comes to obtaining personal views and opinion; questionnaire survey.
- Easy accessibility, negotiability and freedom given to change the colours and implement the study amidst the ongoing factory operation at a time of peak production.

The research subjects were limited to females as there were no male workers involved. The period of investigation was reduced to 6 working days in order to respect the busy schedule of the garment factory. Based on the time schedule for the research, the implementation was carried out during the festive season in Sri Lanka during the month of December, where the production process of the garment factory was at a peak, and the climatic conditions are at a coolest point. Accordingly, the testing time was limited only to 50 minutes of each of three working days.

Even though colour application on walls could have been the best method to come up with more significant results, considering the inconvenience to be caused by such an interference to the ongoing schedules during the peak production season, and the cost factor involved in colour application, the investigation was limited to changing the wall colour using coloured fabric.

Method

CSN garment was the selected case which is situated in Panadura, a district located in the Western province of Sri Lanka. The area can be considered to have hot humid tropical climatic conditions. The investigation was carried out in the month of December 2014 and the average monthly temperature values for day and night temperatures in Panadura were reported to range between 94.4°F (34.6°C) - 80.1°F (26.7°C) respectively.

A preliminary questionnaire survey was conducted initially to test the eligibility of participants to go ahead with the investigation, while comprehending their background with special reference to their perception of the existing thermal condition as well as the preferred fan speed to reach the comfort level.

Research Design

The experimental space was rectangular in form, ventilated using 10 nos. of ceiling fans of identical brand/specification and lit up with fluorescent lights. The space was selected based on the best possible level of controllability by the investigator compared to other spaces of the factory interior. All sources of temperature generation (light fittings, machinery etc.) within the selected space was common throughout the investigation. 22 female factory workers aged between 20 to 50 years took part in the study.

Colour of the work space was the independent variable of the investigation. Accordingly, the three walls which define the visual angle of the workers (wall A, B and C) of the interior were subjected to colour change; white, red and blue respectively. Walls A and C have openable glazed Aluminum windows at its full length, fixed at a height of 5ft, which enable cross ventilation through the space and the ceiling fans generate movement to this air flow to create a thermally comfortable working environment. These windows also provide natural lighting to the space throughout a considerable time during the day. The open area of fenestration and operation of heat generating machinery (Juki Sewing Machines, irons) throughout the experimenting time was fixed and identical during the three colour exposure situations. Heat generated by lighting was not involved as the investigation was executed during early morning from 9.00 a.m. - 9.50 a.m., with natural daylight.

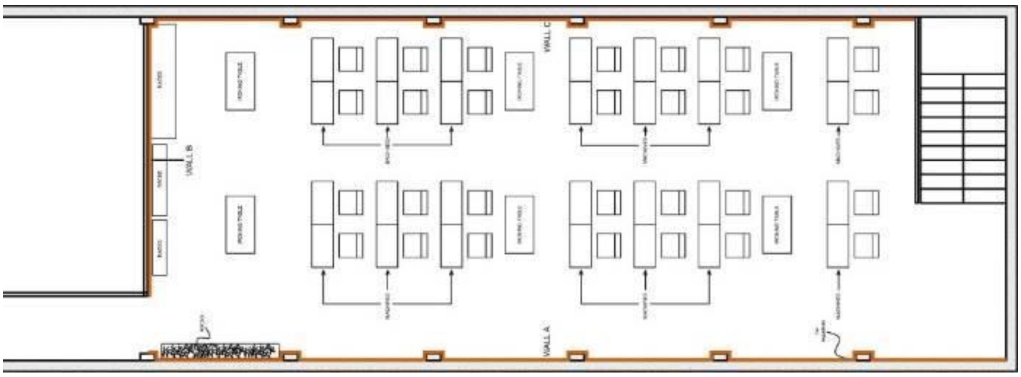

Figure 2: Plan View of the Experimented Area Source: Author (2014).

The selected areas of the walls A, B and C which cover the visual angle of the workers were covered using fabric of white, red and blue respectively. In the process of changing the colour of the interior, as the initial step, plywood boards (2.5 mm thick) covered with white filler were temporarily pasted on the walls to minimize the possible damages to the surface by nailing/drilling. White wall filler was used as a preliminary coat to achieve a pure white surface on the plywood boards. The fabric was fixed on the boards afterwards. The fan speed – the dependent variable of the investigation – was recognized in 5 levels; L1, L2, L3, L4 and L5. The surface temperature (SFT) of the three coloured fabric surfaces were measured by the FLIR I 60 infra-red camera using fixed measuring points located in a grid pattern to understand the nature of heat emittance/reflectance associated with different colours. Indoor temperature (IT) and outdoor temperature (OT) of the factory were monitored during the experiment using a thermometer. The 5-point semantic differential scale was used to record the response of the participant to the perceived level of thermal comfort.

Figure 3: Work Space in Three Experimental Situations Plan Source: Author (2014).

The investigation was carried out within 6 working days. The participants were exposed to the introduced white colour fabric throughout a full working day (d1) and the measurements as well as responses were recorded the following day (d2), within a period of 50 minutes (9.00 a.m. – 9.50 a.m.). Red colour fabric was introduced afterwards and the subjects were exposed to red for a full day (d3) similar to the exposure to white, and the responses were recorded the following day (d4) during the same time duration. The same process was repeated with reference to colour blue (d5 and d6). The fan speed was changed in 10 minute time intervals throughout the experiment starting from the lowest (LI) to the maximum (L5); (L1: 9.00 a.m – 9.10 a.m, L2: 9.10 -9.20, L3:9.20 a.m -9.30 a.m, L4: 9.30 a.m – 9.40 a.m and L5: 9.40 a.m – 9.50 a.m), and the workers were requested to identify the most fitting fan speed to reach comfort level in each colour exposure.

Results and discussion

Analysis - Preliminary Questionnaire survey

Since the majority of participants have worked in this garment factory for more than a period of one year, consequently they are considerably conditioned to the existing thermal environment, and supposedly sensitive to the slightest change. Eye sight being a determinant parameter for colour perception was considered. As 65 % of the subjects were found to be normal sighted, 23 % long sighted, while 40% were short sighted, the contingent in question was advised to wear correctional lenses during the experiment for valid results. The Ishihara test was conducted to identify subjects with colour blindness, and none of them were diagnosed to be colorblind.

The existing thermal condition was neutrally perceived by a majority (73%) supposedly by a homeostasis equilibrium achieved due to prolonged exposure. However 28% perceived the existing condition as warm (14% very warm and 14% warm). Supportive to the homeostasis reaction, 68% of the workers remained neutral in terms of thermal comfort, whereas 9% was satisfied. On the contrary, 23% were dissatisfied in terms of thermal comfort in the existing situation. As revealed by the preliminary questionnaire survey, a majority of participants demonstrated to be conditioned to the existing thermal condition. However, a majority (91%) requested neither a warm nor cool/neutral thermal environment as the desired thermal comfort level (thermal neutrality) as suitable to work effectively in the factory, when 5% requested a cool condition while another 5% suggested to have a warm condition.

The fan speed which they were used to reach the comfort level in the existing situation was investigated. All the subjects (100%) reported that they are allowed to control the speed level of the fan as per their wish. Alarmingly, the majority (82%) of the subjects reported that the fans are being operated in its maximum speed-L5 to reach the comfort level at the existing condition. Only 18% subjects reported to reach the desirable comfort level in L3. It was noted that the lowest fan speed levels L2 and L1 which consume less energy has not been used.

It was interesting to reveal that even though a majority (82%) choose level L5 to reach the comfort range, their personally preferred fan speed represented a fair cross section of all the 5 speed levels (9% -L1, 14% -L2, 27% -L3, 14%-L4 and 36%-L5). Further, none of them personally preferred very high or high air movement. 59% preferred a medium air movement, while 36% and 5% preferred low and very low air flows respectively. Accusingly, their personal preferences which deem to be superseded by the hot, humid thermal conditions for a majority to operate the fans in the maximum speed level.

Indoor and Outdoor temperature

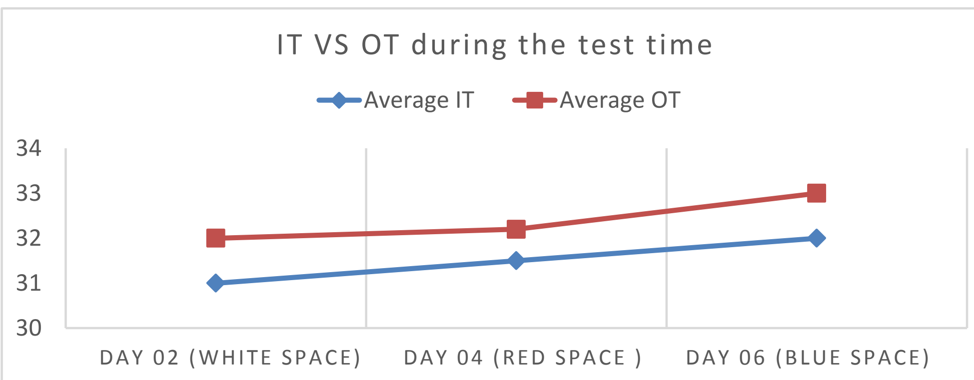

Figure 4: Comparison of Average IT vs OT Source: Author (2014).

It should be noted that IT and OT were beyond the control of the investigator. Unlike a controlled laboratory condition, being a factory space which is naturally lit and ventilated in a real life situation, OT has a direct bearing on IT. It was found that OT was higher than IT and the average temperature difference between the indoor and outdoor temperature between 9.00 a.m. - 9.50. a. m. on the three days that the investigation was conducted were 1o C, .7 °C and 1°C respectively (overall average 0.9 °C). The lowest IT was reported in the white interior (31°C) and the highest IT was recorded in the blue interior (33°C). Red interior was found to have an in-between IT (32.2 °C). Accordingly, it can be predicted that the blue space would have been perceived as warm and fans may have operated in a high level to reach thermal comfort than red and white exposure. White space could have been perceived as the coolest having the lowest IT.

Surface Temperature

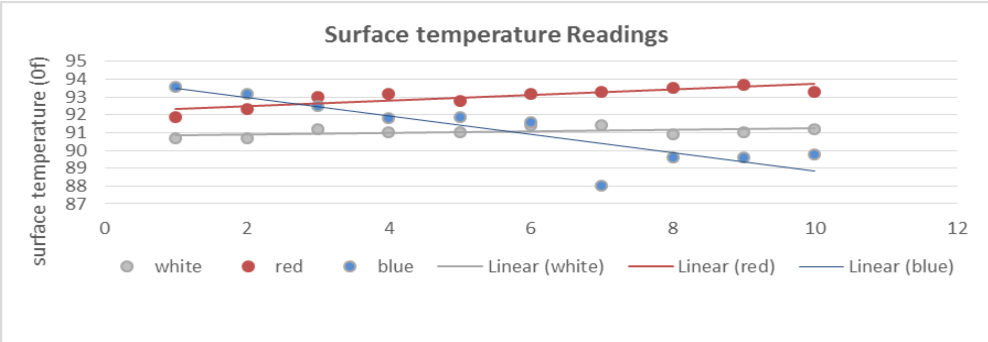

Figure 5: Surface Temperature Source: Author (2014).

Colours absorb and retain heat in various degrees, depending on their light-reflecting ratio (Mahnke, 1996). Surface of the white fabric was found to have the lowest average SFT (91.05°F) as per the infrared temperature readings; supposedly due to the highest reflectance value whereas surface of the red fabric is reported to have a higher SFT (93.02°F) than white surface (1.97°F difference) having a comparatively high absorbing value than white. In the light of physics, the trend line of blue could have been between white and red. However, a deviation can be seen in the blue colour trend line which signifies an error of the measurements. Accordingly, the finding related to SFT of Blue fabric is erroneous and was not included for the analysis. However, based on the tread lines of red and white, it can be suggested that the white surface reflects more heat back to the interior due to high reflectance value compared to red that absorbs heat. Thus, the white space should be perceived as warmer than red.

Thermal Perception Vs. Fan speed.

Thermal Perception Vs. Fan speed – White Space (Reference space)

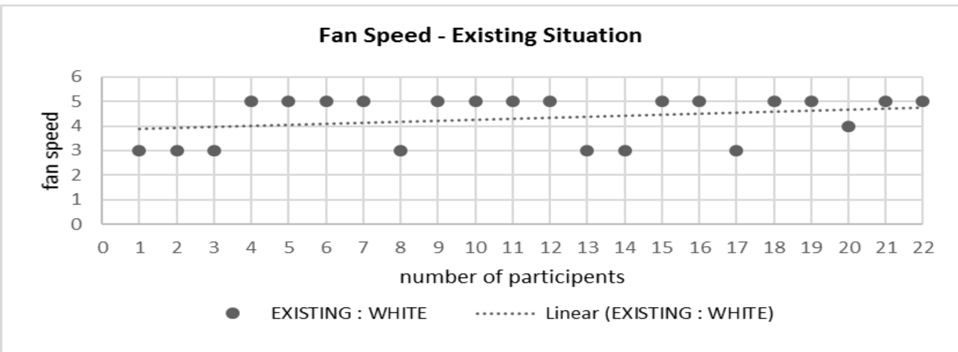

Figure 6: Fan Speed vs Thermal Perception – White Source: Author (2014).

The majority of workers (63.63 %) were found to achieve their thermally comfortable level with the maximum fan speed – L5 when working in the control white space while, only 31.81 % preferred a moderate speed – L3 and 4.5 % was found to be comfortable in L4. None of the workers preferred to use the energy efficient low levels L2 and L1. The trend line of fan speed level in white exposure lies between L4-L5.

Thermal Perception Vs. Fan speed – Red Space

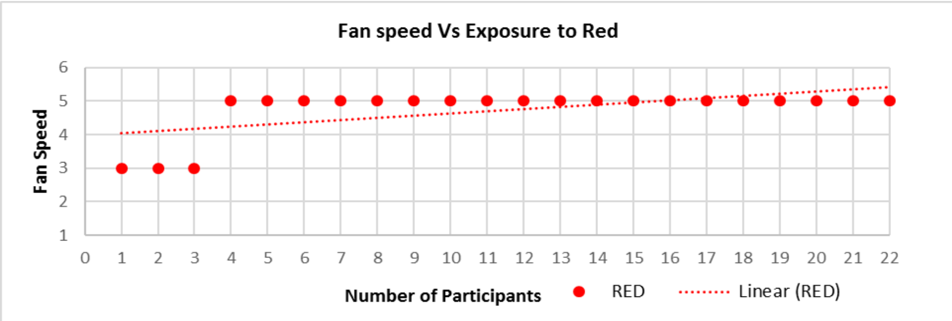

Figure 7: Fan Speed vs Thermal Perception – Red Source: Author (2014).

The majority of workers (86.36 %) were found to achieve their thermal comfort with the maximum fan speed – L5 when exposed to red coloured space demanding high energy consumption, while only 13.63 % preferred a moderate speed –L3. The trend line drives from L4 exceeding beyond L5, signifying high energy consumption. Accordingly, the energy consumed to operate ceiling fans to reach the thermally comfortable level is comparatively high in red space against white space. However, it can be argued that this finding is correlated to the indoor temperature which is reported to be 0.5 ^{o}C higher in the red space (31.5^{o}C), compared to the white space (31 ^{o}C). It is worthwhile to mention here that the workers insisted to remove the red fabric soon after the experiment due to the perceived warmness was over, which in turn, disturbed their work efficiency.

Thermal Perception Vs. Fan speed – Blue Space

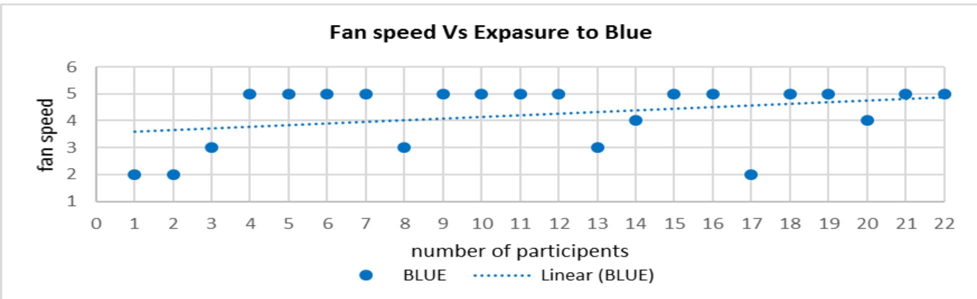

Figure 8: Fan Speed vs Thermal Perception – Blue Source: Author (2014).

Comparable to the white space, 63.63 % workers were satisfied with L5. However, a tendency to prefer low speed levels than white and red spaces to achieve comfort was demonstrated; 9%-L4, 13.63-L3% and 13.63 % - L2. Blue colour has significantly influenced the same group of workers than other colours, for 13.63% of them preferred L2. This remarkable finding correspond to a background where the blue interior was found as the warmest (IT-32^{o}C), characterized by the highest reported outdoor temperature (OT- 33^{o}C). Even though usage of maximum fan speed (L5) could have been expected in the blue space, the presence of blue colour has psychologically altered the perceived thermal condition against real warm condition for these group of workers to reach comfort, while consuming comparatively less energy compared to red/white exposure.

Colour Exposure Vs. Fan speed – Comparison Between White, Red and Blue

When comparing the trend lines of the three colour exposures, it was revealed that trend line representing red exposure distinctly stands at the highest position representing the maximum energy usage against white and blue. Although trend lines representing blue and white exposures are positioned very closely, yet, a large percentage of the blue line stands distinctly below the white line.

Accordingly, manipulating the speed levels of the ceiling fans to achieve thermal comfort was found to have a correlation to the colour of the interior. Based on the hypothesis, the corresponding energy consumed to operate the fans was found to increase from blue, white to red respectively.

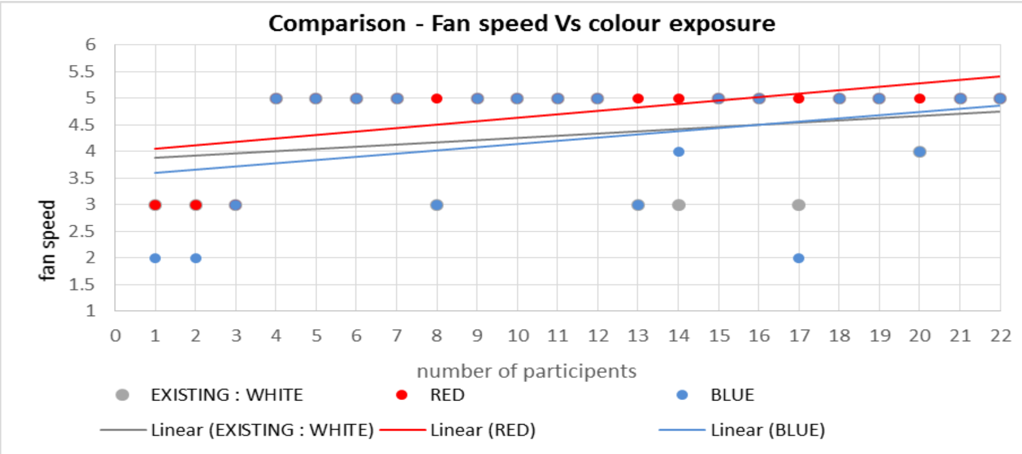

Figure 9: Colour Exposure Vs. Fan Speed – Comparison Source: Author (2014).

Conclusions

The objective of the research study was to see if colour can be used as an energy conservation tool in garment factories – characterized with high energy consumption – in the Sri Lankan context represent-ing a hot humid tropical climate. The study reaffirmed the correlation between colour and human thermal perception. Based on the choice of fan speed, it was evident that the factory workers perceived the red interior as comparatively warm and blue as cool even if the average indoor temperature of red space (31.5 ^{o}C) was found to be 0.5 ^{o}C less than that of the blue space (32 ^{o}C). Accordingly, it can be explicated that overriding the physically transformed thermal information or regardless of the actual indoor thermal condition, the visually-transformed, psychologically-induced thermal impact of colour has made the subjects feel warmer in the red space and cooler in blue space. Accordingly, the study established a distinct relationship between the interior colour and choice of ceiling fan speed levels leading to the correlation between colour and energy conservation.

Thermal impact of blue has allowed the participants to prefer different fan speeds to meet their personal comfort levels compared to red. Accordingly, the psychological impact of blue has overridden the real thermal condition which is comparatively warm (32 ^{o}C); enabling the workers to perceive the space as cooler than the red space.

The comparison between trend lines affirmed the aforementioned explanation. For instance, the trend line which represents choice of fan speed in the exposure to red was positioned on top, while line representing blue was at the bottom. Accordingly it can be established that red colour (warm colours) when integrated in warm thermal conditions may aggravate the energy consumption due to the psychologically-induced warm perception that overrides/ amplifies the processing of thermal information corresponding with real thermal condition. Thus, this is highly disadvantages and needs to be discouraged. Referring to the trend lines, it is evident that the psychologically-induced established cooling impact of blue is highly supportive for the perception of a comparatively cool thermal level to reach the comfort level amidst the actual warm conditions. The vital observation in the trend line comparison is that blue exposure has been able to shift the comfort zone by dropping one speed level in average, which can potentially contribute to a quantifiable impact on energy savings when applied in a mass-scale in the garment industry. Accordingly, incorporating colour blue or cool colours in general was found as a highly favorable, cost effective alternative strategy of energy conservation in a hot humid tropical climate.

It is suggested to follow up the findings in a long term basis with a larger sample size representing both male and female participants of different socio-cultural, religious, age categories, and in controlled conditions within a range of building typologies. Further, it is suggested to test the average impact of an array of temperature fluctuations throughout a given year. Application of paints/pigments against the usage of colored fabric is suggestive to increase the credibility of the research. Supported with future research, utilization of cool colours in the interiors can be established as a policy/ guideline of low energy design, to be followed as a novel strategy in future design interventions in Sri Lanka.

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