Analysis of Thermal Comfort Study in India

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***Abstract*—**The primary purpose of providing a well-designed dwelling with appropriate use of building materials and climatic considerations, has always remained to establish an indoor environment that is conducive to the wellbeing and health of its inhabitants. In the quest for achieving better thermal comfort, the utilization of artificially ventilated systems has been rapidly increasing and its demand has elevated in recent years. To create a thermally complacent environment, provision of air-conditioning systems and HVAC devices is not the solution. It is essential to understand that thermal comfort is a complex issue where occupants interacting within the building may have different preferences. There is an urgent need for establishing Thermal Comfort Studies and setting up thermal laboratories in India to develop its own adaptive comfort approach and thermal standards.

***Index Terms*—**Thermal comfort, India, PMV,PPD, Adaptive Thermal Comfort.

I. Introduction

Mankind has consistently sought to create a thermally comfortable environment, which is reflected in the diverse building traditions and technologies around the world - from pre-historic times to the present day. Regardless of the era and the civilization, the building materials and resources at their disposable or the varied climatic range and technology accessible at that time, the primary purpose of providing a well-designed dwelling remains to establish an indoor environment that is conducive to the wellbeing and health of its inhabitants. Creating a thermally comfortable environment is still one of the most important parameters to be considered in building design.

II. CONCEPT OF THERMAL COMFORT

For an architect, the purpose of any design is to serve the future end users of a building, aiming at providing a favorable and comfortable thermal environment. With reference to Dr . Frederick H . Rohles (1980): "*To deny or ignore the psychology involved in comfort measurement is not only shortsighted, but treats the human subject as a machine, which it is not". [1]*

Therefore, the first step of a good thermal design must be to establish the diverse range of thermal conditions of comfort, and one must go beyond this primary interest and establish conditions that will also allow conditions to become refreshing and also stimulating, without causing any or much ill effects to the occupants in that space. Hence, the need to be conscious of both the possible risk and threat of extremes and also the need to examine conditions that are suitable for thermal comfort.

Thermal comfort is highly subjective sensation. It is a cognitive indicator, which cannot be easily converted in to physical tangible parameters. However, thermal comfort can be defined more qualitatively as the range of climatic conditions which most of the people feel comfortable, neither cold nor warm.

It is defined in the ISO 7730(1994) as "*The condition of mind that which expresses satisfaction with the thermal environment"(ASHRAE). "The main reason for mechanically conditioning office buildings is to create comfortable thermal conditions for occupants ". [2]*

The revised ASHRAE Standard 55-2010 -Thermal Environmental Conditions for Human Occupancy, outlines the characteristics and demands for a healthy indoor thermal environment. The principle of this standard was developed is to determine the specific combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable or tolerable to a majority of the occupants within the space. The standards purpose states that it is based on 80% acceptability and is for an average group of people, and not for an individual.

The purpose of this standard is to establish the various combinations of indoor thermal environmental factors along with personal factors that will produce a comfortable condition of thermal environmental that is acceptable to a majority of the occupants within a given space.

III. ARCHITECTURE AND THERMAL COMFORT

In earlier times until the industrial revolution, buildings were built keeping in mind the outdoor climate factors and the environment it created indoors. Post the industrial revolution, access to power (energy) and the advent of air conditioning changed the scenario. Buildings could be designed regardless of temperature outside and comfort still be maintained indoors. They could be designed and created in any imaginative manner and the air conditioning would take care of the adverse effects on the environment and load on energy demand resulting from the comfort demand expected from the buildings. The concept of living in harmony with climate and environment gradually grew faint, but not compromising on the concept of comfort.

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An indoor environment is required to be thermally comfortable and healthy as the residence period inside a building has been gradually escalating. The utilization of air-conditioning systems and HVAC devices has been rapidly increasing in current years and the demand for artificially ventilated systems have elevated around the world. Due to this reason, energy utilization of buildings and decrease in resources of developed countries has also amplified drastically. The essential purpose of every built structure and heating and air-conditioning systems installed in a building is to provide an atmosphere that is suitable and pleasing, one that does not affect wellbeing or functioning of the inhabitants.

"The experience of a space is depended on what the user expects from that particular space or user needs or aspirations. The architect's role is to realize the aspirations of the user and create a building that responds positively to those needs ". (Sri Nammuni, 1987).

Thermal comfort is principally a mental state and condition of the body that responds to its environment and this is different from the equations for heat and energy balances. Thus, thermal comfort is a subjective way to describe and identify if the surrounding setting is unperturbed and comfortable or not. An indoor environment that is perfect can be defined and summarized as:

1. The inhabitant feels moderately neither hot nor cold i.e., thermally neutral and does not desire the environment to be any colder or warmer.
2. At any particular time, the inhabitant is not exposed to any distinct unwanted cooling or heating at any particular part of their body.

IV. THERMAL COMFORT IN OFFICES

With the rise in temperatures across the world and people working for longer hours becoming the norm, the fundamental requirement for a comfortable working environment and the concept of thermal comfort has become the need of the hour. One must consider that increase in electronics means additional heat generated in an interior space, adding to the design strategies employed for thermal comfort like day lighting, ventilation, control over indoor temperature etc. Production and deployment of HVAC devices is expected to grow at 4.1% annually and is likely to generate a whopping $122 billion demand of HVAC equipment by 2020. [3]

Advancement in air conditioning technology has led to rapid increase in the HVAC load and a direct consequence of this substantial increase in demand and utilization of air-conditioning systems has led to concerns over global energy use and reconsidering the laws for energy efficiency in building codes and policies.

In today's time, it is not acceptable to simply provide protection from extreme cold and heat – we also anticipate fresh air, healthy surroundings, adequate lighting and excellent thermal comfort, i.e. constant supply of adequate air temperature and air flow velocity, all year round. Thermal comfort must consider both physical factors (Environmental factors like Air Temperature, Mean Radiant Temperature, Air Velocity and Relative Humidity) in the building environment, as well as personal factors such as clothing insulation and metabolic heat, or a person's activity level along with Secondary Factors such as Non-Uniformity Of The Environment, Adaptation of each individual, Age and gender and Outdoor Climate.

Research done on indoor environmental qualities for offices have shown that the most critical variable affecting and influencing the productivity of the user is air quality and thermal comfort. [4]. It has been proved that the design and indoor environment of an office can contribute to a turnover of approximately 15% loss or profit in an organization. People working in unpleasant indoor environments (like uncomfortably hot and cold surroundings, poor air quality, lighting etc) are more probable to behave and perform precariously, causing serious threat because their ability to make decisions and/or execute physical manual tasks depreciates. People may, for instance, presume short cuts to take the easy way out to get out of a cold surrounding, or employees may get negligent and prefer not to wear personal protective gear appropriately in hot environments, thus escalating the hazards. Also the chance for an employee's capability to pay attention and concentrate on a given assignment may start to dwindle and hence increasing the risk of mistakes happening.

Many research that has been conducted, have concluded and emphasized the importance of providing improved good quality indoor air quality and thermal comfort to office employees to keep them healthy and promote their productivity. "*Because people spend up to 90% of their time indoors, and much of it in their workplaces, the physical environment in offices should be carefully designed and managed. The physical conditions that occupants experience are important determinants of satisfaction, comfort, well-being, and effectiveness" (Workstation Design for Organizational Productivity, 2004).*

In order for occupants to produce to their full capability in their workplace, the working space needs to be thermally comfortable. Since thermal comfort is based on the occupant's personal thermal adaptation which is correlated to factors such as geographic location and climate, time of year, gender, race, and age [5], the challenge of subjecting a uniform standard of comfort becomes even more complex.

V. THERMAL COMFORT IN INDIA

With its myriad of regional and local climatic conditions and varied building constructions and technology, India does not follow a uniform standard for comfort. The revised National Building Code of India prescribes a temperature range of 21-26 degrees for a person to feel comfortable inside a built structure, irrespective of the building typology, location or season. This was based on the standard of ASHRAE-55. In contrast to the western counterparts and in the absence of Indian Indoor thermal Standards, providing a mechanically ventilated environment while meeting the requirement of comfort environment by following the international standard has led to high energy demand and even higher power consumption in India. The need for research and investigations on thermal comfort and indoor environments besides setting a thermal comfort standard specific to the country, thus becomes the principal concern for designers, architects and engineers. Designers in India have relied on the most recognized thermal comfort model i.e., Fanger's Predicted Mean Vote (PMV) Model or reckoned on adaptive thermal comfort approach to estimate the thermal sensation of the occupants inside that built space.

The PMV, later adopted as an ISO standard, is a thermal sensation scale where the average of opinion of a group of people can vote their thermal comfort on a scale ranging from -3 (Hot sensation) to +3 (Cold sensation). PPD (Predicted Percentage of Dissatisfied), is a function of PMV, considering every individual in that place cannot be forced to feel comfortable in the same way. According to ASHRAE-55, the recommendable and accepted PPD range is less than 10% persons dissatisfied in a built space. Adaptive Comfort model is based on the idea that the occupants can adapt and have an access to control their thermal environment by adjusting the physiological factors like openings (doors or operable windows), fans, heaters, shading devices or even clothing option. The PMV model is usually applied to mechanically ventilated (air-conditioned) buildings, whereas the Adaptive model is applied to naturally ventilated buildings.

Research on thermal comfort field study particularly office buildings in India has gained momentum in recent years. Researchers and Investigators have reported on comfort conditions in summer and monsoon seasons in office buildings in Chennai and Hyderabad in South India (betty3), Adaptive model of thermal comfort for offices in hot and humid climates of India [6], thermal comfort for offices in moderate climate of India [7], etc, besides focus on other typologies like residential buildings or vernacular architectural styles etc. Many studies examining the issue of comfort of occupants in indoor environment for different climatic regions have been done, along with understanding the factors of control, adaptation, outdoor climatic influences etc. However, research correlating occupant's performance and productivity with their comfort satisfaction still remains an unexplored study. Studies done by Leaman and Bordass have proved that occupants who felt uncomfortable with the overall environment reported much lower self-estimated productivity than those who felt comfortable with the overall environment, which in turn had an effect on their job satisfaction and overall performance.

VI. Conclusion

Currently, lack of guidelines for thermal comfort in mechanically ventilated and naturally ventilated office buildings in India has led to uncertainty when planning and designing such buildings. The scenario of occupants in an office and their comfort conditions and requirements in India are not the same as compared to their counterparts in the west. These need to be investigated and explored in detail in order to develop custom made comfort standard. Field studies and survey of actual thermal conditions and gathering occupant response (post occupancy evaluation), computer aided simulation etc would provide vital guidance for both the design and operation of buildings or retrofit of old structures. Various design parameters and way of approaching to improve the thermal comfort and thermal performance can also be implemented like, consciousness and awareness to environment and climate responsive design, energy efficient design including passive deign etc, to enhance and improve the occupants thermal comfort inside.

It is also essential to understand that since thermal comfort is a person's cognitive state and condition of mind, it is not of concern how effective and efficient the equipment or technology is, if the heating and cooling systems along with the building enclosure does create a comfortable condition acceptable to the majority of the occupants in the space, the whole purpose of creating a thermally comfortable environment remains defeated.

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Waste Audit at Food and Beverage Outlet - A Case Study in Selangor, Malaysia.

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***Abstract*—** Commercial sector in Malaysia contributed approximately 24% of total waste generated and 41% of them are food waste. Hotel, restaurant, and café (HORECA) is inevitably the highest food waste generator aside from food processing industries. This research was conducted to study the waste composition and recycling rate in a restaurant. During the one month study, a total of 663.32kg of waste was recorded. The waste composition was food waste (79%), cardboard (7%), glass (6%), plastic (5%), and others (3%). The restaurant's recycling rate is 17.4%, and this study shows that there is a potential to increase its recycling rate to 95.3%. Furthermore, to increase the recycling rate, it was suggested to carry out on-site and off-site waste treatment to reduce the amount of organic waste generated. This study can be used by the food and beverage outlets to carry out their waste minimization plan in the future.

***Keywords*—** waste minimization, hospitality, environment

I. Introduction

Solid waste generation rate in Malaysia has increased approximately 91% for the past 10 years due to high urbanization, industrialization and increased population rate [1]. Study done in Kuala Lumpur showed that commercial sector generate approximately 24% of total waste generated in year 2003. Moreover, 80% of these waste came from food wastes (41.48%), plastic based wastes (20.98%), and paper based waste (18.59%) [7], [14].

Generally, Malaysians generate up to 8 million kg or 8,000 tons of food waste a day, which can feed up to 6 millions of people and it takes around RM1.6 billion to manage these amount of waste [21]. In 2006, the recycling rate is 5.5% while the rate of composting is 1% [6]. However, Malaysia government planned to increase composting rate to 8% and recycling rate to 22% by year 2020. Compare to other countries in Asia, Singapore has increased their recycling rate from 44% in year 2002 to 48% in year 2004, while Korea had increased its recycling rate from 44% to 48% between the years of 2000-2008. Even though, the increased percentage is low, they are way ahead of Malaysia's in term of recycling rate.

In September 2015, Malaysia government had enforced the Solid Waste and Public Cleansing Act 2007 (Act 672) for Household Solid Waste Segregation Programme in six states, for instance, Johor, Malacca, Negeri Sembilan, Pahang, Perlis and Kedah, and the Federal Territory of Malaysia – Kuala Lumpur [23]. This regulation aims to control the solid waste generators and persons in possession of controlled solid waste, enforcement, as well as recovery and reduction of controlled solid waste. However, in Selangor, this regulation is yet to be implemented for both residential area and commercial sectors.

Waste handling and separation at source is a very important step in managing solid waste generated from the food and beverage outlets in commercial sector [16]. A study showed that food waste is averaging around 56% of the total waste generated from restaurant [18]. Various other studies also found that how much preparation food waste and plate waste are generated in the hospitality sectors [12]. Studies done in United Kingdom restaurants showed that 65% of organic waste came from preparation of food such as off cutting, peeling and ruined food while cooking; 30% of organic waste came from plate waste after customers consumed their foods; 5% of organic waste came from the spoiled, expired, or unusable food [15]. This shows the significant amount of food waste generated in a restaurant. Meanwhile, a research done by Environmental Protection Agency (EPA) showed that the commercial sectors in United State generated approximately 24.6 million tons of food soiled and scraps, unrecyclable paper and cardboard annually [22]. EPA also stated that 74% of the restaurant waste stream is made up of organic waste.

There are five common treatment methods that have been widely used for the treatment of organic waste in developing countries, which is *landfilling, incineration, composting or organic fertilizer, animal feeding, and anaerobic digestion* [21]. Landfilling is the most popular method [2]. However, landfilling is not considered as a feasible method for organic waste treatment due to the high emission of greenhouse gases (GHG) such as methane, which is at the rate of 8% [2].

Composting is a biological process where the biodegradable organics are metabolized by microbes into nutrient rich structural component of soil called humus. This process converts the organic waste into products which are useful for gardening, maintaining fertility of agricultural land, slope stabilization, landscaping, and even brownfield remediation [9].

Garbage enzyme is a solution produced from the fermentation of fruit waste, molasses or brown sugar, and water. It is a multipurpose solution that can be used for agriculture, household, or environment. For agriculture, garbage enzyme can be used as fertilizer and pesticide. For household, garbage enzyme can be used as detergent to remove oil and grease, and remove unpleasant odour and dirt. Garbage

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enzyme is a Do It Yourself (DIY) product that not only save cost and time, but also environmental friendly in the sense of reducing pollution [25].

This research aimed to study the waste composition, the recycling rate and the waste treatment in the restaurant.

II. Procedure and Methodology

This study was conducted in an Asian-French-Italian Fusion restaurant located in SetiaWalk, Puchong. It has been operating since December 2014, and it is the only branch in the country at present. There are several identified sources of waste generated in the restaurant i.e. kitchen, bakery, and bar. The data collection was done on daily basis for the period of one month, starting from 4/8/2015 (first Tuesday of August 2015) to 3/9/2015. Data of 4 Monday were not collected due to non-business day for the restaurant, therefore, only 27 days of data were collected.

Recyclables such as papers, cardboards non-contaminated plastics, cardboards, metals, glass, aluminum, and e-waste generated from bar and bakery were stored inside a steel bin, whereby a cardboard box was used for the recyclables generated from kitchen. Non-recyclables from kitchen such as the contaminated plastics disposed plastics (film plastic and torn plastic bags), and used napkins were separated and placed into a plastic bag. Organic waste generated from kitchen, bar and bakery were disposed into conventional garbage bin with plastic bags. Safety gloves and latex gloves were used during data collection. The conventional and digital weighing scale were used to obtain the weight measurement.

III. Results and Discussion

A. *Waste generated in the restaurant*

The restaurant generated a total amount of 663.32kg of waste during the 27 days study period. Total waste generated in the restaurant is shown in **Table 1**. In terms of proportion, organic waste contributed up to 79% from the total waste; cardboard 7%; and glass 6%. From this result, it is proven that the organic food waste has the major contribution on the waste generation in the restaurant. These organic waste can be recycled and transformed into useful product such as bio-enzyme, or waste compost. Overall, average amount of waste generated per day is 24.57kg.

TABLE I:
WASTE GENERATED IN THE RESTAURANT (KG)

	Week 1	Week 2	Week 3	Week 4	Week5	Total Weight	Average
Tuesday	23.81	29.34	27.59	23.26	24.61	128.61	25.72
Wednesday	24.7	19.85	32.09	17.76	25.38	119.78	23.96
Thursday	18	26.19	23.1	25.11	20.44	112.84	22.57
Friday	18.33	23.2	30.35	18.97	-	90.85	22.71
Saturday	29.48	30.89	25.29	22.09	-	107.75	26.94
Sunday	35.02	28.6	23.95	15.92	-	103.49	25.87

In addition, the kitchen area has generated 490.40kg of waste out of 663.32kg of total waste generated, which is approximately 74%; and of the waste generated at the kitchen, 76% is organic waste.

Generally, Saturday and Sunday recorded the highest number of customers in a week. **Fig. 1** shows that Saturday generated the highest amount of waste generated per day (average 26.94kg) as compare to other days, followed by Sunday. When there is more customers, it will eventually increases the process of food preparation and production, which is directly affecting the waste generation rate in the restaurant. Subsequently, Tuesday recorded the third highest amount of waste generated per day. Reason is Tuesday is the first day of business operation for the restaurant. When the restaurant started to prepare for the food which involved cutting of meats, sauces making, precooking, chopping vegetables, and other food preparation processes that may generate food residues. Sometimes, chilled or frozen foods might be found either spoilt or expired during stock checking.

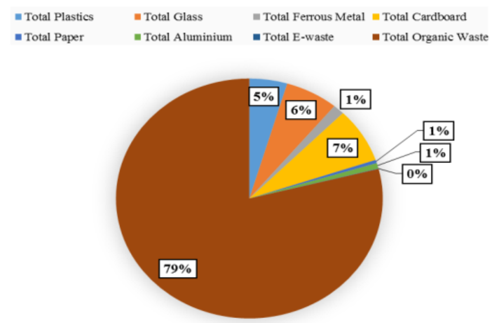

Fig. 1. Waste composition chart.

B. *Correlation between total number of customer and total waste generated*

The correlation study was done to identify whether the waste generated per day is affected by the number of customer visited the restaurant per day. Bases on **Fig. 2**, the R^2 shows a very low value of 0.0741, meaning that the daily waste generated and total daily customer visited the restaurant is not correlated. This outcome can be understood where the majority of waste are produced from the preparation, processing, cooking, or food wastage. Even when the number of customer is low in the day, preparation of cooking ingredients, which ultimately produce wastes, will still take place. Therefore, a low significant correlation is shown between the total daily customer and total daily waste generated. Despite on the low correlation, number of customer increase will still increase the possibility of waste generated from food production and plate waste. Therefore, the visited customer will still affect the waste generated on the same day.

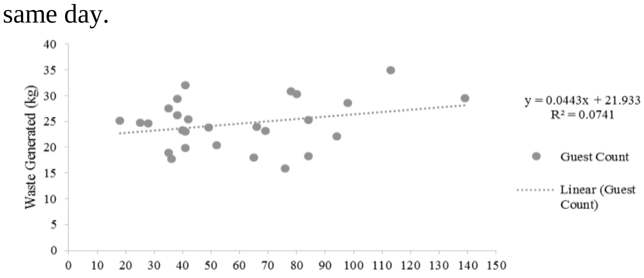

Fig. 2. Correlation graph between total customer and total waste generated.

C. Waste recycling rate and Effectiveness of waste minimization

Study was carried out based on two scenarios. First scenario which is the current practice, where waste segregation was carried out on common recyclable items such as papers, non-contaminated plastics, aluminum, glass, metals, and cardboard. While for second scenario, organic waste was treated instead of disposed. In the first scenario, organic waste was not segregated based on current practice. **Table 2** shows the difference in the recycling rate before and after when the organic waste is being recycled. For current practice, the highest recycling rate recorded was only 38.6% and as low as 2.8%, with an average of 17.4% recycling rate. If the organic waste are recycled, the potential recycling rate can be increased up to 97% and as low as 87.5% with 95.3% average recycling rate. If the organic waste is treated at site, the average recycling rate can be increased by 77.9% and the amount of waste for disposal can be minimized up to 416.98kg per month.

This study had indicated that the organic food waste are dominating the waste from the restaurant. These very good recycling materials can be potentially turned into multipurpose bio-enzyme, or organic compost fertilizers. The benefits of making food waste compost are to reduce the amount of waste significantly, to produce compost as fertilizer, and the restaurant are able to obtain additional income by selling the fertilizers. However, there's no buyer or collector for organic waste, and no composting facility for composting process was found nearby the study area. The garbage composter is comparably costly to be invested, and takes up space to install the machine. Garbage enzyme can be used as deodorant, insect repellent, oil remover and more. It require low initial cost as it only need fruit skins, water, and brown sugar to make it. However, the amount of organic waste used on producing the garbage enzyme would not significantly reduce the amount of waste generated. In fact, the fermentation process of garbage enzymes take up storage space in the restaurant and require at least 3 months before they are ready to be used.

TABLE II
COMPARISON ON CURRENT RECYCLING RATE AND POTENTIAL RECYCLING RATE

	Current Practice	Potential
Total Waste (Recycled) (kg)	115.42	632.4
Total Waste (Non-Recycled) (kg)	547.9	30.92
Total Waste (kg)	663.32	663.32
Highest Recycling Rate (%)	38.57	97.94
Lowest Recycling Rate (%)	2.8	87.55
Average Recycling Rate (%)	17.4	95.3

On the other hand, glass wastes such as glass bottles or jars are also one of the challenge in recycling. The restaurant had generated a total of 42.54kg of glass weight, around 6% of the total waste, which is the 3rd highest category of waste produced during the research period. Despite of its value, glasses were unable to be sold to majority the local buy-back center. Besides, only certain suppliers of beverage will buy back the used bottles. Therefore, glass wastes can only be sent to the drop–off center where there's no incentive given for recycling.

In terms of cost efficiency in the future view, recycler who collect from the restaurant provide the best service for the restaurant on the off-site waste treatment when compared to buy-back center and drop-off center. Drop-off center do not provide incentives, whereby buy-back center do not accept glass waste, which it is a major problem as the glass waste is the third highest contributor of the overall waste in the restaurant. In addition, the recycler also provide the service to collect recyclable such as glass waste and convert them into the credit points for shopping voucher.

IV. Conclusion and Recommendation

In total, the restaurant generated a total of 663.32kg of waste. More than 95% of these waste are recyclable items. Besides, the restaurant waste composition was dominated by organic food waste. 79% out of the total waste generated from the restaurant was organic waste, which is 523.80kg.

Waste generation rate has been determined throughout the analysis. The restaurant had an average waste generation of 24.57kg/day. The highest amount of waste generated fell on the Sunday of Week 1 at 9/8/2015, with 35.02kg of waste generated. Tuesdays of the month of data collection period recorded the highest total waste with 128.61kg. However, Saturdays has the highest average waste generated at 26.94kg/day.

On-site waste segregation is the fundamental waste management of all. The separation of waste into recyclables and non-recyclables ease the process of on-site waste treatment and improve the waste minimization efficiency. Segregation of recyclables into their respective categories can also ease the recycling processes. The current recycling practice of the restaurant had recycled only 115.42kg of waste out of 663.32kg, which is only 17.4%. If the restaurant recycled the organic waste, there's a potential of waste minimization up to 94%, and the recycling rate can also increase to 95.3%.

Further studies are recommended to be done with more restaurants in the same area, city, or even within the state to determine the waste generation patterns for restaurants.

As food waste is the major contribution of the waste from a restaurant, further study is required to measure the effectiveness of waste treatment for restaurant in the country. Similar study has been done in San Francisco Bay Area, United State of America, on the Economic, Ecological, and Social Cost and Benefits of doing on-site composting in restaurant [9]. These studies are able to provide more applicable solution for all the restaurant on their organic waste treatment within the country. These study can also further explain the importance of commercially available composting technologies to expand within the country in order to prolong the lifespan of the landfills available in the country to encounter the rapid growth of waste generation rate in the country.

Finally, further research is recommended to study on the chemical composition of organic food waste to identify the possibility of converting organic waste into renewable energy. The study of chemical composition of food waste can identify the potentiality of organic food waste to generate usable biogas methane. A similar research has been conducted in Singapore to study the energy conversion of organic waste by different biological and thermochemical technologies [27]. On the other hand, there was a research to study on the composition of Organic Fraction of Municipal Solid Waste (OFMSW) and its effect on the biochemical hydrogen and methane gas production potential [28].

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