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Analysis of Indoor Air Quality of a Multi-storied Residential Kitchen in the Tropics

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ABSTRACT

Human body has a thermo receptor which is non-specialized sensory receptor that has relative changes in temperature. Thermal comfort is a very important element for human body so as indoor air. But the good indoor air quality and thermal comfort in the kitchen is often forgotten even though kitchen is an important part of every residence. Cooking in the kitchen is a routine activity which is done from the morning to the evening in most of the tropical countries. But the domestic smoke exposure and thermal strain caused by the kitchen environment for a long period of time increase the risk of common and serious diseases of the users. The aim of the study is to analyse the Indoor Air Quality (IAQ) and thermal comfort of the kitchen environment in the tropical climate and its impact on human health. One residential kitchen of a multi-storied building is observed on the basis of some Subjective Judgment Scales (SJS) including the Air Temperature, 0C (AT), Relative Humidity, % (RH), Indoor Air Quality Index (IAQI), Blood Pressure (BP), Pulse Rate (PR) and overall thermal sensation of the occupant at different conditions. Then the physical environment of the kitchen was analysed through digital documentation and simulation which included poor ventilation, presence of highly heat conductive surfaces etc. A questionnaire survey has also been conducted on 25 families regarding thermal comfort in the kitchen environment and to analyse how the Indoor Air Quality (IAQ) of the kitchen imposes severe health impacts on its users leading to some major health issues. The results indicate that the longer exposure to the heated kitchen environment directly affects the Indoor Air Quality (IAQ) of the kitchen for which the users are experienced with extreme thermal discomfort contributing to their degrading health conditions.

INTRODUCTION

Thermal comfort has a significant influence towards human body. It is a heat balance between human and environment occupied. Human also has a thermo receptor, a non-specialized sensory receptor that has relative changes with temperature. This sensory acts to convey information to the brain in which the brain will give order to maintain human body's temperature stable at 37+/-0.50C under different climatic conditions. It is necessary so that the organs can perform its functions well. Some factors that affect human thermal comfort are clothing, climatic condition and physical activity (Rahmillah *et al.*, 2017). Kitchen is an important part of a home. It is one of the few rooms that must exist in a residence. It is not just a place to prepare food but it can also be used for recreation, family communication or even working for a certain job. Culturally, women in American society have been expected to cook. As the saying goes, "a woman's place is in the kitchen." (Cooper, 1998c). There is a cultural expectation that women are biologically more "nurturing" of the sexes and the better way to nurture the family is through the nourishment of a home cooked meal. Moreover, along this line of thinking, the mother is the most suitable person to complete such a domestic task. To simplify, that it is a woman's role to take care of the house, the cooking, and the children while the husband is out of the house with a career and salary. (Platzer, 2011b). Same is the case for the South Asian countries of the tropics. A country like Bangladesh where majority of the people are Muslims, are used to have a food culture that involves cooking in gas-stoves rather than in microwaves. Common meals including Rice, Dal, Meat etc. are usually cooked on gas-stoves for which most of the houses in Bangladesh have a designated area for a kitchen. The way in which food is prepared, consumed and shared, as well as when and by whom, tells much about the links between religion and social context of a particular place. (Fadil and Fernando 2015; Schielke 2015; Schielke and Debevec 2012). It also considers the way in which the domestic, intimate spaces of home, family gatherings, and community spaces are embodied, materialized and memorialized in the preparation, distribution, and consumption of food (Baderoon, 2002). But people are very much focused on areas like private rooms, a family living room and even in some cases on bathrooms but not in the kitchen, both in terms of design and maintenance despite its crucial importance. However, kitchen is also a contributor to the discomfort because it causes odour and smoke while cooking and increases the heat surrounding the room. Again humans are always exposed to the air and atmospheric contaminants, both gaseous and particle matter (PM) at each time he breaths. These Particle Matter (PM) is associated with causing the most adverse health issues. Along with particular matter

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(PM), carbon monoxide (CO) is equally toxic since it reacts with blood and converts it into carboxihemoglobin leading to cardio-vascular abruptions. The concentration of particular matter (PM) intensifies with the rise of temperature from cooking of oil and food (Chiang *et al.*, 2000). Again, carbon dioxide (CO2) of the ambient air absorbs heat and the temperature of the kitchen keeps rising around the kitchen appliances as most of them are major heat sources such as gas stoves, microwaves etc. (Chowdhury *et al.*, 2012). This high temperature of kitchen leads to thermal strain in kitchen which is related to the health status of the kitchen user associated with acute blood pressure, heat stroke, heart-disorder and blood circulation problem. It can also cause unsafe conditions, discomfort, performance deterioration and other harmful health hazards. (Haruyama *et al.*, 2010). The purpose of the study is to observe the Indoor Air Quality (IAQ) of kitchen environment and to analyse the corresponding health impacts on the users. In order to analyse the Indoor Air Quality (IAQ) of the kitchen, several measurements were taken such as Air Temperature, 0C (AT), Relative Humidity, % (RH), Indoor Air Quality Index (IAQI). Blood Pressure (BP), Pulse Rate (PR) of the occupant at different conditions from a residential kitchen of a multi-storied building. The overall thermal sensation of the user was also monitored to understand the health impact of the Indoor Air Quality (IAQ) of the kitchen on its user. Also, a questionnaire survey was run on 25 families to analyse the thermal comfort of kitchen environment under different working conditions to justify the experiment. The experiment focused on both physiological aspect of the kitchen environment and its psychological impact on its users both of which had a serious impact on the health conditions of the users.

LITERATURE REVIEW

Thermal comfort is very important as it affects the perception as well as occupants' health and well-being. According to CIBSE (2010) 'overheating within a dwelling occurs when the actual indoor temperature for any given day is hot enough to make the majority of people feel uncomfortable'. This can also be experienced when the indoor temperature is exceeded long enough to make occupants feel unacceptably uncomfortable, linking overheating to one of the major reasons causing occupants' discomfort and dissatisfaction in the thermal environment. According to CIBSE (2006), for overheating not to occur within a dwelling, the temperature threshold (25ºC/28ºC) should not be exceeded for more than a reasonable duration of hours (5%/1%) throughout the year. Furthermore, indoor temperature ranges 25°C-28°C during the summer can result in an increasing number of occupants feeling hot and uncomfortable, while the majority of the occupants will feel increasingly dissatisfied when the indoor temperatures stay at or above 25°C for long duration of hours in a day. (Adekunle, 2014). Previous studies showed that women had lower levels of perspiration and heat tolerance, a higher heart rate and rectal and skin temperatures than males, particularly when physical work was required, and elderly persons also showed the same results (Yousef *et al.*, 1984; Wolf *et al.*, 2022b).In order to maintain a constant and balanced body temperature which should be around 370C, body must dissipate all the surplus heat it produces due to metabolism to the environment. But women working in the residential kitchen of the tropical climate are always exposed to a highly heated environment due to working extremely close to gas stoves for which their body cannot dissipate the surplus heat it produces and unusual heat gain occurs. In Bangladesh, 90% of the women spend most of their lifetime within 6feet range from gas stoves. So, it is clear that the women of our country are at high risk of major health issues. (Li, 2001). Again, most of the residential kitchen in the tropics are poorly ventilated for which the humidity level is relatively high impeding body-heat loss by evaporation too. As a result, overheating continues, sweating starts, blood-pressure and pulse rate increases exposing the user into high-risk health issues. In order to testify the fact, physiological evaluation of the surveyed kitchen was implemented using Subjective Judgmental Scales (SJS) which included Ambient Temperature 0C (AT), Relative Humidity, % (RH) and Indoor Air Quality Index (IAQI) of the surveyed kitchen from which the thermal condition of the kitchen environment was analyzed and the user's response toward the thermal occurrence was recorded by measuring her Blood Pressure (BP) and Pulse Rate (PR). Kitchens are complex environments where Air Temperature, Relative Humidity, Radiant Heat and Air-flow interact (Matsuzuki *et al.*, 2011). There are no specific regulations or even parameters to guarantee that the thermal conditions in such environment are either comfortable or cost-effective (Simone & Olessen, 2013). The strength of this study is that it attempts to establish standardized methods and procedures for setting criteria that have to be met for the design and operation of a thermally comfortable tropical kitchen. The sample size was small, and there was a high response rate (95%). The environmental condition of the kitchen was measured using the Subjective Judgment Scales (SJS) using 5 in 1 meter (LM-8102) in a close observation. Such factors directly had an impact on the overall kitchen environment and heat strain faced by the kitchen user. To further measure the kitchen composition and its thermal condition, thermal image camera was used to get the best possible result where different magnitudes of heat strains generated by gas-stove were identified. Therefore, it should be regarded as a feasible study for assessing the heated working environment. There are several limitations in this study too. The survey was done during winter season for which the highest threshold of maximum Air Temperature, °C (AT) and Relative Humidity, % (RH) could not be plotted. Due to time and survey limitations, the study sample became smaller and only one tropical residential kitchen of a multi-storied building with a particular organization was recorded. The questionnaire survey also relied on verbal and written response only without any supporting physiological data of the kitchens used by the samples. The health measure of different women working in different kitchen scenarios of tropical Bangladesh could also not be documented. So it is evident from the results of this study that despite having few limitations and time constraint, some astounding outcomes were generated such as: the proportionate relationship between kitchen's thermal environment and its user's health condition which both deteriorated with time and longer heat exposure. This study correlated physiological measures of a kitchen environment with the psychological response of the user to identify the health risks caused by the poor Indoor Air Quality (IAQ) of a kitchen which has much to do with the overall spatial organization and the activity patterns of the kitchen in a tropical country. Due to lack of instrument, accurate magnitude of air velocity and wind-flow rate could not be plotted but this study combined the multifaceted aspects which included the nature, culture, spatial organization, environmental measures of a kitchen, all of which ultimately contributing to the thermal strain and major health issues faced by its users. The research clearly shows how the daily-life food pattern of a Muslim country like Bangladesh demands a longer duration of service in the heated environment of a kitchen which involves a good amount of time spent in front of gas-stoves and smoke which increases thermal strain and health risks of the user with the degrading physical environment of the kitchen, a situation worsen by poor ventilation and inadequate air-flow to dissipate the generated heat.

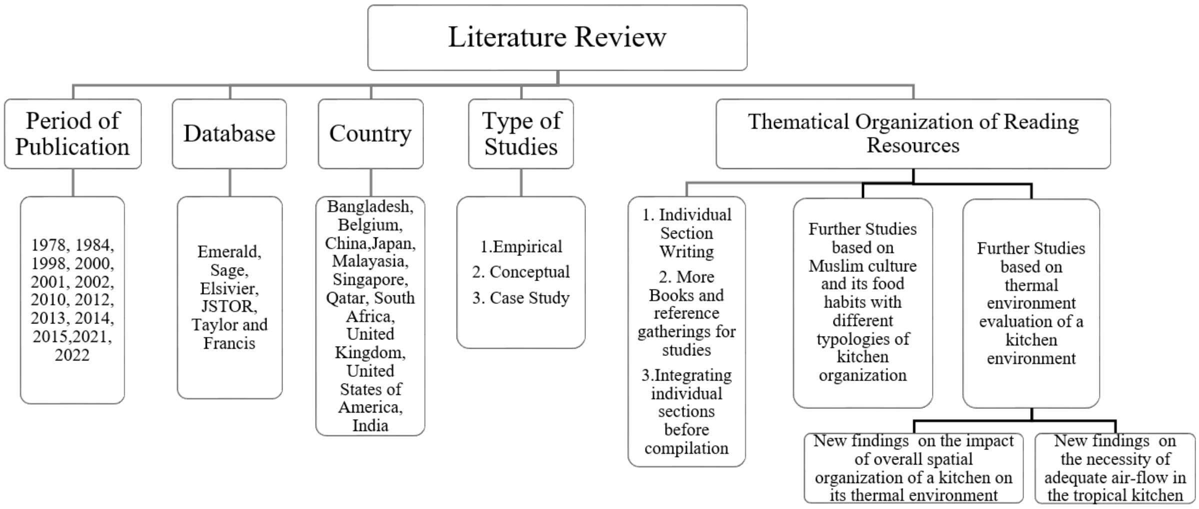


Figure 1: Diagram of literature review

MATERIALS AND METHODS

Study Design, Subject and Survey

A cross-sectional study design and field measurements were used. The study was conducted into two phases. At first phase, a residential kitchen was chosen from Chandgaon R/A of Chattagram city, Bangladesh. Then the measurements of subjective judgment scales (SJS) including Air Temperature, °C (AT), Relative Humidity, % (RH), Indoor Air Quality Index (AQI), were carried out from the kitchen under 3 basic periods which were breakfast, lunch and dinner period when the kitchen is the most active along with Subjective Fatigue Estimates (SFE) which included the measurement of Blood Pressure (BP), Pulse Rate (PR) and thermal sensation of the occupant. Here the subject was the kitchen user of the residence. At second phase, a questionnaire survey was conducted over 25 families of Bangladesh. The self-reporting questionnaire assessed the thermal comfort of the kitchen users and their work environment. The magnitude of thermal comfort was evaluated by classifying it into 5 categories such as cold, slightly cold, slightly hot, hot and neutral. All the data were collected by questionnaire survey via field survey, mails and telephone calls.

Case Studies

For case studies the dwelling unit typologies of tropical

Figure 2: Kitchen images in different settings in Bangladesh.

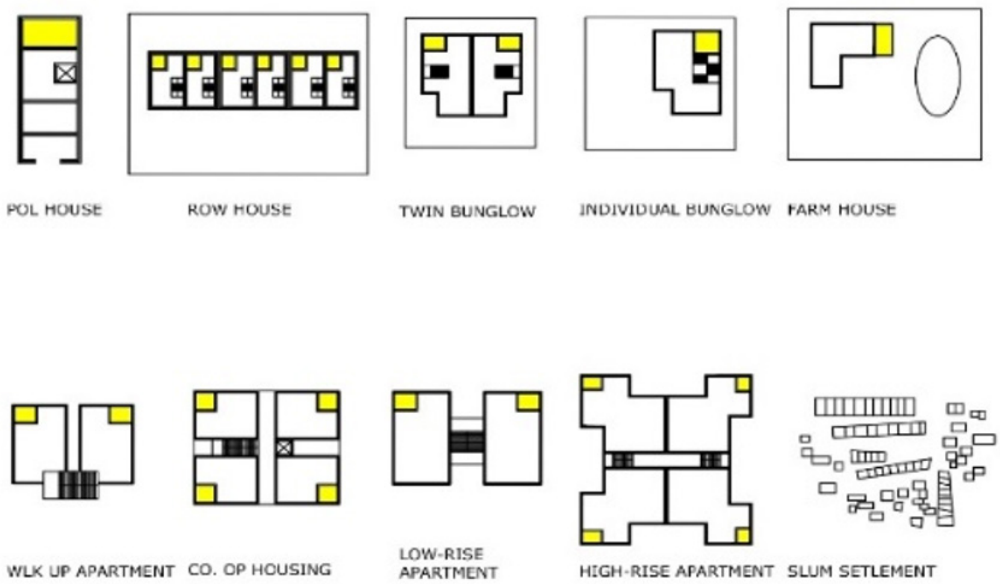


Figure 3: Housing typologies found in Bangladesh with kitchen positions identified.

climate were studied and 10 types of dwelling units found in Bangladesh were drafted, most of them occupying kitchen at different locations. The surveyed kitchen belonged to the low-rise residential apartment. The kitchen measured 7'-11"x 8'10" with a northern opening (kitchen balcony door) facing toward a 5'-0" void of the 2 unit 6 storied residential urban apartment.

Studied Kitchen Information

Residential apartments in the tropics need adequate air-flow and daylight for the indoor comfort as there is a negligible Air Temperature, °C (AT) difference between indoor air and outdoor air. As Residential kitchen consists of metallic surfaces and heat appliances, heat generated within the kitchen can only be dissipated if they are carried away by convection air which makes the presence of opening and void within the kitchen extremely necessary (De Liège, 2013b). Therefore, the surveyed kitchen was an efficient sample to study the overall thermal scenario of residential kitchen. The kitchen was mainly used 3 times a day by the subject which included: breakfast time (8.00am-10.00pm), lunch time (12.00pm to 2.00pm) and dinner time (7.00pm to 9.00pm). The subject mainly used gas-stove for cooking and no other heat appliance was in use during the survey time.

But the kitchen consisted of metallic surfaces of the exhaust fan and other kitchen utensils. These metallic surfaces contributed to the rapid conduction and radiation of heat but due to poor air flow from northern opening, the Air Temperature, °C (AT) was rising so as the thermal discomfort of the subject. The kitchen had an opening (the kitchen balcony door) on its northern side facing a void of 5'-0"although the local wind direction was from South-West. (Figure 5)

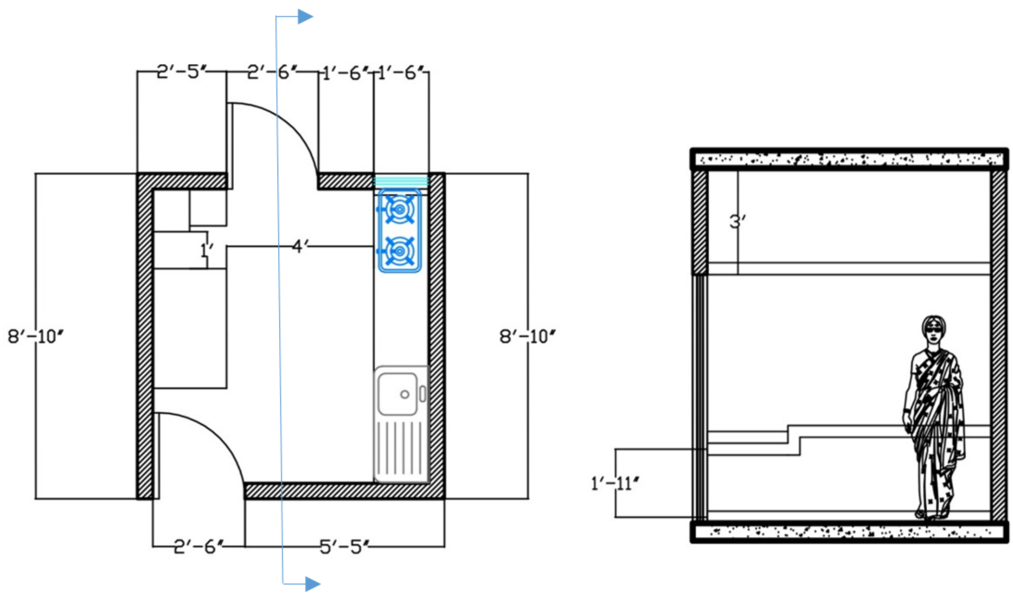


Figure 4: Plan & cross-section of the studied residential kitchen

Figure 5: Surveyed kitchen location in key-plan of the Multi-storeyed Residential Building

Environmental Monitoring

The environmental measurement was conducted in a low rise residential apartment kitchen with a gas stove from January 4 to January 8, 2019 in Chandgaon R/A, Chattagram, Bangladesh. The survey was done during winter season. The Subjective Judgmental Scales such as Air Temperature, °C (AT), Relative Humidity, % (RH), Indoor Air Quality Index (IAQI) surrounding the main heat appliance which was the gas stove were digitally recorded once in every 30 minutes interval during the breakfast, lunch and the dinner time using 5 in 1 meter (LM-8102) Positioned at 3feet height from the floor level and at 2' away from the gas stove. Each time the measurements were taken twice, first time with the stove opened and second time with the stove closed. Then after each measurement the subject was taken outside of the kitchen and allowed to sit for a while after which the Blood Pressure (BP) and Pulse Rate (PR) of the subject was measured by wrist blood pressure monitor. Thermal image camera (FLIR) was used to take few pictures within 1 hour at 10 minutes intervals. The study was approved by the authorities of the environmental lab of Chittagong University of Engineering & Technology, Bangladesh. The subject was fully informed of the purpose of the study and gave verbal consent. The subject was a housewife and spent most of her lifetime in the same kitchen. It was worthy to mention that the subject was already suffering from high Blood Pressure (BP).

Figure 6: From left (a) Position of 5 in 1 meter, (b) 5 in 1 meter (LM 8102), (c) Experimental process with 5 in 1 meter (LM 8102), (d) Subject with wrist blood pressure monitor.

Questionnaire Survey

A questionnaire survey was conducted over 25 kitchen users of Bangladesh with field survey, telephone conversation and mailing. The purpose of the survey was to analyse the thermal comfort of the kitchen environment in different conditions in the tropics. The magnitude of thermal comfort was evaluated by classifying it into 5 categories such as: cold, slightly cold, slightly hot, hot and neutral. 78% of the users agreed to the fact that they felt hot, 16% of them felt slightly hot and 3% of them felt neutral while working in their kitchens.

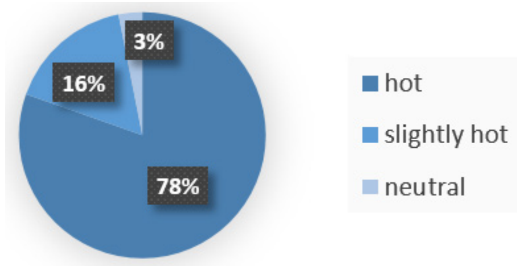


Figure 7: Overall findings on the thermal sensations of the kitchen users

Table 1: Questionnaire for Sample Data Collection

Experiment date:				
Subject name:				
Age:				
Gender:				
Please spare a few minutes of your valuable time to answer the simple questionnaire.				
1. How many hours do you spend in kitchen in 24 hours?				
a)1-3 hours	b)4-6 hours	c)7-9 hours	d)10-12 hours	
2. What is the longest duration of working continuously in kitchen?				
a) 2-3 hours	b)4-5 hours	c)6-7 hours	d)8-9 hours.	
3. Which time is more comfortable?				
a) Day	b) Night			
4. When do you start sweating?				
a)within 2 minute	b)within 5 minute	c)within 10 minute	d)within 20 minute	e)within 30 minute
5. Demonstrate the air flow condition of your kitchen.				
a) No air flow	b) Slight air flow	c) Adequate air flow	d) high air flow	
6. Demonstrate your thermal comfort feeling.				
a) Slightly cool	b) Neutral	c) Slightly hot	d) Hot	e) Very hot

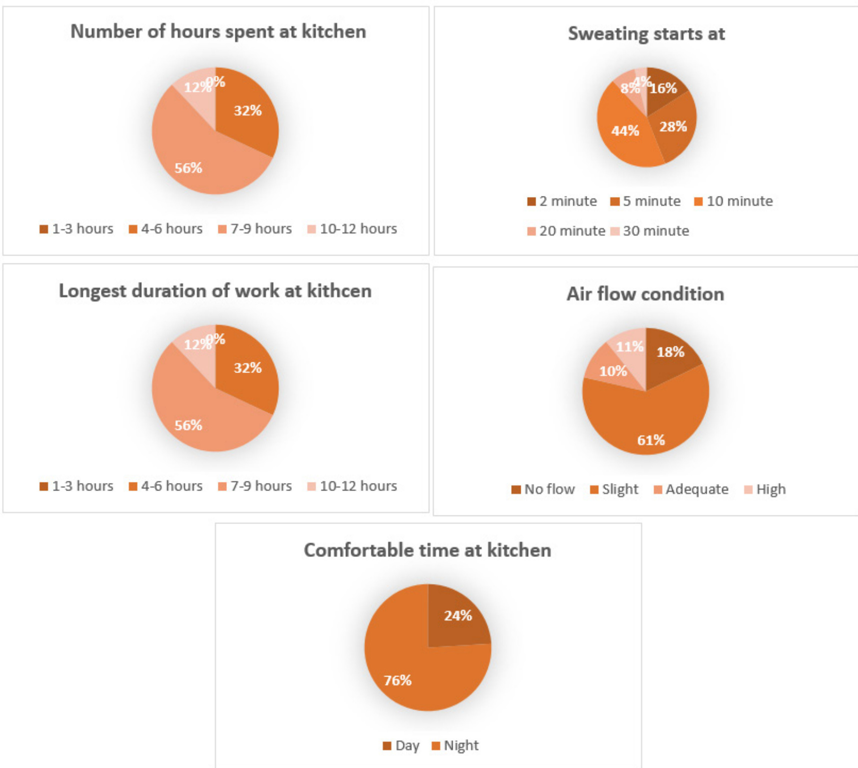
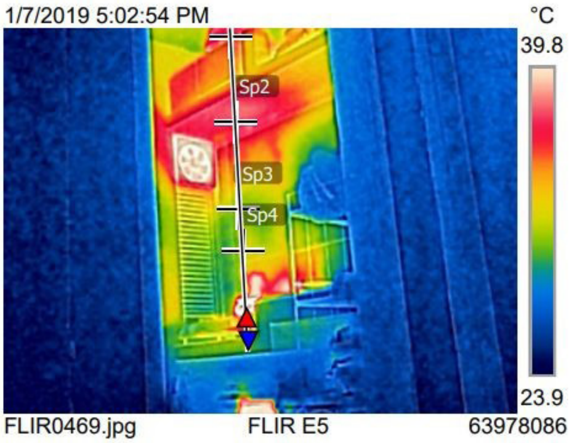


Figure 8: Survey data from questionnaire

Digital Documentation

The next step was to digitally record the thermal condition of the surveyed kitchen with the thermal image camera. A 1 hour long survey was carried using the Thermal Image Camera by taking snaps at 10 minutes intervals. The subject was taken out of the kitchen and the balcony

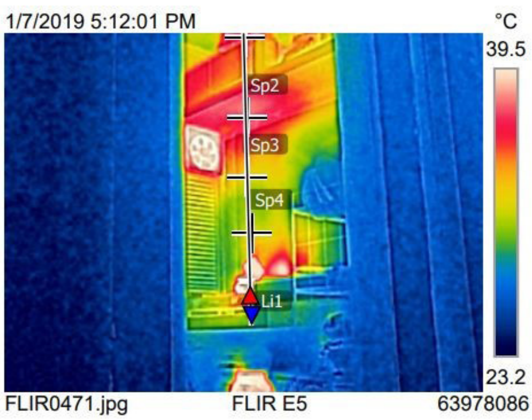


Measurements		
Sp1		33.0 °C
Sp2		34.6 °C
Sp3		27.8 °C
Sp4		28.6 °C
Li1	Max	77.7 °C
	Min	27.2 °C
	Average	32.3 °C

Parameters	
Emissivity	0.95
Refl. temp.	20 °C
Distance	3.3 ft
Atmospheric temp.	20 °C
Ext. optics temp.	20 °C
Ext. optics trans.	1
Relative humidity	50 %

Measurements		
Sp1		33.8 °C
Sp2		34.9 °C
Sp3		27.1 °C
Sp4		27.9 °C
Li1	Max	70.9 °C
	Min	25.7 °C
	Average	31.5 °C

Parameters	
Emissivity	0.95
Refl. temp.	20 °C
Distance	3.3 ft
Atmospheric temp.	20 °C
Ext. optics temp.	20 °C
Ext. optics trans.	1
Relative humidity	50 %



Measurements

Sp1		33.0 °C
Sp2		34.2 °C
Sp3		28.7 °C
Sp4		28.7 °C
Li1	Max	78.5 °C
	Min	26.0 °C
	Average	33.1 °C

Parameters

Emissivity	0.95
Refl. temp.	20 °C
Distance	3.3 ft
Atmospheric temp.	20 °C
Ext. optics temp.	20 °C
Ext. optics trans.	1
Relative humidity	50 %

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Measurements

Sp1		34.8 °C
Sp2		36.4 °C
Sp3		33.1 °C
Sp4		28.4 °C
Li1	Max	72.4 °C
	Min	26.8 °C
	Average	32.5 °C

Parameters

Emissivity	0.95
Refl. temp.	20 °C
Distance	3.3 ft
Atmospheric temp.	20 °C
Ext. optics temp.	20 °C
Ext. optics trans.	1
Relative humidity	50 %

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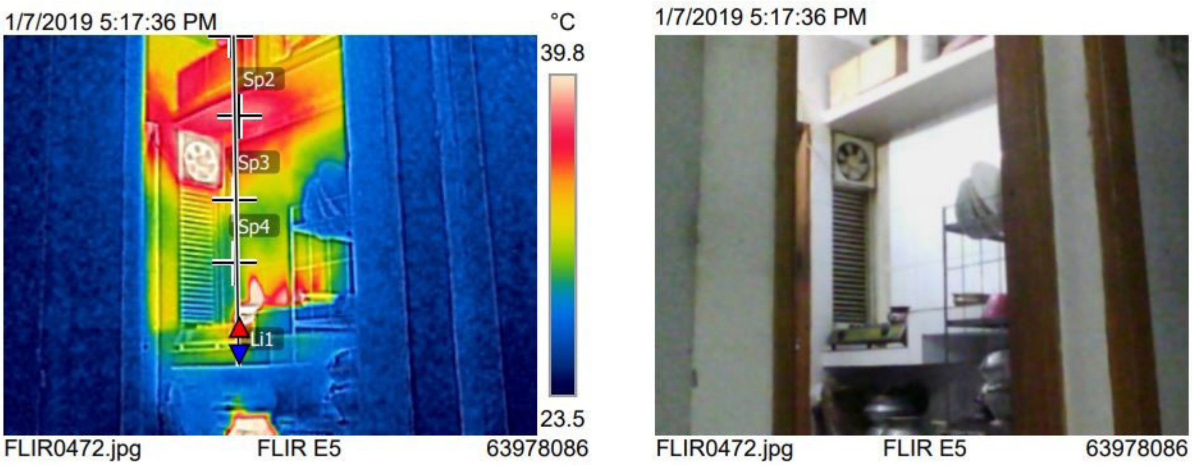
Measurements

Sp1		33.2 °C
Sp2		36.0 °C
Sp3		31.4 °C
Sp4		27.8 °C
Li1	Max	63.9 °C
	Min	25.4 °C
	Average	31.6 °C

Parameters

Emissivity	0.95
Refl. temp.	20 °C
Distance	3.3 ft
Atmospheric temp.	20 °C
Ext. optics temp.	20 °C
Ext. optics trans.	1
Relative humidity	50 %



Measurements

Sp1		33.8 °C
Sp2		36.0 °C
Sp3		29.5 °C
Sp4		27.2 °C
Li1	Max	58.4 °C
	Min	26.1 °C
	Average	31.5 °C

Parameters

Emissivity	0.95
Refl. temp.	20 °C
Distance	3.3 ft
Atmospheric temp.	20 °C
Ext. optics temp.	20 °C
Ext. optics trans.	1
Relative humidity	50 %

Figure 9: Images from Thermal Image Camera

door (the main source of air-flow) of the kitchen was kept open. The window of the kitchen was never in use and sealed from outside soon after the construction of the building. The main heat appliance i.e. the gas stove was turned on and all other heat or mechanical appliance were turned off.

Simulation

To further analyse the indoor air quality and thermal condition of the surveyed kitchen, a simulation was run on a digital software. The simulation was basically done to identify how the daylight condition in the kitchen may change with the changed position of windows, with the size of windows and how this can affect the overall thermal situation of kitchen. A 3d model was created replicating the surveyed kitchen in the Ecotect software. The kitchen had an opening at the north. The first simulation model had opening at north side. Later, the opening size was changed to compare simulation data among different window sizes (25% and 50% opening of the north wall of the kitchen). This process was repeated for the south, east and west wall. The output of the simulation came in the form of a colour mapping where yellow colour shows the maximum temperature, and blue

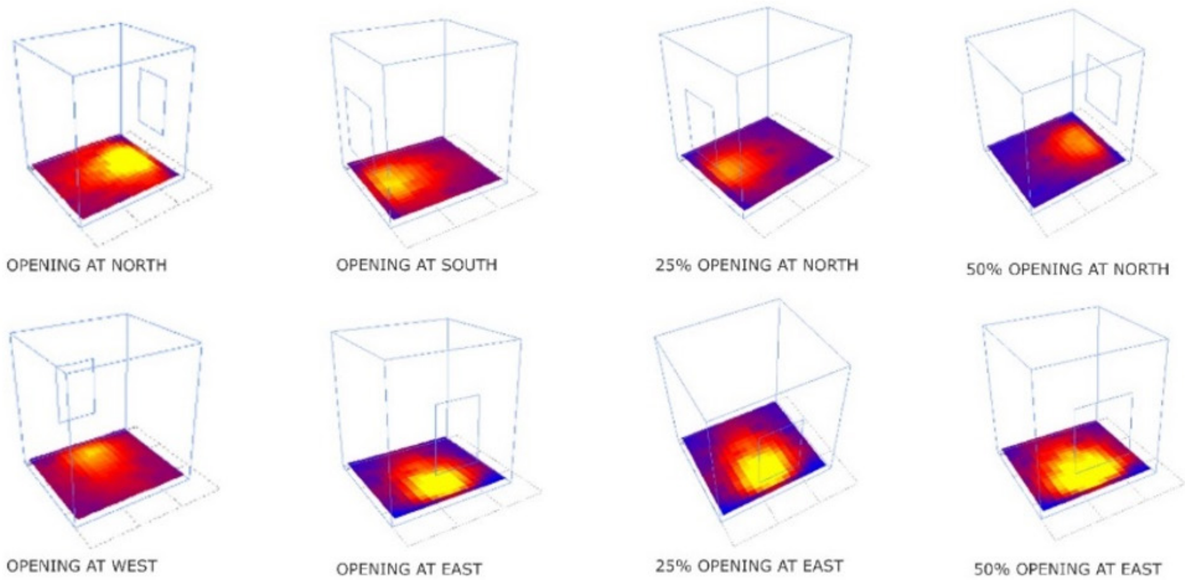


Figure 10: Findings from simulation

represents the minimum (Figure 10). From the simulation data, window positioning at North had the least impact on the overheating of the kitchen irrespective of window size although windows located at South, West or East had major impact on the overall heating of the kitchen. There were some boundary conditions for the simulation. First of all, the kitchen model was simulated as an independent form- detached from the overall building mass. Secondly, the surrounding building mass were not also considered, whereas this can contribute a great change in day lighting inside the kitchen. Thirdly, the simulation was done with the environmental data for a particular month and a particular season (winter). So, it doesn't address different situation that might appear in different time of the year.

The first experiment session began with the recording of Subjective Judgmental Scales (SJS) which included Air Temperature, °C (AT), Relative Humidity, % (RH), and Indoor Air Quality Index (IAQI) of the observed residential kitchen with both the stove turned on and turned off during breakfast period. The experiment lasted since 7.00am to 10.00pm by using 5 in 1 meter (LM 8102). The measurements were recorded at each 30 minutes intervals.

The subject was not too uncomfortable at the beginning of the experiment but started sweating after the first 20 minutes of the experiment and started feeling slightly hot. The subject was wearing simple suit with half sleeves. After the measurements being taken each time with both the stove turned on and turned off, the subject was moved out of the kitchen and allowed to sit for a while. Then the blood pressure (BP) and the Pulse Rate (PR) of the subject were measured accordingly.

The blood pressure (BP) of the subject was gradually increasing though the increase was more dominant when the stove was opened. The Pulse Rate (PR) was rising with increasing time.

The same method was repeated during lunch time (12.00pm-2.00pm) and dinner time (7.00pm-10.00pm). The results are shown below:

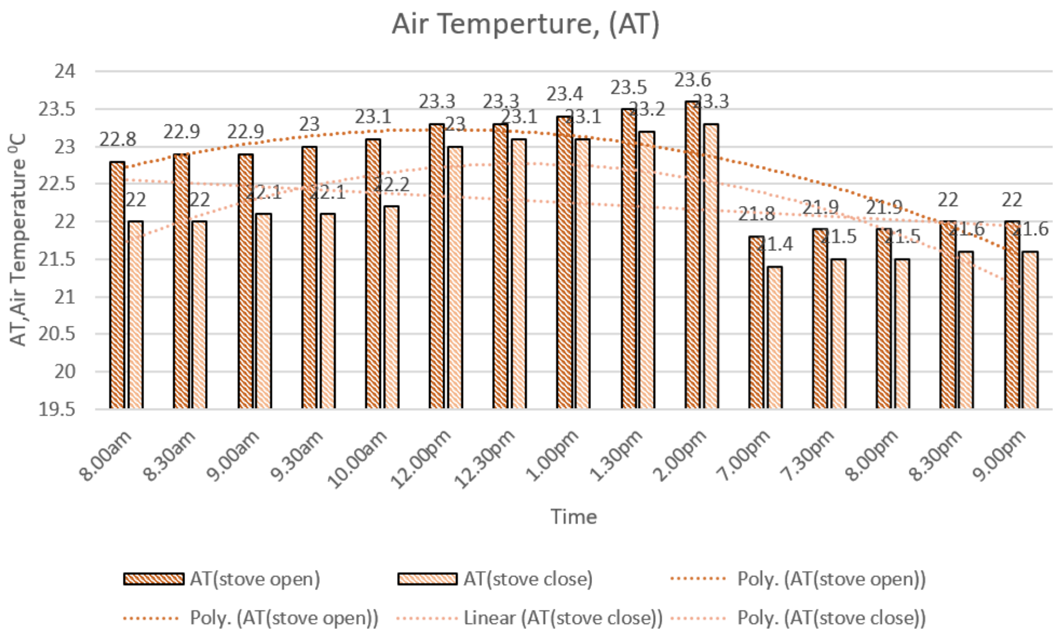


Figure 11: Graph showing time to Air Temperature, °C (AT)

Mean average temperature:
Stove opened: 22.76 ^{0}C
Stove closed: 22.20C

The graph clearly shows the highest Air Temperature, °C (AT) was observed during day-time around 2.00pm which recorded as 23.6 0C with gas-stove turned on and 23.3 0C with gas-stove turned off. Since the survey was done during winter time, the summer time observation might show a greater magnitude in the Air Temperature, °C (AT). The graph also showed a proportionate relationship between the active duration hours of heat-source with the Air Temperature, °C (AT) from 8.00am to 2.00pm as with time the Air Temperature, °C (AT) increased. But when the gas-stove was turned off after lunch hour, the Air Temperature, °C (AT) dropped for which the lowest Air Temperature, °C (AT) was recorded at 7.00pm measuring 21.4 0C with the gas-stove being turned off. The Air Temperature, °C (AT) again began to rise during dinner hour when the gas-stove was turned on. It is also observed from the graph that the subject was exposed to high Air Temperature, °C (AT) during most of her time spent in the kitchen.

Mean average relative humidity:
Stove opened: 73.5%
Stove closed: 65.95%

The graph shows that the highest recorded Relative Humidity, % (RH) of magnitude 74.5% was observed during 9.00pm meaning the air was most saturated at that time when the stove was turned on whereas the lowest recorded Relative Humidity, % (RH) was 65% recoded at 8.00am when the stove was turned off. The graph clearly shows that the active status of the gas-stove directly

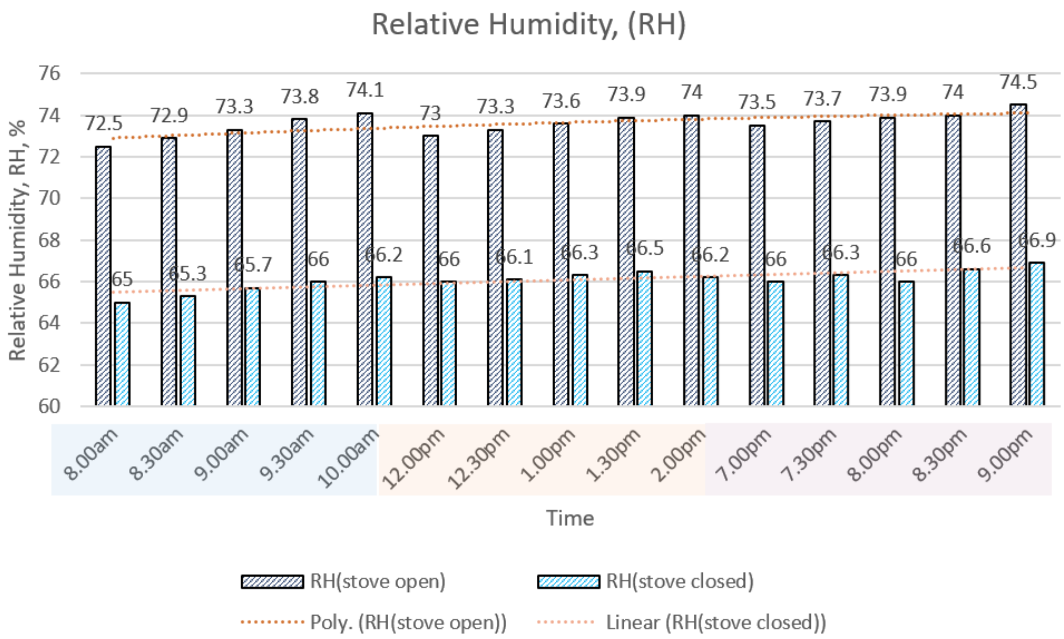


Figure 12: Graph showing time to Relative Humidity, % (RH)

contributed to the increase in the Relative Humidity, % (RH) of the kitchen which means that the subject who was exposed to high Air Temperature, °C (AT) due to the heat coming from the gas-stove could not dissipate surplus heat through evaporation due to the saturated air and high Relative Humidity, % (RH) of the kitchen. This was the main reason of the sweating of the subject which started right after 20minutes of the experiment. Since the kitchen had an opening at its northern side, there was no adequate air-flow for which the Relative Humidity, % (RH) remained almost constant. The Relative Humidity, % (RH) alone had a very little influence over the thermal sensation of the kitchen user. (Djamila *et al.*, 2014).

The next step was to determine the Indoor Air Quality Index (IAQI) of the kitchen environment. For determining The Indoor Air Quality Index (IAQI) of the surveyed residential kitchen, the ratio of Indoor Air Temperature, °C (AT) and Relative Humidity, % (RH) was calculated and presented on a scale of 1-6 with a rating of Excellent to Severe. A rating higher than 3 requires action to be taken on either adjusting the temperature or the humidity of the building, so as to best minimize mould risk and air pollution while maximizing comfort. (Heinecke, 2021). Again high temperatures and humidity contribute to increase the concentrations of certain pollutants which deteriorates the indoor air quality. So, the attempt was to

Table 2: Indoor Air Quality Index (IAQI) Chart of the surveyed residential kitchen

RH	**Indoor Air Quality Index (IAQI)**												
90%	6	5	4	3	3	3	3	4	5	5	6	6	6
80%	5	4	2	2	2	2	2	3	4	5	5	5	6
70%	5	4	3	2	1	1	1	2	3	4	5	5	6
60%	5	4	3	2	1	1	1	2	2	3	4	5	6
50%	5	5	4	3	2	1	1	1	2	3	4	5	6
40%	6	5	5	4	3	3	3	2	2	3	4	5	6
30%	6	5	5	4	4	4	4	4	4	4	4	5	6
20%	6	5	5	5	5	5	5	5	5	5	5	5	6
10%	6	6	6	6	6	6	6	6	6	6	6	6	6
AT	**16C**	**17C**	**18C**	**19C**	**20C**	**21C**	**22C**	**23C**	**24C**	**25C**	**26C**	**27C**	**28C**

plot the Indoor Air Quality Index (IAQI) of the surveyed kitchen and determine the magnitude of Indoor Air Quality (IAQ) of the kitchen. Since the Kitchen's indoor Air Temperature, °C (AT) never fluctuated below or above 210C -240C and Relative Humidity, % (RH) also remained between 60%-80% during the survey period, the target was to locate the Indoor Air Quality Index (IAQI) from the Indoor Air Quality Index (IAQI) chart using these values and then rate the air quality of the kitchen environment.

It was found from the chart that the indoor Air Quality Index (IAQI) of the kitchen fluctuated among the values of 1-4 meaning Excellent to Poor and during the peak hour at 2.00pm when the indoor Air Temperature,

Table 3: Chart showing Indoor Air Quality Index (IAQI) rating

Rating	AQI	CO2 ppm	Meaning
Excellent	1	0 – 400	The air inside is as fresh as the air outside.
Fine	2	400 – 1000	The air quality inside remains at harmless levels.
Moderate	3	1000 – 1500	The air quality inside has reached conspicuous levels.
Poor	4	1500 – 2000	The air quality inside has reached precarious levels.
Very Poor	5	2000 – 5000	The air quality inside has reached unacceptable levels.
Severe	6	from 5000	The air quality inside has exceeded maximum workplace concentration values.

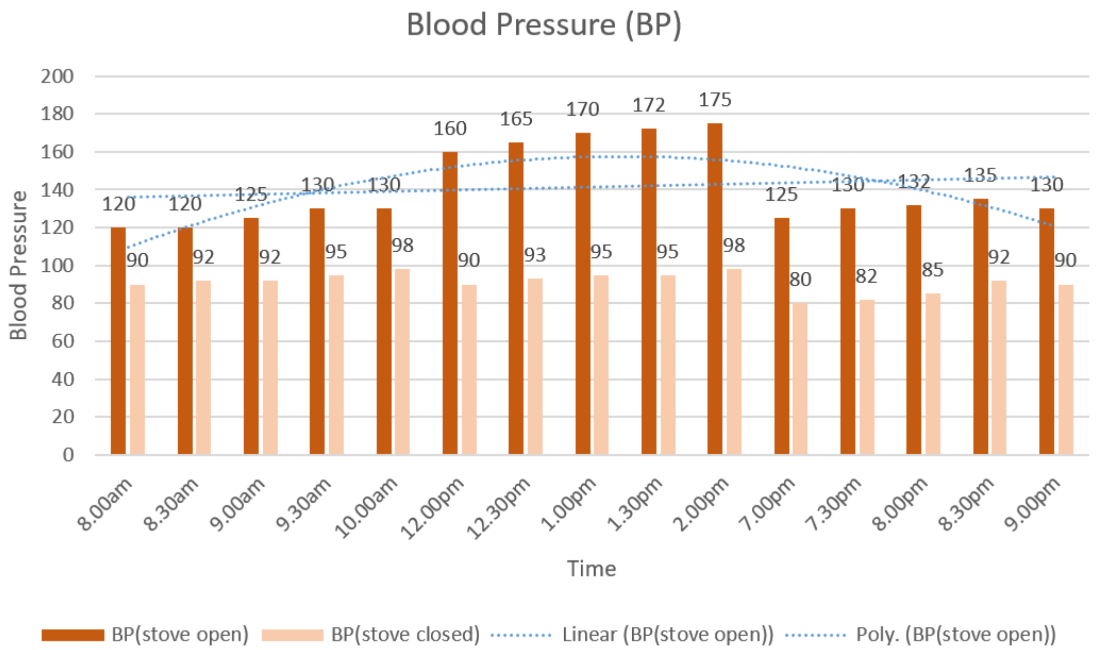


Figure 13: Graph showing time to Blood Pressure, (BP)

°C (AT) was 23.60C and Relative Humidity, % (RH) was 74%, the Indoor Air Quality Index (IAQI) of the kitchen was among 2-4 meaning it was the time when the kitchen environment was the most uncomfortable for the user which was later testified by measuring the health condition of the user.

Mean average Blood Pressure:

Stove opened: 141 mm/Hg

Stove closed: 91 mm/Hg

The graph clearly shows that the subject faced the most uncomfortable situation and the highest Blood Pressure (BP) at 2.00pm when the Air Temperature, °C (AT) was also the highest with the gas-stove being turned on. The lowest Blood Pressure (BP) was recorded at 7.00pm when the Air Temperature, °C (AT) was also the lowest with the gas-stove being turned off. The graph also shows that, the subject was a patient of high Blood Pressure (BP) with an average Blood Pressure (BP) range of 141/91 mm/Hg which is slightly above the standard high Blood Pressure range (140/90) mm/Hg. This experiment was a part of Subjective Fatigue Estimates (SFE) and Repetitive Psychometric Measures (RPM) which included the measurement of subject's Blood Pressure (BP), Pulse Rate (PR) and thermal sensation. Since heat is a sensation and have direct health implication on its subjects, to support the results from the physiological survey and analysis which included the measurement of the indoor Air Temperature, °C (AT), Relative Humidity, % (RH) and Indoor Air Quality Index (IAQI), the psychological evaluation of the fatigue situation of the subject caused by the poor environmental condition of the kitchen and high heat exposure was necessary. It was quite evident that the Blood Pressure (BP) of the subject was rising as the Air Temperature, °C (AT) was rising with time. Longer exposure to heat appliance furthered the process and thermal discomfort began to rise. There is a significant amount of Blood Pressure (BP) drop during breakfast hour (8.00am-10.00am) and dinner hour (7.00pm-9.00pm) comparing to the lunch hour (12.00pm-2.00pm). There is also a significant amount of Blood Pressure (BP) difference when the gas-stove was turned on and turned off in every cases. There is a very little interval between breakfast and lunch hour meaning at 2.00pm, the subject had the longest exposure to heated environment of the kitchen which significantly contributed to increase the Blood Pressure (BP) while a significant amount of interval between lunch and dinner hour or heat exposure caused a significant drop in the Blood Pressure (BP) of the subject.

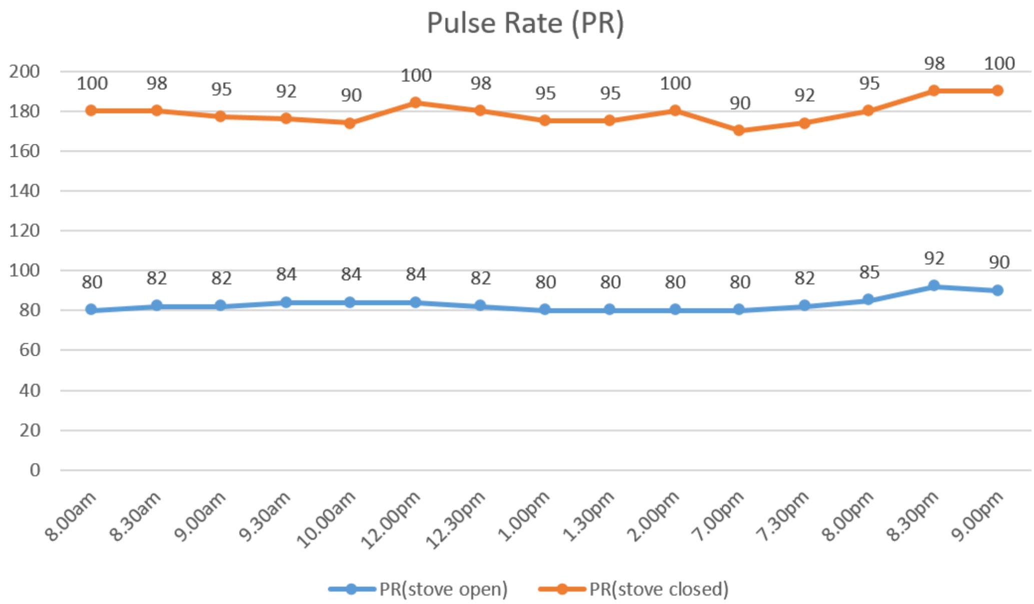


Figure 14: Graph showing pulse rate (PR) fluctuations of the subject

Maximum pulse rate:
Stove opened: 100pulse/min
Stove closed: 92pulse/min
The graph clearly shows that the subject faced the highest Pulse Rate (PR) of 100pulse/min at 2.00pm when the Air Temperature, °C (AT) and subject's Blood Pressure (BP) were also the highest with the gas-stove being turned on. This magnitude was also observed at 8.00am, 12.00pm and 9.00pm respectively. The lowest Pulse Rate (PR) of 90pulse/min was recorded at 7.00pm when the Air Temperature, °C (AT) and subject's Blood Pressure (BP) were also the lowest with the gas-stove being turned off. It was clearly visible that while the heat-appliance was turned on, the Air Temperature, °C (AT) was relatively higher than what it would be normally in all cases, with the maximum temperature of 23.6 0C at 2.00pm, the corresponding Relative Humidity, % (RH) was also gradually rising by time causing major thermal discomfort to the subject.
The subject had higher blood pressure in between 12.00pm to 2.00pm (lunch time) with the maximum pulse rate of 100 pulse/min. So, it is evident that the kitchen user had the most significant changes in her health during the lunch period (12.00pm – 2.00pm). (Figure 16). Being exposed to the gas stove for a longer hour meant being exposed to a poor indoor air condition for a longer hour which significantly affected the subject's health condition and thermal sensation. The high Pulse Rate (PR) of the subject supported the high Blood Pressure (BP) measurement data of the experiment. Thus the user's thermal comfort for all over the day was graphically plotted that showed the following result:

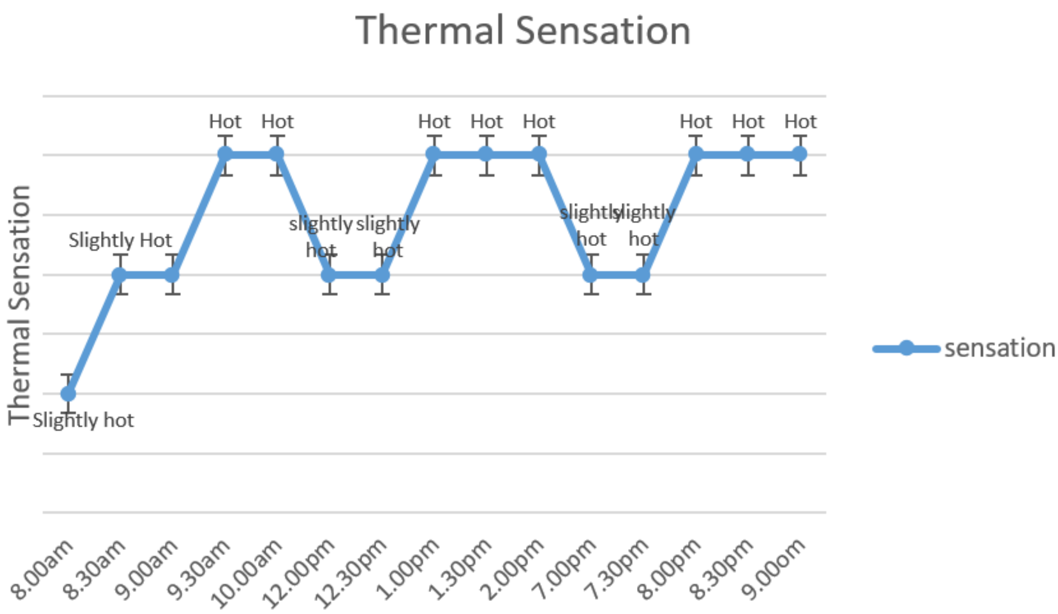


Figure 15: Graph showing the overall thermal sensation analysis of the subject

Astonishingly, the graph showed that the extreme thermal discomfort faced by the subject was during the peak hours of breakfast (9.00am to 10.00am), lunch (1.00pm to 2.00pm) and dinner (8.00pm to 9.00pm). The analysis also showed that the longer duration hour of heat-appliance caused greater thermal discomfort.

To further analyse the temperature rise in the kitchen environment, another survey was carried out with the stove opened by the thermal image camera taking pictures at 10 minutes interval within an hour which showed a drastic temperature rise of the kitchen ceiling with the passing time.

Many studies show that women are less heat tolerant than men, particularly when physical work is required. Much of the difference is related to women's relatively low level of physical fitness and lack of heat acclimatization, which are in turn a result of their traditionally sedentary lifestyle. (Nunneley, 1978).

The subject of the study was also a housewife who spent most of her life doing household chores which included a significant amount of her lifetime spent in the residential kitchen which is usually the most thermally uncomfortable space of the residential flats. It is generally accepted that physiologically tolerable heat stress can adversely affect human performance, but it is difficult to predict the impact of a specific environment (Nunneley *et al.*, 1978). Experiments were designed to determine the effects of thermal conditions occurring in the residential kitchen of tropical climate, where both high Air Temperature, °C (AT) and high Relative Humidity, % (RH) play important roles ultimately affecting the Indoor Air Quality Index (IAQI) of residential kitchen. Subject was exposed to heat for 6 hours which included breakfast time (8.00am-10.00pm), lunch time (12.00pm to 2.00pm) and dinner time (7.00pm to 10.00pm), had a 30-min breaks in intervals, and then was repeated to the exposure. The main heat appliance which was the gas stove was turned on and off at regular intervals to collect measurement data regarding Subjective Judgement Scales (SJS) which consisted of Air Temperature, °C (AT), Relative Humidity, % (RH) and Indoor Air Quality Index (IAQI).

The analysis showed that the highest Air Temperature, °C (AT) 21.4 0C was recorded at 2.00pm during the lunch hour when the gas stove was turned on with a Relative Humidity, % (RH) of 74% which was the third highest recorded Relative Humidity, % (RH) from the experiment. With the continuous activation and deactivation of heat appliance and the presence of conductive surfaces like metals in kitchen utensils and exhaust fan, the Air Temperature, °C (AT) of the kitchen was continuously rising making the subject exposed to thermal strain clearly shown in the correlation matrix (Figure 16). Since the kitchen did not have adequate air flow due to its northern opening, the increasing heat of the kitchen could not dissipate. There always remains a very little difference between indoor and outdoor Air Temperature, °C (AT) in the tropical climate which makes adequate air-flow the only means of heat dissipation (Wang & Hein, 2011). But the surveyed kitchen environment clearly lacked that. It was also observed that the subject started sweating after 20minutes of the experiment which clearly supports the fact that the Relative Humidity, % (RH) of the kitchen during the experiment was high and the air was saturated but enough fresh air was not circulating during the experiment to carry away the surplus heat from subject's body through evaporation. Since, Indoor Air Quality Index (IAQI) has a direct relation with the ratio of indoor Air Temperature, °C (AT) and Relative Humidity, % (RH), further findings showed that during lunch hour around 2.00pm when both the Air Temperature, °C (AT) and Relative Humidity, % (RH) were high, the Indoor Air Quality Index (IAQI) value was approximately 4 (poor) meaning the Indoor Air Quality (IAQ) of the surveyed kitchen had reached a precarious level although the

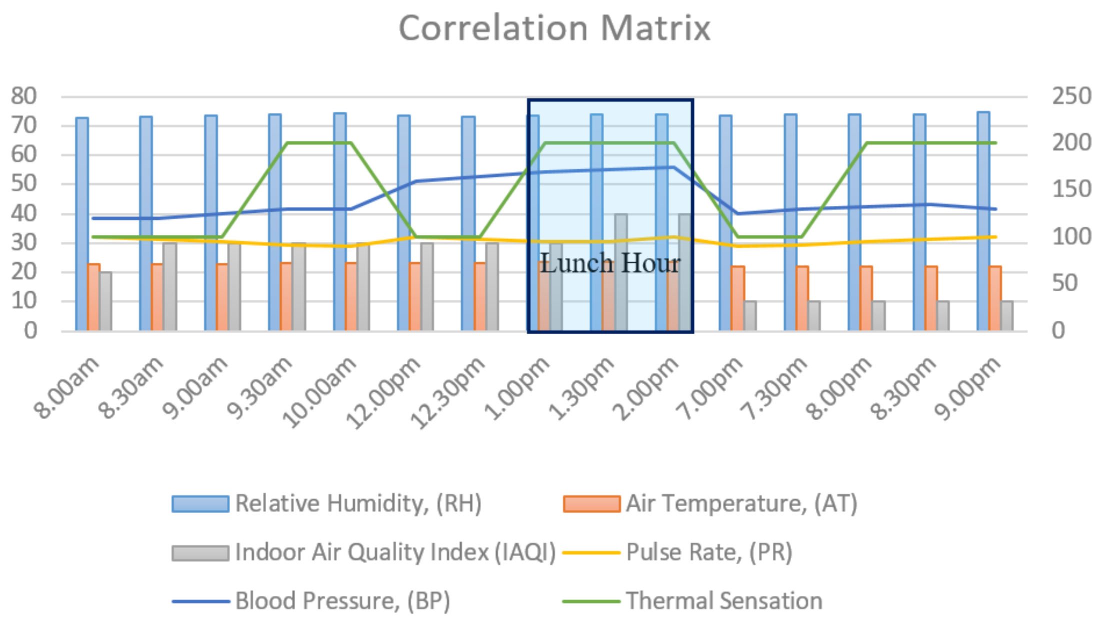


Figure 16: Correlation Matrix

overall Indoor Air Quality Index (IAQI) during the survey remained moderate among the values of 1-3. Subjective Fatigue Estimates (SFE) and Repetitive Psychometric Measures (RPM) were performed after each heat stress scenario which included the measurement of subject's Blood Pressure (BP), Pulse Rate (PR) and thermal sensation too. These measurement clearly indicated that it was the lunch hour around 2.00pm when the subject had faced the extreme thermal strain justifying the previous experiment on environmental monitoring of the surveyed kitchen. Although the subject also felt thermal discomfort during the peak hours of breakfast (9.00am to 10.00am) and dinner (8.00pm to 9.00pm) which happened due to the longer hour being exposed to the heat appliance.

The images from Thermal Image Camera showed a drastic increase in the ceiling temperature of the kitchen as most of the metallic surfaces including the exhaust fan of the kitchen were located there which acted as conduction medium of the heat dissipating from the gas-stove. Those surfaces were also radiating heat as there was a poor natural ventilation in the kitchen to carry away those heat. The simulation also showed how little contribution a northern opening can have to increase air-flow in the kitchen despite its size.

All these factors majorly contributed to Air Temperature, °C (AT) and Relative Humidity, % (RH) rise in the surveyed residential kitchen which had a significant impact on the subject's health condition. It was found that the subject was already a patient of high Blood Pressure (BP) from the measurement data of Blood Pressure (BP) and Pulse Rate (PR) and her everyday exposure to such kitchen environment could cause several health issues and thermal strain for her. The thermal sensation diagram of the subject also supported the outcomes of the questionnaire survey where most of the kitchen users of the tropical climate felt the similar thermal sensation falling into the category of hot and slightly hot due to extreme exposure to high heat and humid environment with inadequate air flow causing a poor Indoor Air Quality (IAQ) in the residential kitchen of the tropical climate.

CONCLUSIONS

The residential kitchen considered for the detailed analysis shows that the kitchen composition and kitchen's indoor environment greatly affects the thermal behavior of the subject. It is found from the study that occupant's adaptation on the kitchen's indoor thermal environment is regulated by the Subjective Judgmental Scales (SJS) which includes Air Temperature, °C (AT), Relative Humidity, % (RH) and Indoor Air Quality Index (IAQI). Results from the study shows that the kitchen temperature rises rapidly with the heat appliance being turned on multiple times and being used for longer hours, which is a regular phenomenon in a country like Bangladesh due to cultural and religious reasons. With the increase in temperature, the thermal comfort and air purity fall and Relative Humidity, % (RH) increases. The study further stresses that the subject faced difficulty to maintain constant and comfortable thermal conditions throughout the time spent in the kitchen and had high Blood Pressure (BP) and Pulse Rate (PR) which was a clear denotation of the fact that the user exposed to gas stove was subjected to higher thermal strain and health issues. The study also shows from the comparison of the results coming from different period of days that the lunch period was the time where the thermal impact of the kitchen on its user was the most severe because of being exposed to the heat appliance for the longest duration of hours during that particular time. The continuous sweating of the user, increasing Blood Pressure (BP) and Pulse Rate (PR) clearly testified to the fact that the poor ventilation due to the northern opening of the kitchen had a very little contribution to create thermal comfort in that tropical kitchen as the local wind-direction of the surveyed location was south-west and the northern part of the kitchen was blocked by the other unit of the same building. The multifaceted analysis combined physical conditions like Air Temperature, °C (AT), Relative Humidity, % (RH) and Indoor Air Quality Index (IAQI) of the kitchen with the Subjective Fatigue Estimates (SFE) i.e. Blood Pressure (BP), Pulse Rate (PR) and thermal sensation of its user which concluded to the fact that longer exposure to gas-stove increased the health-risks of the user. Although Blood Pressure (BP), Pulse Rate (PR) vary from person to person, similar scenarios were also found in other kitchens of the tropics where most of the users felt thermally uncomfortable while working in their kitchens respectively. The research may act as a guideline to set up physiological parameters for designing a thermally comfortable kitchen environment in the tropics with appropriate spatial organization and proper thermal considerations.

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